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Infusing Design, Engineering and Technology into K–12 Teachers' Practice*

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A graduate course for teachers on Design, Engineering and Technology (DET) was designed to infuse DET concepts and activities into the teachers' own practice. Three teachers who took the course were studied in depth to document the impact of the course in helping them implement DET in their lessons. Data for this study consisted of open-ended pre and post surveys, seven reflection papers, a DET unit plan written by the participants and participant interviews. An emergent-theme qualitative data analysis revealed meaningful patterns of change as the data were organized, categorized, reduced, coordinated and verified. Four key themes were revealed through this process: Reflections on Practice; Changes in Practice; Intentions to Change Practice; Changes in Knowledge. The case studies showed the following changes that occurred in participants' own teaching activities. Alice, an elementary school teacher, changed her practice by using DET concepts through having her children design a desert tortoise habitat. Denise, who taught at a science centre, changed her practice by shifting from crafts-based to design-based activities. Dana, a high school honours chemistry teacher, changed her practice by having her students design and build a lab instrument (calorimeter) and design associated lab activities. The teachers reported that the course's sharing and interactive activities promoted their ability to change. These activities included: reading and discussing research on classroom applications of DET; discussing possible changes in their own practice; sharing successes and failures in developing and trying their own lessons; receiving feedback to refine their lessons over the semester. Overall, the course and its activities were a catalyst in transforming the teachers into a community of learners who supported one another as they infused DET into their practice.

Keywords: engineering design in K–12 practice; emergent-theme data analysis; community of learners

INTRODUCTION

AS THE TECHNICAL COMMUNITY in the US deals with critical national issues such as globalization, pollution and sustainability, it is more important than ever to attract and support well-qualified K–12 students emerging into the engineering education 'pipeline'. In the National Academy of Engineering document, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century* [1], one of the 'guiding strategies' highlighted is to engage and support K–12 teachers in ways that will support the development of future engineers. This need and concern is also reflected in the national education standards as discussed below.

The National Research Council recognized the importance of technology and engineering in education when, more than a decade ago in 1996, the subject area of 'Science and Technology', was added to the National Science Education Standards (NSES) [2]. The goal was to emphasize the process of design and to promote linkages between science and technology. Standard E (Science and Technology) addresses: 'abilities to distinguish between natural objects and objects made by humans . . . abilities of technological design . . . and understanding about science and technology'. Standard F (Science in Personal and Social Perspectives) addresses the challenges of science and technology, locally to globally, the process of invention and the socioeconomic, political and ethical impacts of science and technology. Standard G (History & Nature of Science) addresses the historical impact of science on society. Overall, in summarizing the content of these standards, it can be said that technology education involves teaching the design, engineering and technological issues related to conceiving, building, maintaining and disposing of useful objects and/or processes in the human-built world.

In order to emphasize this broader meaning of technology education, we use the phrase 'Design, Engineering and Technology' or DET in this article. Our definition of DET is synonymous with what the national science standards call 'technology'; it encompasses a number of concepts and skills that parallel the engineering design process. These include the ability to:

1) identify a problem or a need to improve on current technology;

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2) propose a solution to a problem;
3) identify the costs and benefits of solutions;
4) select the best solution from among several proposed choices by comparing a given solution to the criteria it was designed to meet;
5) implement a solution by building a model or a simulation;
6) communicate the problem, the process and the solution in various ways.

In spite of the presence of the NSES standards that address topics tied to DET, they are often neglected in K–12 education. Although scholars [3, 4] have argued that DET is a rich context for learning science, teachers usually do not include DET concepts in their curriculum [5, 6, 7]. Thus, the goal of this research was to determine the effectiveness of teaching a DET course on the participant teachers' ability to infuse DET concepts and activities into their own practice.

TEACHERS' FAMILIARITY WITH DESIGN, ENGINEERING AND TECHNOLOGY CONCEPTS

Including DET concepts in K–12 curricula became a priority more than a decade ago in Australia [8], New Zealand [9] and Northern Ireland [10]. However, researchers in these countries found that many teachers had limited knowledge about the aim, meaning and content of technology education [11]. A case study of Australian teachers found that they had difficulty in scaffolding students' learning when they taught DET for the first time [8]. In the United States, teachers felt that DET was important to teach but they lacked knowledge, time, training and equipment to implement DET in the classroom, especially because it was not part of the curriculum [12, 13].

A common misconception held by the general public, including teachers and administrators, is that technology education is limited to computers [14]. For example, primary and intermediate teachers stated that they used technology across the curriculum; e.g. computers and calculators in maths and word processors in language arts. These teachers were generally positive about introducing DET in primary schools, but wanted it integrated into other subject matter [15].

Research on teachers trained to use DET concepts, however, has shown that DET has a positive impact on students. For example, the Materials Technology Institute project provided teachers in Singapore with the background and curriculum needed to create a high school course in Materials Science and DET [16]. Students reported that, taking such a course:

a) increased their interest in a science career;
b) increased their enjoyment of laboratory activities;
c) helped them to develop skills for working with equipment and in the lab.

