Not Just for Nerds: Embedding Science Activities within a Design, Engineering, and Technology (DET) Environment

Dale Baker 1, Senay Yasar 2, Sharon Robinson Kurpius 3, Steve Krause4, Chell Roberts 5

Abstract - Design, Engineering, and Technology (DET) holds the promise of interesting students in STEM (science, technology, engineering, and math) careers and developing a better understanding of STEM in their own lives. However, the current K-12 curriculum devotes little time to DET concepts despite their being addressed in the National Science Education Standards. This paper presents data from a DET course developed for science education graduate students which uses the existing curriculum for introducing DET into the classroom. Data from lesson plans, weekly reflections on readings, trial activities in K-12 classrooms, and focus groups tracked changes in understanding DET and the ability to embed DET into existing science activities. Data was coded using qualitative techniques and a rubric with six categories (engineering as a design process, gender and diversity, social relevance of engineering, technical self-efficacy, tinkering self-efficacy, and transfer to the classroom) that measured achievement of course goals. Understanding and progression of metacognition was linked to instructional activities and readings.

Index Terms – Design process, K-12 curriculum, metacognition, rubric

LITERATURE REVIEW

DET IN THE K-12 CURRICULUM

In 1996, the content standard, “Science and Technology,” [1] was added to the National Science Education Standards [2], which include concepts on the subject of Design/Engineering/Technology (DET) for the K-12 curriculum. These standards emphasize the process of design (identify a problem, propose a solution, implement the solution, evaluate the product/design, communication) and links between science and technology. The DET concepts are in Standard E (Science and Technology) address “abilities to distinguish between natural objects and objects made by humans,” “abilities of technological design,” and “understanding about science and technology” (p.135).

TEACHERS’ FAMILIARITY WITH DET CONCEPTS

Several countries have made design and technology concepts a priority in K-12 classrooms including; Australia [3], New Zealand [4], and Northern Ireland [5]. However, researchers in these countries have found that many teachers have limited knowledge about the meaning, content, and aim of technology education [6]. A case study of three Australian teachers revealed that even experienced teachers had difficulty scaffolding their student’s learning when they taught DET for the first time [3].

DET activities are also found in after-school programs. However, these programs are usually not as successful as embedding DET into the curriculum because most engineers who mentor and implement the after-school activities lack pedagogical knowledge. On the other hand, research on teachers who are trained to use DET concepts has shown that students’ attitudes significantly improve. For example, a project by The Materials Technology Institute (MTI) aiming to provide teachers with the background and curriculum needed to create a new high school course in Materials Science and DET was implemented in Singapore [7]. Students who participated in this project reported that the courses: a) made them much more interested in a science career; b) increased their enjoyment of laboratory activities; and c) helped them develop their skills for working with equipment and in the laboratory setting. One of the most important responses was that 96% of the students would recommend, or probably recommend, the class to their peers.

The work of Jones and Carr [8] highlight the importance of understanding teachers’ perceptions of a new curriculum before implementation. In their examination of perceptions of technology education, they found that secondary teachers interpreted technology in terms of the
subject they were teaching rather than in terms of design concepts. In addition, science teachers thought that technology was covered in science, although not to the extent they wanted. On the other hand, some teachers were not aware that they were teaching some aspects of DET.

A common misconception held by many people, including teachers and administrators, is that technology education is limited to computers [9]. Jones and Carr [8] found this perception in interviews with teachers. Technology education was often confused with educational technology taken during pre-service training. Primary and intermediate school teachers stated that they used technology across the curriculum and used computers and calculators in math and word processors in language courses. These teachers were generally positive about introducing DET in primary schools; however, they wanted it to be integrated rather than being a separate subject.

Of the eight National Science Education Standards, these three are frequently ignored. Sherwood and his colleagues [10]-[12] have argued that, despite being neglected, DET is a rich context for learning science. In spite of the positive effects of design on children’s knowledge, teachers often do not include DET concepts in their curriculum [13]-[15]. Some factors that may contribute to the absence of DET in the curriculum are teachers’ lack of preparation to teach DET concepts, their self-efficacy related to teaching DET, the importance they place on DET concepts, barriers that limit their teaching DET, and their beliefs about which students can best learn DET.

