AC 2012-3949: ENGINEER YOUR WORLD: AN INNOVATIVE APPROACH TO DEVELOPING A HIGH SCHOOL ENGINEERING DESIGN COURSE

Ms. Cheryl Farmer, UTeachEngineering

Cheryl Farmer is the founding Program Manager and Project Director of UTeachEngineering. Funded through a five-year, $12.5 million Math and Science Partnership grant from the National Science Foundation, UTeachEngineering offers a well-designed, well-rounded, design-based high school engineering course that can be implemented at low cost in virtually any setting, as well as a variety of professional development programs for pre-service and in-service teachers who want to add engineering to their teaching portfolio. Prior to co-founding UTeachEngineering, Farmer spent several years managing programs for both K-12 and higher education. Before entering higher education, Farmer worked as a project manager in the environmental field. Her education includes graduate work in mathematics and business administration and a B.A. in mathematics and liberal arts, with highest honors, from the University of Texas, Austin.

Dr. David T. Allen, University of Texas, Austin

David Allen is the Gertz Regents Professor of chemical engineering, and the Director of the Center for Energy and Environmental Resources, at the University of Texas, Austin. He is the author of seven books and more than 200 papers primarily on urban air quality, the engineering of sustainable systems, and the development of materials for environmental and engineering education. The quality of his work has been recognized by the National Science Foundation, the AT&T Foundation, the American Institute of Chemical Engineers, the Association of Environmental Engineering and Science Professors, and the state of Texas. He has won teaching awards at the University of Texas and UCLA. Allen received his B.S. degree in chemical engineering, with distinction, from Cornell University in 1979. His M.S. and Ph.D. degrees in chemical engineering were awarded by the California Institute of Technology in 1981 and 1983. He has held visiting faculty appointments at the California Institute of Technology, the University of California, Santa Barbara, and the Department of Energy.

Dr. Leema Kuhn Berland, University of Texas, Austin
Dr. Richard H. Crawford, University of Texas, Austin

Richard H. Crawford is a professor of mechanical engineering at the University of Texas, Austin, and is the Temple Foundation Endowed Faculty Fellow No. 3. He received his B.S.M.E. from Louisiana State University in 1982, and his M.S.M.E. in 1985, and Ph.D. in 1989, both from Purdue University. He joined the faculty of UT in Jan. 1990 and teaches mechanical engineering design and geometry modeling for design. Crawford's research interests span topics in computer-aided mechanical design and design theory and methodology, including research in computer representations to support conceptual design, design for manufacture and assembly, and design retrieval; developing computational representations and tools to support exploration of very complex engineering design spaces; research in solid freeform fabrication, including geometric processing, control, design tools, manufacturing applications; and design and development of energy harvesting systems. Crawford is Co-founder of the DTEACh program, a ”Design Technology” program for K-12, and is active on the faculty of the UTeachEngineering program that seeks to educate teachers of high school engineering.

Ms. Lisa Guerra, NASA

Lisa Guerra has 25 years experience in the NASA aerospace community. Guerra is currently working with the UTeachEngineering program. She recently completed a four-year assignment from NASA headquarters to establish a systems engineering curriculum at the University of Texas, Austin, as a pilot for national dissemination. Her efforts in systems engineering curriculum can be located at http://spacese.spacegrant.org/. Guerra's most recent position at NASA Headquarters was Director of the Directorate Integration Office in the Exploration Systems Mission Directorate. In that position, her responsibilities involved strategic planning, international cooperation, cross-directorate coordination, architecture analysis, and exploration control boards. Guerra also spent three years at the Goddard Space Flight Center as Program Integration Manager for future high-energy astrophysics missions, particularly the James Webb Space Telescope. She began her career at the Johnson Space Center working for Eagle Engineering and SAIC, focused on conceptual design of advanced spacecraft for human missions to the moon and Mars. Guerra earned a B.S in aerospace engineering and a B.A. in English from the University of Notre Dame. She received a master's of science degree in aerospace engineering from the University of Texas, Austin.

Engineer Your World: An Innovative Approach to Developing a High School Engineering Design Course

Abstract

As standards for K-12 engineering learning emerge with the development of the Next Generation Science Standards, the nation's school systems will likely struggle with the question of whether engineering should be employed as a tool for teaching science and mathematics content (*i.e.*, embedded in science and mathematics courses) or treated as a unique discipline in which science and mathematics are employed as tools for solving design challenges (*i.e.*, offered as a stand-alone course). Acting on the belief that the latter paradigm is a more appropriate depiction of engineering, the UTeach*Engineering* project at The University of Texas undertook to demonstrate how rigorous engineering content can be deployed in secondary classrooms by developing a year-long high school engineering course built on a foundation of solid research in the learning sciences, couched in the context of a rigorous engineering design process and scaffolded to build engineering skills and habits of mind.

This paper explains why UTeach*Engineering*, a program initially designed to prepare pre-service and in-service educators to teach design-based engineering courses at the secondary level, shifted focus early in the project to developing, piloting, evaluating and refining such a course. It describes the target student population for the course, details the engineering development work required, describes the research- and practice-based principles upon which pedagogical decisions are based, and offers a view into the course content. Finally, it describes the piloting of the course in a small number of Texas high schools during the 2011-2012 academic year, discusses how feedback from this pilot is informing course revisions, and outlines plans for leveraging a partnership with NASA to expand implementation of the revised course and pilot a new teacher mentorship model in 2012-2013.

