

AC 2010-2053: SYSTEM SCAFFOLDING OF CONTENT INTEGRATION IN HIGH SCHOOL ENGINEERING AND DESIGN

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System Scaffolding of Content Integration in High School Engineering and Design

Abstract

Here we present results from a study examining the use of technological scaffolding for facilitating content integration in the development of high school engineering instruction. Considering engineering as an integrated discipline – that is, intertwining science and math content knowledge with design and problem-solving strategies – and with recent literature highlighting the value of content integration in existing high school engineering programs, we developed The UTeach Design Challenge Engine, a collaborative, online tool designed to aid in the development of challenge-based engineering instruction. The tool was put into practice in a professional development program for new and continuing engineering educators. Over several weeks, users’ instructional development did appear to take more into account a broader and more realistic selection of content potentially involved in a given classroom design challenge activity.

Introduction

New legislation now requires Texas high school students to complete four years of math and science to graduate. This change has catalyzed the creation of new science electives designed to meet a variety of academic needs and interests. One fourth-year science elective is engineering. While already offered at some schools, this is overwhelmingly a new opportunity for students as well as teachers; while some of its present and future instructors have degrees and professional backgrounds in engineering, most have qualifications and training most closely related to the math and science courses they teach currently.

Just as the job descriptions of engineers and scientists are related but different, engineering in the classroom demands a different style of instruction than may be effective in the science or math classroom. Style of instruction aside, high school science and math courses rest on a foundation of relatively well-defined content; contrast this with Koen’s definition of the engineering method as “the strategy for causing the best change in a poorly understood situation within the available resources”¹. Even retreating from this abstract definition and focusing on more familiar territory such as electrical or mechanical engineering does not necessarily illuminate the fundamental engineering content these disciplines share. An extensive National Academies survey on the present state and future of K-12 engineering education identifies several concepts key to engineering as a general discipline, particularly to engineering design as a problem-solving process: systems, modeling, and optimization². That all three of these are more techniques and heuristics than knowledge-based content areas points towards our framing of engineering as an integrated discipline – that is, intertwining science and math content knowledge with design and problem-solving strategies. Classroom instruction that captures this perspective frequently takes the form of Design Challenges, which bring together science and mathematics content with engineering and design principles under the umbrella of extended, design-focused projects. Unsurprisingly, this approach also demands potentially different and more holistic modes of assessment than may typically be observed in science and math classrooms.

While the design challenge format has been discussed at length in the literature³, much of

this research focuses on specific instructional packages that address pre-determined content areas, such as the Learning by Design program⁴. While research has identified qualities of effective design challenges⁵, their systematic development is relatively unexplored.

That said, there is ample precedent for the use of scaffolding tools in the development of curriculum and classroom activities. Wikis and other online workspaces provide a wholly unbounded opportunity for development of materials of all kinds; tools have also positively addressed specific educational demands including the needs of diverse levels of learners in a single classroom⁶ and development of teacher content knowledge in conjunction with the development of curriculum⁷. This intervention is deeply indebted to the Star Legacy Cycle for its theoretical basis as well as format in practice. The Legacy Cycle is a challenge-based instructional format designed to “teach deep understanding of disciplines – while simultaneously fostering the skills of problem-solving, collaboration, and communication”^{8,9, 10}.

Papert’s philosophy of constructionism is a powerful influence on not only our notion of design challenges but also on this intervention and its focus on their development¹¹. Constructionism builds on Piaget’s constructivism in maintaining that learners do not imbibe knowledge and ideas but rather create them based upon experiences in the world. It takes this idea a step further in asserting that optimal experiences for knowledge construction are those that are focused on the creation of a product with significance to its maker. As such, we encapsulate this nature of engineering question in the very system that instructors use to develop classroom activities and materials.

The integrated presentation of engineering is not simply a realistic reflection of the careers awaiting students who will choose to pursue engineering professionally; it begins to access the “meta-skills” that will be integral to the workforce of the future in fields both close to and distant from engineering. With the ever-accelerating pace of technological and social change, students are being prepared for a world about which we can predict little, and in many cases for jobs that are currently nonexistent. The skills at the foundation of a quality engineering education - nonspecific strategies for design and problem-solving, the ability to identify, learn, and implement content knowledge as needed – are vital components of readiness for this unknown future.

Methods

Having received IRB approval, data for this paper was gleaned from the coursework of a summer class of in-service teachers, all anticipating teaching engineering courses in fall of 2009. While a minority had experience teaching engineering or related courses (robotics, engineering design graphics), most did not and arrived with a background in science (primarily physics) or math (algebra I & II) instruction.

For half of their class time, teachers assumed the roles of their future students and worked on design challenges with the guidance of University engineering faculty, becoming acquainted with the content they would be teaching as well as with the pace of design challenge based instruction.