**TEACHER DET BELIEFS (SELF-EFFICACY)**

Teachers hold a variety of beliefs about themselves and their abilities as well as beliefs about students that potentially impact their teaching. One type of belief is one’s perceived self-efficacy [16], [17]. Self efficacy is a belief that one is able to complete a specific task successfully. Since DET self-efficacy may be a barrier to teachers using more DET related activities in their classes, understanding teachers’ efficacy beliefs in DET education is important. According to Ramey-Gassert, Shroyer, and Staver [18], personal science-teaching efficacy and teaching outcome expectancy are two components of teaching self-efficacy. They define the former as teachers’ beliefs in their ability to teach science and the latter as teachers’ belief in students’ ability to learn. In their review, they found that several factors affected teaching self-efficacy. These were teachers’ beliefs, attitudes and anxieties about science; personal teaching efficacy and outcome expectancy beliefs; teacher preparation and professional development; early science-related activities; and perception of gender roles. It is reasonable to assume that these factors may also be important to understanding and teaching of DET.

**BRIDGING EDUCATION & ENGINEERING COURSE**

The Bridging Education and Engineering course was created using feedback from a statewide survey and current literature. The course was designed by a science educator and two engineers. It consisted of an exploration of the design process, readings and discussions of research in engineering and science education, discussion of Standards, writing reflection papers, weekly tests of understanding, transfer activities to apply the DET concepts to enhance lessons in K-12 science, and a design project. This project consisted of preparatory inquiry labs using sensors, actuators, and microprocessors, and writing code. Groups of students worked together to identify a problem, develop a prototype drawing, order materials, use the materials to build a device, test the device, and refine the device. The culminating activity was a formal presentation and demonstration of a working device.

**METHODS**

**SAMPLE**

Nine students were enrolled in the DET course (5 females, 4 males). All were science education masters and doctoral students with strong content backgrounds, including one male and one female with an engineering background. They worked in 3 groups on design projects. One group was composed of only women, and two were composed of two men and one woman. These groups came about because three of the women preferred not to work with the males whom they found to be too competitive.

**DATA SOURCES**

Data was obtained from several sources. Students were observed during their design activities and notes were made about engagement with materials (actuators, sensors, microprocessors, volt meters, soldering irons etc.) and group interactions. Students were asked to respond to three open ended statements (Honesty describe your tinkering self-efficacy. Honestly describe your technical self-efficacy. How are science and technology related) three times as a pre, post and delayed post test. Students also read and discussed articles related to DET and teaching science (e.g. designing a model of an elbow, redesigning can openers) throughout the course and wrote weekly reflection papers on readings. As students gained experience in the engineering design process they participated in transfer activities to map DET knowledge to lesson plans using state and national standards for engineering design and technology.

**DATA ANALYSIS**

All written materials were analyzed by looking for themes, changes over time and gendered patterns by applying a rubric developed to determine whether the course had met our intended objectives. The rubric consisted of six categories with 46 sub categories (Figure 1). The data was coded by one researcher and confirmed by a second. Changes were discussed and made where disagreements over coding were found. Group observations were compared to coded statements to triangulate data. Pseudonyms were given to the students and used in the reporting of the data.
A. ENGINEERING DESIGN PROCESS
   1. A successful artifact
   2. Vocabulary and Concept
   3. Tool use
      i. process
      ii. analytical (modeling)
      iii. experimental
      iv. technology
      v. communication
   4. Team building
   5. Shift in understanding
   6. Metacognitive processes
   7. Recognition of design in daily life
   8. Steps in design process
   9. Connections to science
   10. Connections to readings and research

B. GENDER AND DIVERSITY
   1. Shifts in understanding
   2. Stereotypes or gender roles of self/others/students
   3. Changes in behavior
   4. Connections to readings and research
   5. Metacognitive processes

C. SOCIETAL RELEVANCE IN ENGINEERING
   1. Metacognitive processes
   2. Shifts in understanding
   3. Connections to science
   4. Recognition of engineering in daily life
   5. Awareness of misconceptions (self/others)
   6. Applications (present /future)