Background and Motivation

Every year, thousands of American students enroll in high school engineering courses, but few of these courses are built on a foundation of solid research in the learning sciences, couched in the context of a rigorous engineering design process, and scaffolded to build engineering skills and habits of mind. This paper describes the creation and piloting of such a course: *Engineer Your World*, a product of the UTeach*Engineering* project at The University of Texas at Austin.

The UTeach*Engineering* project was launched in 2008 with a Math and Science Partnership (MSP) grant from the National Science Foundation (NSF). Originally focused on preparing in-service and pre-service high school teachers to teach engineering, the project was agnostic on which course materials those teachers should use with their students. However, an NSF site visit in the project's second year led to a shift in project priorities as site visit representatives argued convincingly that professional development activities must be designed with a particular end (*i.e.*, a well-designed high school engineering course) in mind and that the development of such a course was, therefore, the first and most critical outcome of the UTeach*Engineering* MSP[12].

In its 2010 report to the project, the NSF site visit team urged UTeach*Engineering* to carefully define the content and pedagogy of a new high school course by making explicit the core content of engineering design, clarifying student learning outcomes, and establishing research-based course design principles before developing course materials[12]. UTeach*Engineering* responded to this charge by convening a course design team comprising engineering faculty, clinical engineering faculty (professionals with experience as both practicing engineers and secondary classroom teachers), engineering research fellows, and learning sciences faculty. Incorporating feedback from high school teachers involved in an earlier pilot project, this team undertook a rigorous, 18-month course design process.

Defining the Target Student Audience for *Engineer Your World*

The target student audience for *Engineer Your World* was defined by the opportunity to which the UTeach*Engineering* project has responded: the approval of Engineering Design and Problem Solving to be offered for fourth-year science credit to students in an academic track in Texas. The state-developed standards governing the course content are detailed in the Texas Essential Knowledge and Skills for Engineering Design and Problem Solving[17]. While *Engineer Your World* was developed assuming the state-mandated prerequisite courses of Geometry, Algebra II, Chemistry and Physics, the development team has since identified adaptations that make the course appropriate for use with students in earlier high school grades.

Standardizing the Engineering Design Process

The *Engineer Your World* design team accepted as a first principle that the course would teach engineering through design by structuring all units as engineering design challenges. While engineers frequently refer to “the engineering design process” as a means of solving such challenges, they rarely have the same representation of that process in mind. Recognizing the need for a standardized representation of this process to structure students’ experiences, the team undertook to clearly articulate such a representation. This effort, which is described by the authors in a related paper[10], resulted in the development of a unique, multi-level representation (Figure 1) that is accessible to high school students, applicable in engineering teacher preparation courses, and authentic to the experience of professional engineers.