Teachers spent the second half of their day on curriculum development or learning theory. In their curriculum development class they produced their own versions of the design challenges in which they were participating, modified for their own classrooms. This paper will focus on two of these development cycles. The first was the Vehicle Design Challenge, which involved managing the tradeoff between speed and carrying capacity in a model vehicle design. An ideal

example of a broad design challenge problem, it involves pure science (potential and kinetic energy of the vehicle and the conservation thereof), applied (or engineering) science (drag and friction), math (calculation of areas and volumes), general design methodology and, more specifically, the evaluation of quantitative tradeoffs. It also connects with pressing real world concerns about fuel efficiency and environmental impact. In the Reverse Engineering Challenge, teachers deconstructed and analyzed a household hair dryer; for their version they were charged with developing a challenge around a consumer product of their choice. While the reverse engineering prescription in this challenge may have constrained the engineering content to some degree, it offered the opportunity for addressing a wide variety of science and mathematics content. Teachers worked together on their new design challenges in groups from two to five. Groups did not remain the same from the first week to the second and during week two some teachers contributed to the projects of multiple groups.

UTeach Design Challenge Engine

For the two development cycles described above, teachers used the UTeach Design Challenge Engineer (UTDC), a web-based tool developed by the authors. In addition to providing collaborators with an online workspace and a template for classroom-ready lesson plans, the UTDC scaffolds the development of design challenges by engaging users in essentially a guided brainstorming procedure. While it is designed to accommodate multiple points of entry, the process would typically begin with the user being prompted for science, math, and engineering content ideas that could potentially play a role in the classroom investigation of a broad theme (such as “vehicle design” or “reverse engineering a pocket calculator”). From here the tool continues to prompt the user with careful questions while revisiting input information at just-in-time junctures, helping the user to hone their ideas into a well-defined design challenge.

Figure 1 below illustrates the UTDC design cycle. The usage described in this paper stopped at the ‘Create a Prototype’ phase; a web-based implementation of the evaluation and redesign phases is currently under development.



Figure 1 - UTDC design cycle

Figure 2 shows one page of the UTDC. Users have already entered content and design ideas on which a particular design challenge could or should focus; this information is repeated for the user here as he or she is prompted to consider real world engineering challenges in which this content would be involved (this page also invites the user to think about societal needs likewise related to the content and possible evidence of learning the content). The design challenge is progressively fleshed out in comparable fashion.

UTeach Design Challenge Engine

A Tool for Engineering Educators

Reverse Engineering Generate Approaches

Content & Constraints	Generate Approaches	Generate Challenge Ideas	Choose a Challenge	Create a Prototype	Evaluate Prototype	Revise & Reflect
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Features determined in the Content section:

What is the technical content embodied in this lesson?

Friction and drag
Energy and conversion of energy
Basic mechanics (speed, acceleration, momentum)

What design principles will be emphasized?

System efficiency
Tradeoffs and optimization
Analysis of customer needs

Real World Engineering Problems - Societal Needs - Evidence of Learning

What are real world engineering problems that embody the technical content? ?

Look around - you will see the solutions to engineering problems virtually everywhere, in the form of structures, devices, and processes. Considering your content ideas and engineering principles above, what are some real world case studies where these are present?

Figure 2 - UTDC Interface

The addition to using the UTDC in class work as described above, near the end of the course three groups of teachers used the UTDC to begin development of a design challenge revolving around the design of a portable bridge. This exercise was unique in that it was not based on a design challenge in which the teachers had participated during the summer course (though some did take advantage of experience with bridge-related instruction).

Teachers developed a wide variety of creative design challenges in the curriculum development class. For instance, ‘Vehicle Design Challenge: Room vs. Efficiency’ was a four-day challenge focused on designing and building a foam board vehicle that optimized volume vs. drag, including lecture material on air flow and friction, a classroom wind tunnel, design and redesign in groups, hands-on construction, and concluding with a class vehicle competition. ‘One-Dollar Calculator Tear-apart,’ a simple two-day challenge, invited students to disassemble a simple calculator and produce a functional diagram of its main components; it also focused on the role of technology in society, asking students to consider how the unit was manufactured and sold so inexpensively, and what might be some ways that we have been impacted by such inexpensive electronics.

Data Sources

The data in this paper comes from the Design Challenge Engine, where users are prompted to list the assorted science, math, and engineering content (the “big ideas”) that will be addressed by the design challenge under development. Many of the entries in this section can be

mapped to proficiencies from the Texas Essential Knowledge and Skills (TEKS) in science, mathematics, and engineering – in practice the TEKS could be guiding lights for development of design challenges.