D. TECHNICAL SELF-EFFICACY
   1. Metacognitive processes
   2. Shifts in understanding
   3. Stereotypes or gender roles of self/others/students
   4. Changes in behavior
   5. Shift in negative to positive self-talk
   6. Comments on competency

E. TINKERING SELF EFFICACY
   1. Metacognitive processes
   2. Shifts in understanding
   3. Stereotypes or gender roles of self/others/students
   4. Changes in behavior
   5. Shift in negative to positive self-talk
   6. Comments on competency

F. TRANSFER TO THE CLASSROOM
   1. Metacognitive processes
   2. Shifts in understanding
   3. Integration of design in lessons
   4. Integration of standards in lessons
   5. Seeing old activities in new DET perspective
   6. Connections to readings and research
   7. Integration of science and technology
   8. Application in own teaching
   9. Engineering as a career
   10. Critical Perspectives
   11. Awareness of misconceptions (self/others)
   12. Team building (engineering vs. teachers)

FIGURE 1.
RUBRIC FOR DESIGN COURSE

ENGINEERING AS A DESIGN PROCESS

The students recognized the differences (as well as similarities) between science and technology; developed an understanding of the design process; developed a vocabulary (e.g. sensors, actuators, microprocessors) on and discovered the importance of team work in the design process and problem solving. They also uncovered their own misconceptions about design and modeling, particularly as a result of the hands-on activities and group projects. Amy wrote “I thought design was another word for drawing, and since then have learned that drawing is a part of the process, designing incorporates a thought process, a problem solving process, modeling and then presenting.”

David wrote “Our group learned an important lesson last week. Our original design for our project was going to transmit location, direction, speed, identification and whether or not the device had crashed or not. After speaking with an advisor about the chip and feasibility of our design, we found that this was nearly impossible within our time and funding constraints. Much like the problem with concept designs, this has given us a glimpse and new respect into the world in which engineers live. I had never realized how nearly impossible a project can be, yet in the beginning it seemed so simple. We had this dreamy view like we would simply slap this here, rewire this there, reprogram that there and whala, done. Even with a concept design as simple as ours, just getting the sensor to read and display location is nearly impossible. Thus our project has been whittled down to merely displaying location. This, as Steve has so politically called it, a “proof of concept”. The point being that if we can display location, taking the derivative of this we can find speed as our next step. Simply adding on pressure sensors and relaying the vehicle description is a simple task. Getting the sensor to display position is crucial to the project.”

The data also indicated a shift in understanding of the design processes that emerged toward the end of the semester. Below is Isabel’s answer to the question, describe the design process, as you understand it, as she wrote it at the beginning of the semester and at the end of the semester - “The design process involves a combination of technical expertise, team-building skills and creative thinking. It is more than just putting an idea on paper and building it. Like research, you have to find reasons why your idea won't work (disconfirming evidence) and try to come up with other plausible solutions. It is only when those alternative ideas are exhausted and you still think you have a good idea, you can proceed with creating an artifact from this idea.”

GENDER AND DIVERSITY

Students realized how technical problem solving can provide learning opportunities for all. This led to an understanding of the importance of gender diversity in the design process so that the students were able to see how DET could support diversity. They also recognized the gendered nature of their own
interactions with their peers as they developed their group projects and created lesson plans. Both male and female students commented on the gender differences they saw in their own group interactions. Eric wrote “So how to address these issues, not only in my classroom as a teacher, but also in my classroom as a student? These are not just theoretical questions; I would like to find strategies that will work in my current situation. In the next few labs, I plan to experiment with approaches to 1) encourage the female students in my group to take a firmer lead in our investigations, and 2) find a way to diminish the perception that I am the sole “tool expert” in the group.”

Amy, who was also teaching at a middle school, thought about how design projects can be used to promote diversity in her own classroom. She wrote “…on some level I have found these “projects” to be an equalizer in my class. The students that have excelled in this section were students that you wouldn’t expect, including girls, special needs, English limited students and low academic students. They have a natural curiosity of the world which falls nicely into the definition of technology and its components.”