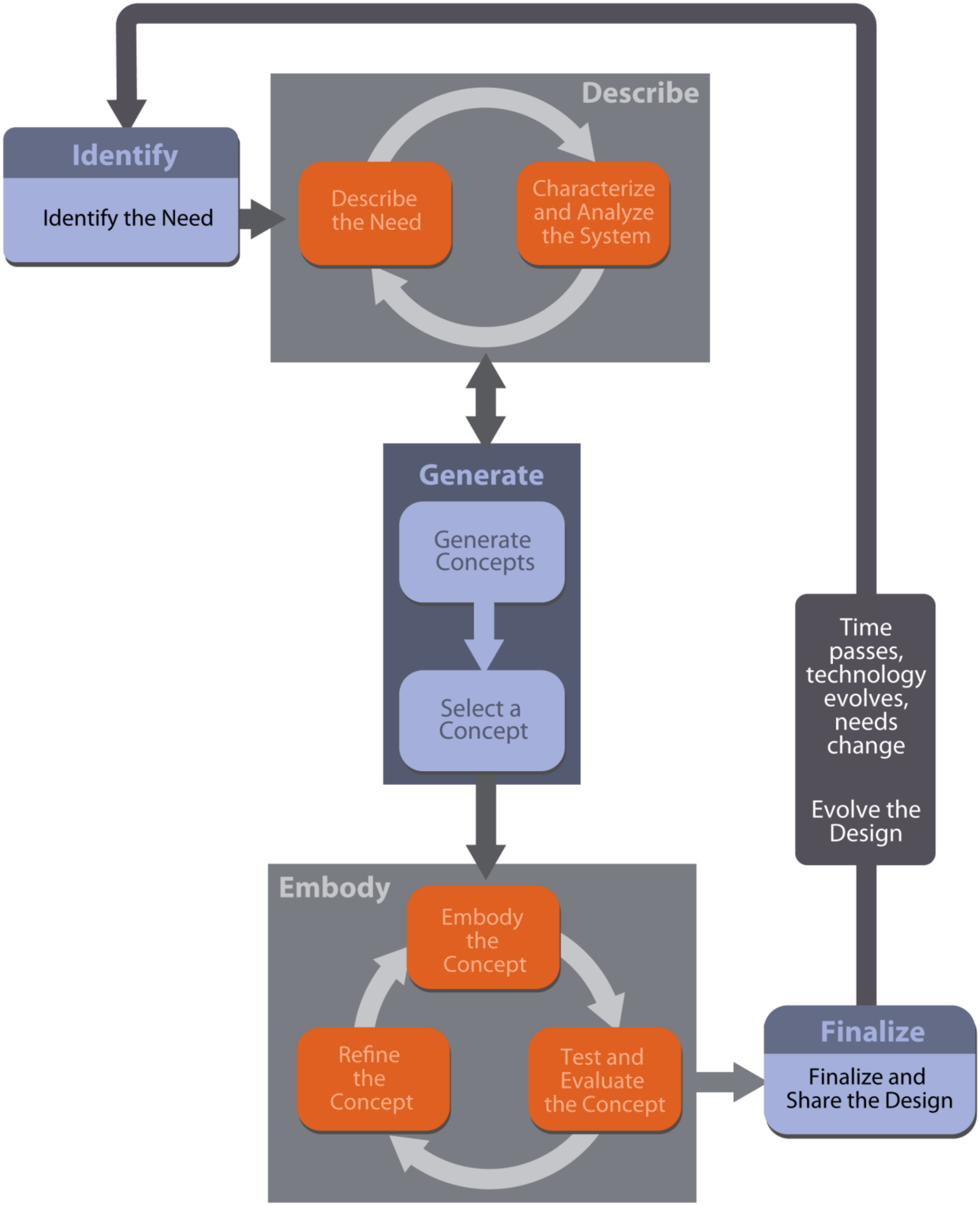

*Figure 1 – The UTeach*Engineering *representation of the engineering design process.*

Establishing Student Learning Objectives

Although national efforts are currently underway to develop K-12 engineering standards as part of the Next Generation Science Standards, no such nationally agreed-upon standards existed when the *Engineer Your World* design team began its course development work in 2010. Indeed a publication of the National Academy of Engineering released as *Engineer Your World* course development efforts began, concluded "that the evolving status of K-12 engineering education severely limits the potential value of developing traditional content standards… (and thus) that an initiative to develop such standards should not be undertaken at this time."[8] Without established standards to rely upon, the *Engineer Your World* design team was required to spend considerable time developing a set of expected student learning outcomes for the course. These were eventually organized into three categories: engineering practice, engineering process, and engineering skills and habits of mind.

Student Learning Area 1: Engineering Practice

Learning objectives in understanding engineering practice are intended to guide students through an exploration of engineering's societal impacts. Students are required to explore past accomplishments; current and future challenges; and the interplay between science, technology, customer needs and evolving designs. Students also learn about engineering disciplines and careers, the multidisciplinary nature of practice, and professional codes and standards to which engineers adhere. Figure 2 shows how these objectives align with learning advocated by the following nine sources:

1. ***Engineering in K-12 Education***[6], a publication of the National Academy of Engineering that examined the status in 2009 of efforts to teach engineering in American primary and secondary schools;
2. *Standards for Technology Literacy*[13], a publication of the International Technology and Engineering Educators Association that includes relevant sections on design and on technology and society;
3. The American Association for the Advancement of Science's *Benchmarks for Science Literacy*[2], which describes what students should know and be able to do in science, mathematics, and technology at key milestones in their K-12 careers;
4. The National Research Council's *A Framework for K-12 Science Education*[5], a document intended to inform the development of the Next Generation Science Standards for K-12 students;
5. ***Changing the Conversation***[7], a publication of the National Academy of Engineering that identified effective messages for improving public understanding of engineering;
6. ***Texas Essential Knowledge and Skills* for *Engineering Design and Problem Solving***[17], the state-developed standards for a design-based engineering course that is offered for fourth-year science credit;

7. ***Space Systems Engineering***[11], an undergraduate senior-level course developed at The University of Texas and replicated at universities across the nation;
8. **ABET criteria**[1] for accrediting post-secondary engineering programs; and
9. The **professional practice** of team members.

N.B., bolded sources were consulted during the development of the learning objectives; the others were consulted for comparison after the objectives had been developed.

Student Learning Objectives Area 1: Engineering Practice	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7	Source 8	Source 9
Engineering's Societal Impacts	X	X		X	X	X		X	
Greatest Engineering Achievements of the 20th Century				x	x			x	
Grand Challenges for Engineering	x			x	x			x	
Innovation and design evolution		x				x		x	
The Practice of Engineering	X	X	X	X	X	X	X	X	X
Engineering disciplines and careers, including the multidisciplinary nature of practice		x	x	x	x	x	x		x
Engineering ethics and codes of practice	x					x	x	x	x
Safety considerations with respect to the system, the engineer and the user		x		x		x		x	x
Engineering standards and regulations including the role of government		x				x	x	x	x
Legal aspects including intellectual property, patents, and trademarks		x				x		x	x

Figure 2 – Sources supporting student learning objectives related to Engineering Practice.

<u>Student Learning Area 2: Engineering Process</u>

The acquisition of engineering design skills is central to the *Engineer Your World* course experience. All units employ the UTeach*Engineering*-developed engineering design process (Figure 1) so that the process becomes ritualized for students. This enables students to focus their efforts in each unit on learning and applying engineering skills and habits of mind to solve the immediate challenge at hand.