The science, math, and engineering ideas identified by the teacher groups as potentially integral to the challenges in weeks one and two as well as to the bridge challenge in week five were gathered and coded, with explanations and examples of the seven codes appearing below in Table 1:

Code	Explanation	Examples
Pure Science	Pure science concepts are domain non-specific and can be capably discussed at a level of abstraction removed the “real world.”	“Work = Force X Distance” “conservation of energy”
Applied (or Engineering) Science	Applied science addresses pure science concepts in concrete application. Applied science is often the bulk of coursework for engineering undergraduates.	“air flow and drag” “Structures-Beams and column, trusses”
Applied Math	Similar to applied science, this category utilizes fundamental concepts from mathematics.	“mathematical model” “trajectory”
Design Methodology	In some cases, teachers would include all or many of the steps of a standard engineering design methodology. While these steps were could arguably be considered multiple entries, teachers did learn them as part of a process and they were generally presented as such; therefore, they are coded as a single entry here.	“Idea generation, Choosing an approach, Sketching a prototype, Building a prototype, Predicting performance, Testing and Evaluating a prototype, Revision of prototype”
Auxiliary Design Approaches	Under this heading are a collection of engineering design techniques or more specified elements of the standard design methodology.	“tradeoffs (vol vs. time)” “life cycle of consumer products”
Hands-On Procedure	These were technical procedures that students would need to perform at a certain level of proficiency to complete the challenge.	“sheet metal layout” “measurement”
Technology Content	This classification included a variety of devices and processes that figure heavily in the world of the engineer.	“use of plastics” “batteries”

Table 1 – Content Codes

Results

The coded data for all groups in the three samples can be found below in Figure 3. The numbered vertical bars represent individual groups, which did not remain the same across data collections. The vertical axis represents the quantity of ideas generated by the group and the width of each bar reiterates the number of content categories present (the latter value also being found in the number of colored segments making up each vertical bar):

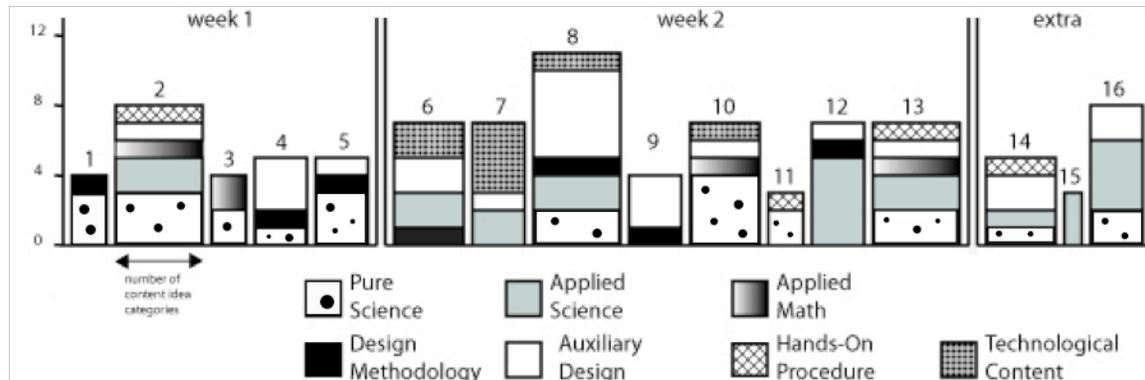


Figure 3 - Coded Content Results

Returning to the integrated nature of engineering, in examining these results we are somewhat more interested in the diversity of categories present in the work of a group than in the sheer quantity of content ideas generated. Encouragingly, the two most well represented categories in weeks one and two are ‘Auxiliary Design Concept’ and ‘Pure Science’ (with ‘Applied Science’ replacing ‘Pure Science’ in the third sample); this reflects the coexistence of science and design fundamental to engineering practice.

Comparing weeks one and two, we find a clear increase in the number of content categories represented in most groups’ work. It is possible that the change is due more to the difference in content and challenge type than time with the tool. However, it is relatively easy to imagine a role that any of the above content categories might have played in week one’s vehicle design challenge; this increase is not obviously due to the prescriptions of the reverse engineering challenge. The teachers had also recently completed creation of their first design challenge, including creating a lesson plan describing several days’ worth of activities in the classroom. Having connected the first week’s challenge back to the classroom may play some plausible role in the change, especially as ‘Technology Content’ appears for the first time in more than half of the groups. Also, teachers were free to choose their own subject for the reverse engineering exercise. If teachers are generally “on board” with engineering as integrative and our challenge is simply to help them communicate it effectively, then having this autonomy may have played a part.

We have not addressed the third sample, gathered several weeks after the first two; three groups of teachers were asked to undertake the initial brainstorming phases of creating a design challenge focusing on a portable bridge design. Here we find results that

more closely resemble those from week one. What most glaringly set this exercise apart from the others was simply that the teachers had not participated in anything similar to this in their engineering coursework – in some cases objections were raised precisely to this effect. It is unclear the degree to which this newness can or should impact design challenge planning at its most abstract (intuition would seem to point towards its adversely affecting the planning of actual day to day activities).

Conclusion

This tool, together with the work of its creators as well as users, represents a new approach towards challenge-based instructional development. Prior research has little addressed the use of tools for facilitating instructional design at this level of abstraction; that is, helping instructors effectively integrate a variety of content under the heading of a single overarching goal while simultaneously acquainting them with this style of instruction. While in only limited use during school year, feedback has valuably informed redesign of the tool for its anticipated implementation in summer of 2010. In addition to producing a tool valuable to educators in Texas and beyond, we anticipate useful contributions to the theoretical literature dealing with technology's impact on learning and instruction as well as on creativity and collaboration.

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