SOCIAL RELEVANCE OF ENGINEERING

All the males in the course had a good initial understanding of the technical relationship of science and technology. As the course progressed their understanding expanded to include a greater number of commonalities, the social impact of science and technology, and the reciprocal relationship of science and technology. Women’s initial understanding varied from incorrect, simple, and good. The student with an incorrect understanding did not have her views changed by her experiences. At the end of the course, the other three women’s understanding became more complex with a greater emphasis on the social impact (e.g. help make the world better), the reciprocal nature of science and technology, and the commonalities between the two fields. There was a consensus among the females that they looked at the built world spontaneously or without purpose. For example Isabel said “I notice my confidence level increases upon the value of the object that I tinker with. If it is expensive or a hard to find object, I am much more cautious with tinkering. But, if it is cheap and easily replaced I am very confident with tinkering.” At the end of the course she said “I did it [tinkering] without having an engineering background. I learned what tinkering should be”.

Beth, despite an engineering background, also stated her level of self-efficacy was related to the context of the tinkering. She said “My tinkering self-efficacy all depends upon the value of the object that I tinker with. If it is expensive or a hard to find object, I am much more cautious with tinkering. But, if it is cheap and easily replaced I am very confident with tinkering.” At the end of the course she described her self as “confident with tinkering” but still context dependent e.g. “I notice my confidence level increases when there is less at stake.” This was in sharp contrast to the unconditional expressions of confidence expressed by Eric who had a comparable background in engineering.

Tinkering was not something females did spontaneously or without purpose. For example Isabel said “I don’t necessarily enjoy pulling things apart just to see what is inside or how I could make it better.” and Helene said “[at the] beginning of this course I can not imagine creating any kind of devices using my tinkering ability.”

The four males exhibited a different pattern. Frank, a student in physics education, provided a one word answer, “low”, at the beginning of the course when asked to describe his tinkering self-efficacy. The class experiences did not alter his perceptions of his tinkering ability. In response to the post test question he said “I am not very confident in my tinkering skills”. George started with moderate self-efficacy. He said “I like to tinker with tools, materials (wood, metal, erector sets, and science lab materials). OK self confidence”. By the end of the course he said “I have a great deal of tinkering confidence. I will accept the risks and I don't mind embarrassing myself. I've made a career out of that it seems”.

Conference:

October 20 – 23, 2004, Savannah, GA
Eric had an engineering background and started the course with very high tinkering self-efficacy even when compared to Beth, the other student with an engineering background. He started the course by saying “Very confident. I've taken apart many things just to see how they work.” and ended by repeating his earlier sentiments “Very high, I like nothing better than to pull something apart or put things together to see how they work”. David also started with high tinkering self-efficacy saying “I love ripping apart stuff. I give myself a 10/10 on this. I give myself an 8/10 on putting it back together. The amount of parts left over is directly proportional to how badly it works after I get hold of it.” His response on the post test was “the same”.

In contrast to the females, males, with the exception of Frank, liked to tinker for fun. In addition to Eric and David who liked to take things apart, George said “I like to think about solving design problems and visualizing what component parts I could use, how I could assemble them, and how they might work to solve a problem.”

**Transfer to the Classroom**

Students’ lesson plans became less contrived as students saw that implementing DET and the NSES was not an additional task but integral to science lessons. They voluntarily tried DET activities in their own classrooms and were able to see how the readings were applicable to their own teaching. The students in the course could readily identify common lessons, such as clay boats, that with modest modifications could address design issues. For example, the modification for clay boats included determining what the real problem is (e.g. the relationship of the number of paperclips held to the boat shape and the properties of materials used to build the boat) or real boats and systematically generating, implementing, and testing solutions against a set of design criteria. Amy described her experience in teaching boat design writing “When the kids were designing the boats there were many times he thinks I should have stepped in and told them that they needed this or how to do it right because the way they were doing it won’t work. I took an outside observer position, asking them the questions so that they could figure it out on their own. For example on the girls’ boat and their supports, they figured they need supports so they made them so that they ran along widthwise, but the lengthwise supports were shorter than the length. I questioned them about it and they said on the bottom they had put supports around the others. I asked about cutting a support won’t it make it weak, and they had lots of explanations on what they did to fix it so I left it, because they thought they had solved the problem.”