<u>Student Learning Area 3: Engineering Skills and Habits of Mind</u>

Engineer Your World seeks to equip students with the skills and habits of mind that engineers use to address and solve design challenges. These are divided into seven categories, namely the following:

- Systems Thinking – Systems thinking is a set of habits or practices based on the belief that the parts of a system can best be understood in the context of relationships with each other and with other systems, rather than in isolation. Emphasis is placed on a top-down perspective, the system environment, and critical interfaces.

- System Understanding and Quantification – Students learn to characterize the system using quantitative techniques common in the practice of engineering, enabling a deeper understanding of the system.
- Creativity – Engineers think creatively within well-defined constructs. Students experience a variety of design approaches using concept generation and selection techniques employed by engineers.
- Verification – Engineers must verify that their selected concept satisfies the design constraints, requirements, and customer needs.
- Communication – Students learn good communication skills and unique aspects of how engineers document and present design ideas and analytical results. Emphasis is placed on creating communication artifacts to ensure accurate interpretation by others (with an eye toward clarity, detail, precision of process, and completeness).
- Collaboration – Students learn the importance of working on multidisciplinary teams and understand what type of team member they are. Emphasis is placed on engineering personality types, integrated product teams, and examples of successful engineering teams.
- Common Engineering Tools and Techniques – Students learn to use common tools and techniques that engineers employ to approach and solve problems and to manage projects. Approach and application are based on the design challenge at hand. This category includes the understanding and application of domain-specific science and mathematics knowledge and appropriate technology tools, alluding to the importance of integrating science, technology, engineering and mathematics (STEM) concepts in modern courses.

As shown in Figure 3, the learning objectives in these seven categories align with learning advocated by the following 10 sources:

1. The National Academy of Engineering's ***Engineering in K-12 Education***[6];
2. The International Technology and Engineering Educators Association's *Standards for Technology Literacy*[13];
3. The National Research Council's 1996 publication *National Science Education Standards*[15], which outlines what scientifically literate students should know, understand, and be able to do at different grade levels;
4. The American Association for the Advancement of Science's *Benchmarks for Science Literacy*[2];
5. The National Research Council's *A Framework for K-12 Science Education*[5];
6. ***Texas Essential Knowledge and Skills*** **for** ***Engineering Design and Problem Solving***[17];
7. A senior-level undergraduate ***Space Systems Engineering***[11] course;

8. **Discipline-based capstone design courses** offered at The University of Texas;
9. **ABET criteria**[1]; and
10. The **professional practice** of team members.

N.B., bolded sources were consulted during the development of the learning objectives; the others were consulted for comparison after the objectives had been developed.

Student Learning Objectives Area 3: Engineering Skills and Habits of Mind	**Source 1**	Source 2	Source 3	Source 4	Source 5	**Source 6**	**Source 7**	**Source8**	**Source9**	**Source 10**
Systems Thinking	X	X	X	X	X		X	X	X	X
System context and top-down perspective	x	x		x	x		x	x	x	x
System decomposition (system, subsystem, element, component)		x		x	x		x	x	x	x
Functional models, including input/output					x		x	x	x	x
System Understanding and Quantification	X	X		X	X	X	X	X	X	X
Research (background, context, benchmarking)		x					x	x	x	x
Information gathering (constraints, requirements, customer needs)	x	x			x	x	x	x	x	x
Data acquisition, analysis and representation to develop performance targets				x	x	x		x	x	x
Using appropriate instrumentation and experimentation techniques				x	x	x		x	x	x
Creativity	X	X	X			X	X	X	X	X
Design approaches (*i.e.*, new design, redesign, design modification, reverse engineering)	x								x	x
Techniques for concept generation and selection	x	x	x			x	x	x	x	x
Verification	X	X	X	X	X	X	X	X	X	X
Design embodiment (*e.g.*, modeling, prototyping)	x	x			x	x			x	x
Data acquisition, analysis and representation to verify performance		x		x	x	x	x	x	x	x
Communication	X	X	X	X	X	X		X	X	X
Engineering notebooks and configuration management						x			x	x
Formal documentation (*e.g.*, reports, presentations)	x	x	x	x	x	x		x	x	x
Collaboration	X	X				X	X	X	X	X
Teamwork (*e.g.*, types of teams, group dynamics, team composition)	x	x				x	x	x	x	x
Common Engineering Tools and Techniques	X	X	X	X	X	X	X		X	X
Project management techniques (*e.g.*, system cost and schedule estimation)			x			x	x		x	x
Risk analysis techniques (*e.g.*, failure modes and effects analysis)			x	x		x	x		x	x
Software and technology tools	x	x			x	x			x	x
Understanding/application of domain-specific math/science knowledge	x			x	x	x			x	x

Figure 3 – Sources supporting student learning objectives related to Engineering Skills and Habits of Mind.

Establishing Research- and Practice-Based Course Design Principles

As is common in the design of high school engineering materials, the *Engineer Your World* team agreed on a project-based approach in which students are given problems—or challenges—that motivate the exploration of the desired engineering concepts as well as the relevant mathematics and science concepts. In engineering education, this is typically called Challenge-Based

Instruction (CBI). CBI courses contextualize student exploration of the desired content within a broader challenge, supporting the introduction, application, exploration, refinement and assessment of mathematics, science, and engineering concepts[16]. However, while the CBI approach provides a guiding philosophy (*i.e.*, that of contextualizing all student work within a challenge) it does not offer the level of specificity required to develop a course with a consistent pedagogical approach across units and engineering domains. The *Engineer Your World* design team resolved this challenge by adapting design approaches found in the learning sciences and science education research to create a set of principles to guide course development work. These principles, which are discussed in depth and exemplified in the context of a key unit by the authors in a related paper[4], are the following:

Design Principle 1: Contextualize all student work within STEM-design challenges.

In keeping with the National Research Council's synthesis of the research on K-12 engineering education research[6] the *Engineer Your World* design team chose to organize all units around STEM-design challenges that can only be completed through the purposeful application of engineering principles and relevant mathematics and science concepts. Each unit requires that students design a "product" whose nature will vary depending on whether the challenge requires a paper design, design and production of a requested product, design and creation of a model, or design of a process. Based on current understandings of effective messaging about engineering[7], challenge topics were selected to make explicit the multidisciplinary nature of engineering and to emphasize engineering's ability to address societal needs. All challenges have multiple valid solutions, allowing for creativity and requiring that students consider the benefits and drawbacks of multiple options before selecting a final design[15].

Design Principle 2: Teach engineering through design by using a standardized engineering design process and employing it as an instructional framework.

In addition to focusing all student work on fulfilling STEM-design challenges, the course design team developed the units such that student work follows a standardized engineering design process (Figure 1). The commitment to employing a standardized engineering design process consistently across the year is motivated by a desire to enable core engineering practices to become "ritualized"[14] for students so that they may focus on the novel aspects of their work (*i.e.*, the particular challenge and content at hand) rather than the details of the engineering practice.

The use of the engineering design process as an instructional framework is intended to ensure that all classroom work is contextualized within the engineering design process so that students research, calculate, test, brainstorm, build and perform other activities only when these activities are in the service of the engineering design process. The team's commitment to this approach manifests in that there is almost a one-to-one relationship between lessons in a unit and steps in the engineering design process. Students learn that there are particular processes to follow and particular artifacts to be created in each step of the engineering design process (*e.g.*, the "characterize and analyze the system" step always requires the creation of a functional model) so that deciding what to do next, identifying necessary artifacts, considering the ways in which these artifacts are useful, and deciding the information that should and can be communicated by these artifacts becomes background knowledge for the students; in other words, the artifacts and processes become part of the ritualized engineering design process.

Design Principle 3: Engage students in meaningful versions of the practices of engineers.

Engaging students in a standardized engineering design process such that they ritualize the enactment of particular engineering practices can be dangerous. As seen in the use of the Scientific Method in science classes, this standardization can quickly become a script that students perform without understanding the purpose of the practices[20]. The course development team addressed this concern by ensuring that students engage in "meaningful" versions of design practices. Lessons are constructed such that every activity is thematically connected to the ones before and after so that students experience engineering activities as being cohesive and coherent within the engineering design process. Activities are required only when they are necessary for the fulfillment of the STEM-design challenge at hand so that engagement in these practices becomes purposeful.

Design Principle 4: Employ science and mathematics concepts, technology tools, and techniques when and only when they are necessary for students' successful completion of STEM-design projects.

The UTeach*Engineering* team argues that engineering is not simply a tool for teaching science and mathematics content, but a unique discipline with unique pedagogical requirements in which science and mathematics serve as tools to solve design problems. In *Engineer Your World*, science and mathematics concepts are used when they are clearly and immediately applicable to students' work on a STEM-design challenge (*e.g.*, to characterize and analyze systems, to predict design performance, to test and evaluate concepts).

Beyond influencing the selection of science and mathematics concepts to be addressed in each unit, this principle also guides when and how such concepts are introduced. That is, science and mathematics concepts are presented only after students have felt a need for the information—after they have realized that they will be unable to complete their design without applying the particular concept. This realization is how the learning is "initiated by the learner"[9].

Design Principle 5: Align with current standards for high school engineering education.

As described earlier, student learning objectives for *Engineer Your World* were drawn from multiple sources including the Texas Essential Knowledge and Skills for Engineering Design and Problem-Solving. In addition to ensuring that the Texas standards were addressed in the initial development of the course, the *Engineer Your World* team has undertaken to demonstrate how the course aligns with standards or requirements in other states and is closely following the development of the Next Generation Science Standards to ensure that all of the eventual engineering standards for grades 9-12 will be covered in the course.

Design Principle 6: Adhere to standards of effective curriculum design.

In keeping with research on effective curriculum design, particularly the concept of "backward design" or "design with the end in mind"[19], all learning objectives are assigned to particular units before the units are designed (Figure 4). Based on these objectives, each unit includes well-defined expectations for individual and/or group deliverables (*e.g.*, presentations, design artifacts, engineering notebook entries) that are selected both to allow students to demonstrate understandings[3, 18] and to offer teachers opportunities to assess student learning.

Design Principle 7: Attend to the constraints of high schools and school district systems.