Students also were able to create new lessons with real world contexts such as designing “smart” shopping carts that would not bump into cars in a parking lot, a better student locker, a device to help you do your chores, a safer teeter totter, and amusement park rides. The students found ways to integrate DET in other ways too. David wrote “the physics labs that I've designed have 'themes'. Although these themes were designed with the goal of learning such as 'why steel ships float' the students are free to investigate whatever they want.” Frank felt that comparing the scientific method to steps in the design process was a good way to integrate DET into the curriculum. He wrote “the scientific method closely parallels the design process of the engineer. So if the science classroom is used to instruct students in the scientific method (by practice) then learning the design process can then be taught by comparison.”

George wrote about changes he would like to make in his biology classroom. “Watson employed this (tinkering and building) prior to his and Crick's invention of the DNA molecular shape. I would like to see some design technology activities that can be conceived by students to explain hypothetical conceptual systems (like DNA structure).”

Isabel, a former elementary school principal and Amy a fifth grade teacher looked at integration the most broadly. Isabel wrote: “I believe it (technology) should not necessarily be separate nor incorporated into only science, but integrated in math, social studies, and communications classes too. Just like math is a natural part of science and writing happens in history class, why can't technology be looked upon as an integrated class within several disciplines?”

Data from the reflection papers indicated that the students were not naïve about the challenges to bringing DET into the classroom. David was concerned about curriculum and reflected “the question is: how do you contextualize a design so it keeps the novices interest and at the same time give them an opportunity to de-contextualize the concepts from the design?” Isabel also raised curricular questions and wrote: “Before we can commit ourselves to adopting a new curriculum, I think we need to understand the implications for doing so both academically and socially. Being able to produce students that can “reconcile the conflict between the biosphere and technosphere” (referring to a topic in the readings) is not important until we can answer how we can teach these students effectively.”

George also saw the issue of integration as one of changing the teacher’s role. He wrote: “Many of the classroom environments are unsatisfactory for successful learning of design and technology. Both the learning philosophy of the teacher and the amount of “control” the teacher is willing to “give-up” to students are significant variables in the measure of student learning in design and technology. Design and technology are processes and products, thus the facilitating role of the teacher and the assessments utilized need to address them both. From my perspective, a strong case is made for creating a design / technology course for all pre-service teachers and encouraging all current science and math teachers to attend workshops or take a course on design technology in education.”

Amy saw implementing DET into the classroom as an awareness of her own misconceptions. She wrote: “We were given copies of curriculum that are aligned to SAT9 and AIMS, for sixth grade science 3 of the 4 standards are about technology. For example SCT1 students should be able to: identify a problem; design a solution or a product; implement a proposed design; and evaluate how well the product or solution satisfied the problem. Before this class I would have
never known what this was about, or what I should be teaching. Part of changing curriculum should be training teachers. These standards are just words if I have my own misconceptions about technology.

**IMPLICATIONS**

We recommend that DET become a part of both graduate science education programs and undergraduate science methods courses. In an increasingly technological world, the neglect of DET and especially the reciprocal nature of science and technology leaves teachers ill prepared to address education in the 21st century. Currently, technology is understood in limited contexts i.e. the computer. The integration of DET into the curriculum gives the teacher an important conceptual tool to live in an increasingly technological world where citizens will be called upon to make decisions concerning the impact of technology on society. Integrating DET into the curriculum can also expose students to science, technology, engineering and mathematics careers in more concrete ways than the current curriculum.

The current stranglehold of the traditional disciplinary divisions in our schools (chemistry, biology, physics and to a limited extent geology) does not include engineering. The inclusion of DET, an essential component of engineering, would provide teachers with the freedom to address the mostly neglected and important standards (Cajas, 2001) of Science in Personal and Social Perspectives, Science and Technology, and History and Nature of Science.

**REFERENCES**