Developing an exceptional course is of no value if the course cannot be implemented. The development team identified essential elements to ensure that *Engineer Your World* would work within high school and district systems. These are

- The course is affordable. *The course uses common equipment and technology that schools may have on hand, and reuses as much equipment and technology as possible within the course.*
- The course is scaffolded. *Each challenge includes clearly marked core content (that which must be taught because it is critical to course scaffolding) and optional content (that which may be explored as time and student interest allow.)*
- Wherever possible, the course offers a library of challenge options that teach the necessary skills for each unit. *Teachers should be able to fit the course to student interests without sacrificing critical learning.*
- The course starts with an engaging engineering design challenge with the central purpose of piquing student interest. *Attracting and retaining students in engineering is a central concern.*
- Lessons allow for, but do not include instructional materials to support, the review of prerequisite content knowledge. *Lessons indicate places where teachers might review key information with students. Remedial materials are not included but may be found in standard sources well known to secondary teachers.*

- The course accommodates a variety of physical and technological configurations. *Units are designed to require little specialized equipment or technology. Materials are developed with the intent of accommodating multiple platforms (Mac, PC) and to be reasonably completed both in classrooms with computers at hand and in those with more limited (or remote) computer access.*
- The course can be adapted for a variety of class sizes. *Materials are written for classes of approximately 20 students, but indicate options for small (fewer than 10) and large (more than 30) class sizes.*
- Course materials will be available electronically. *Courseware decisions will be aligned with current standards but will be forward-thinking. Courseware will offer both learning management functionality and opportunities for collaboration and communication among and across groups (teachers and students).*
- Teachers from a variety of backgrounds can successfully teach the course. *The ideal instructor is comfortable with the uncertainty inherent in open-ended design (where there is no single "right answer") and is comfortable serving as a guide in a student-driven process. While an engineering background is ideal, all effective teachers of mathematics (algebra II and higher) and physical science can be prepared and supported to teach this course.*
- Associated professional development and ongoing support prepare and enable teachers from various backgrounds to lead the course. *A two-week, course-specific professional development is required to ensure that teachers have the engineering content knowledge, pedagogical content knowledge, and contextual understanding necessary to effectively teach the course.*

Adherence to these constraints, which were developed with input from district administrators and pilot teachers, will ensure that the course is implementable in a variety of settings.

Developing Course Materials

Having completed the essential work of making explicit the core content of engineering design, clarifying student learning outcomes, and establishing research-based course design principles, the *Engineer Your World* development team next created a course framework to make clear how student learning should be scaffolded over the course of an academic year. It is important to note that, while the number of skills reflected in this framework may appear large, these skills are integrated into six-week learning units so that students experience them as necessary tools for addressing STEM-design challenges rather than as a panoply of items to be learned and checked off of a list. Concepts related to engineering practice are woven throughout the course and, as appropriate, addressed in depth through unit projects. The engineering design process is "discovered" by the students at the beginning of the course and applied in subsequent units. A handful of engineering skills and habits of mind are introduced in each structured engineering design challenge and reinforced in subsequent challenges to help students build their intellectual toolkits so that, by the end of the course, students should be prepared to solve a more open-ended culminating design challenge. This scaffolded approach is demonstrated in Figure 4.

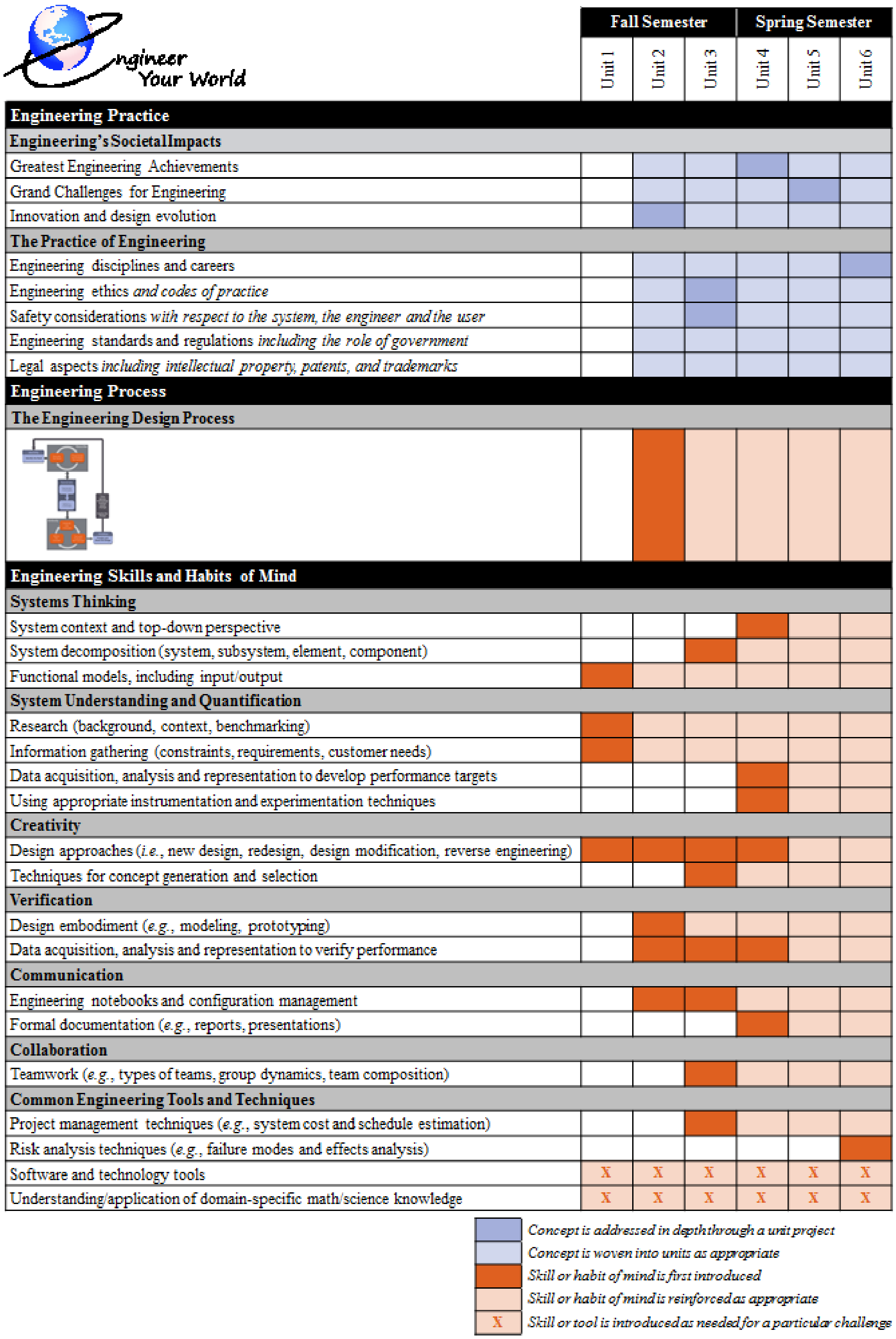

Figure 4 – Scaffolded course framework for Engineer Your World.

After building this scaffolded framework, the *Engineer Your World* development team selected the topics for a sequence of design challenges to create a narrative of engineering and its role in the world while allowing students to acquire and practice engineering design skills and engineering habits of mind. Design challenges developed for the pilot version of the course are

Unit 1: Engineering Impacts Our Everyday Lives

To illustrate how engineering impacts students' everyday lives, the course opens with a unit (*Reverse Engineer Your World*) in which students reverse engineer an everyday product. Teachers may either select from UTeach*Engineering*-developed materials for reverse engineering simple products (*e.g.,* a hand-powered flashlight, an electric hairdryer) or allow their students to select products about whose inner workings they feel some curiosity. This short unit addresses the following student learning objectives for the first time: functional modeling, research, information gathering, and reverse engineering.

Unit 2: Engineers Design Products to Satisfy Customer Wants and Needs; Engineered Products Must Evolve

To illustrate that engineers design products to satisfy customer wants and needs, and that engineered solutions must therefore evolve in parallel with science, technology and societal needs, the team agreed that the second unit would center on imaging. In this unit (*From Pinholes to Pixels: The Evolution of Imagery*), engineering students employ the engineering design process for the first time, designing and building pinhole cameras to meet the specifications of art student customers. Simultaneously, they complete a unit project on the evolution of imaging technology (one of engineering's greatest achievements).

The primary focus of this unit is the engineering design process. Other student learning objectives introduced in this unit are innovation and design evolution; information gathering (specifications); new design; design embodiment; data acquisition, analysis, and representation for performance verification; and individual engineering notebooks.

Unit 3: Engineers Work in Teams to Design Solutions

The *Engineer Your World* development team selected a system-based challenge to illustrate the importance of engineering teamwork. In this challenge (*Change Your World View: Aerial Imaging*) students work in multi-level teams (with each team comprising three subsystem teams) to design and launch an aerial camera that must meet design requirements related to weight, performance, and reproducibility. Students also learn about the advances in and applications of remote sensing technology. In parallel, playing off of the unit's space theme and the activity of "launching" an aerial imagery system, students are asked to explore engineering ethics and safety through a unit project focusing on the 1986 Challenger disaster.

The primary focus of this unit is teamwork. Other student learning objectives emphasized or introduced in this unit are safety considerations; system decomposition; requirements; design modification; concept generation and selection; operations planning; team engineering notebooks; and engineering project management techniques.

Unit 4: Engineers Improve Lives

To illustrate how engineers can improve lives, the team selected a design challenge (*Green Energy for Clean Water*) in which students redesign a model wind-powered water delivery system for a village in the developing world. Since this challenge relates to two of engineering's greatest achievements (*i.e.*, electrification, water supply and distribution) the team decided to include a unit project in which students explore and attempt to quantify the effects of other great achievements.

The primary focus of this unit is data acquisition, analysis and representation to develop performance targets. Other student learning objectives emphasized or introduced in this unit are engineering's greatest achievements, system context and top-down perspective, instrumentation and experimentation, redesign, and formal documentation.

Unit 5: Automation Opens New Frontiers

The team adapted a NASA-developed design challenge to illustrate how automation and control systems let engineers meet challenges in extreme environments. In this unit (*The Search for Lunar Ice*) students design, build, and program a robotic vehicle for lunar exploration. Since this challenge relates to a realistic challenge that has not yet been met the team decided to include a unit project in which students explore engineering's grand challenges.

The primary focus of this unit is on automation, control, and programming.

Unit 6: Culminating Design Challenge

The design team reserved the final unit for an open-ended culminating design project whose intent is to allow students to reinforce the skills and habits of mind that they have developed over the course of the year. Whereas the first five units are teacher-guided in that teachers follow day-by-day lesson plans aligned to the engineering design process, the free design unit intends student ownership of the entire process. As such, this unit comprises not scripted lesson plans but rather guidelines such as a schedule of milestones that teams should meet, resources to which teams may need access, and examples of the level of student work that might be expected. The culminating design challenge is to be drawn from a library of challenges (*Mission to Mars*, *Engineering Better Medicines*, *Emergency Shelter*, and

Designing Better Helmets), allowing students and teachers to customize the end of the course to their interests.

Engineer Your World in the Classroom: Piloting, Evaluating, and Revising

Engineer Your World is being piloted by eight teachers with more than 230 students in seven Texas high schools during the 2011-2012 academic year. The pilot schools range from rural to suburban to urban, with student populations between 860 and 2800 students. The smallest pilot class has just seven students, while the largest has 30. Half of the pilot teachers have an engineering degree or engineering work experience. Teaching experience among pilot teachers ranges from two to 20 years; their primary teaching assignments include physics (six teachers), mathematics (one teacher) and computer-aided design (one teacher).

The *Engineer Your World* classroom is a project-based environment in which approximately 80 percent of students' time is spent in hands-on activity and the balance is spent on documenting and reflecting on their work, preparing presentations and reports, and participating in direct instruction. Because so much of the course is student-driven, teachers of *Engineer Your World* play a role akin to that of a project manager. In early units, teachers facilitate and monitor the process closely and offer regular feedback on student and group performance. As the year progresses, students are encouraged to take on more responsibility so that by the end of the course they should be able to design project plans, create schedules, self-monitor and self-assess.

All pilot teachers are participating in research and evaluation activities (*e.g.*, submitting redlined lesson plans, project-requested student artifacts, and pre- and post-tests for all units; participating in evaluator-led focus groups; providing informal feedback during classroom visits). Early feedback is impacting course revisions in a number of ways, including the following:

- It appears that some modification of scaffolding is in order. For instance, although data analysis is a key focus of the wind-driven water pumping system STEM-design challenge (currently Unit 4), teacher feedback indicates that an explicit focus on these skills would bolster student performance in the aerial imaging STEM-design challenge (currently Unit 3). As a result of information such as this, the course design team is reconsidering scaffolding decisions to better meet student needs.

- The course design team elected to begin the course with what it believed to be an engaging engineering design challenge that would pique student interest. *Reverse Engineer Your World* was intended to lead students to think about the impact of engineering on their everyday lives and to allow them an immediate hands-on experience via product exploration and disassembly. Feedback from pilot teachers, however, indicates two problems with this approach. First, while students already drawn to engineering enjoyed the experience of disassembling a product, the activity was not as appealing to students who are historically underrepresented in the field. Secondly, launching immediately into a project, even a short one, was awkward for teachers and students in that it did not allow for teachers to adequately establish classroom norms and expectations. To address these problems, the course design team has decided to extract two short activities from the second and third units to create a new opening week for the course. These activities on engineering notebooks and teamwork, which are hands-on and engaging, will emphasize the importance of these elements in engineering practice while allowing teachers to establish communication and collaboration norms for their classrooms.

- The *Engineer Your World* team has found it difficult to evaluate student performance and improvement based on teacher-submitted student artifacts. Teachers were asked to submit examples of excellent-, average- and poor-quality student work for each artifact requested, but were not given rubrics to assess these artifacts. The apparent differences in teacher judgments about student work have led the project team to undertake a more comprehensive approach to identifying key work products for each unit and developing validated assessment rubrics for those work products. As a result of this work, the project team anticipates that both teachers and the project will be better able to assess student performance and growth over the year-long course.

Additional formative feedback, including student performance on unit and course pre- and post-tests, is being gathered and analyzed at the time of writing.

Discussion

The process of developing, piloting, evaluating and refining a rigorous high school engineering design course offers an opportunity to explore many timely issues in secondary engineering education, including what high school students without previous engineering experiences can reasonably be expected to learn, what teachers without engineering backgrounds can reasonably be expected to teach, and what options might exist to facilitate taking such a course to a meaningful scale. During the 2012-2013 academic year the *Engineer Your World* team will continue to explore and address these issues in a number of ways. In addition to continuing research and evaluation of student learning in an expanding network of Texas classrooms, *Engineer Your World* will begin to explore how the course might work in other states. Through a partnership with NASA, teachers in up to eight additional states will be paired with engineer mentors who will support them in offering *Engineer Your World* in urban, suburban and rural settings; in comprehensive high schools and STEM academies; to single-gender and mixed-gender populations; and in grades 9, 10, 11 and 12. Feedback from this effort will offer a broader picture of the course's effectiveness in a variety of settings, allow for refinement of the mentorship model, and inform project decisions about courseware and online resources.

The emerging importance of engineering in K-12 education standards will require that curriculum developers address many of the issues faced by the *Engineer Your World* design team. By documenting the process of course development, the results of pilot implementation and the reasons for and results of revisions, the *Engineer Your World* team hopes to inform others' efforts in this increasingly important field.

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