Approximately 96% of the students said they would recommend the course to peers.

The National Science Foundation (NSF) has stated that there are a 'disproportionately high number of girls who lose interest in science during middle and high school' which has resulted in 'the low number of women who enroll in advanced high school science and maths courses to prepare for college'. Thus, NSF has responded to 'the disproportionately low number of women' with science, technology, engineering and maths (STEM) undergraduate majors by developing a multimillion dollar programme to support and increase girls' and women's participation in STEM education [17]. Many of the resultant intervention programmes addressed what are known as pipeline issues—not enough females taking STEM courses and entering and persisting in STEM majors. Some of the pipeline issues facing engineering today can be directly attributed to the two factors described above which, briefly stated, are ignoring the standards related to DET and teachers' lack of familiarity with DET. These two factors are clearly linked. If teachers are unfamiliar with DET concepts and activities, then they will not address the standards related to teaching DET, nor will they recognize the ways in which DET concepts can be infused into existing curricula. We argue that students would be significantly impacted if a K–12 curriculum explicitly addressed DET-related standards and provided opportunities for students to engage in science studies through DET activities. This would result in an increase in students' interest in engineering as well as more students choosing engineering majors at the university level. Broadly testing this assertion is beyond the scope of this work. Instead we are reporting on the demonstration of an approach to a first step in the process of increasing the number of students entering engineering—which is to help teachers infuse DET into their own curriculum.

PURPOSE

This study documented the effect of a course designed to help teachers integrate Design, Engineering, and Technology (DET) into their curriculum. The research question that drove this study was 'How does a graduate course for teachers focusing on DET concepts and activities change teachers' classroom practice?' Three case studies were developed that described the effect of the course on four categories that unfolded from the qualitative data as developed by an emergent-theme data analysis method. The four categories or themes were:

1) Reflections on Practice;
2) Changes in Practice;
3) Intentions to Change Practice;
4) Changes in Knowledge.

RESEARCH METHODS

Participants and course description

This study was a component of a graduate course in science education supported by a NSF Bridging Engineering and Education grant. The course was developed and taught by a team that consisted of two faculty members from the Mary Lou Fulton College of Education, a counselling psychologist and a science educator and two faculty members from the Ira A. Fulton School of Engineering. The course on DET was a follow-up to a previous course on DET for science education graduation students. In the previous course there was a major emphasis on learning the nature of the engineering design process and using the process to create functioning real-world artefacts. There was a minor emphasis on how the engineering concepts and activities might possibly be infused into their own classrooms. The major emphasis of this second course on DET was learning the engineering design process with the goal of incorporating the DET concepts and activities into the teachers' own practice.

Three of the students in the course were in a science education master's programme and agreed to be studied in depth and allowed us to use their written reflections and teaching units as data sources. The first student was Alice, an elementary school teacher with more than five years of experience. She taught 3rd grade at an alternative school that gave teachers great freedom in deciding on their curriculum. The school's philosophy was constructivist and student-centred. Textbooks were not used and students were not assessed by any mandated standardized tests. Alice had a good science background that she had acquired on her own.

The second student was Denise, who taught at a Science Centre and developed activities/workshops for children and their teachers that were related to an NSF grant awarded to the Centre. The grant funded the writing of pre and post classroom experiences and assessments to accompany the museum visit activities. Although Denise had considerable flexibility in terms of the content, she was required to link the content to the museum exhibits and the grant. Denise had a weak background in science; her content knowledge was acquired on her own. She had never taught in a public or private school.

The third student was Dana, a high school honours chemistry teacher and the science department chair. She was the most constrained by the existing curriculum and the need to teach so that students did well on the district and state standardized tests. Her classes were small and her students were highly motivated. She had a strong background in science, especially in chemistry, and had been a teacher for 15 years.

The course met weekly for fifteen weeks in an industrial engineering lab with access to a wide range of materials, tools and technical assistance. The course consisted of discussions of research articles related to using DET to teach science in K–12 classrooms, written reflections linking the readings to classroom practice and hands-on activities that exemplified aspects of DET. The first half of the course was spent learning the engineering design process and applying it to hands-on activities such as use of the properties of materials in design, redesigning nutcrackers for ease of use and the structure and function of skeletons as related to bioengineering. Before and after each class, teachers answered a set of online pre/post questions to determine the impact of readings, discussions and activities on their understanding of DET.

The second half of the course was spent developing and implementing a design activity for the teachers' own practice. Teachers were required to prepare a prospectus for a science unit that integrated DET into their current curriculum and to then present this to classmates for comments and critique. Once the teachers began teaching the units, they prepared weekly presentations of problems and successes. This included examples of their students' work and discussions that focused on revisions of the unit lessons. Presentations and discussions were an iterative process with characteristics of the Japanese lesson study. The unit included a statement of need, literature review, standards, a week or more of lessons, assessments and a report of the impact of the unit on their students.

DATA SOURCES

Four sets of data were collected for this study:

1) open-ended pre/post questions;
2) seven reflection papers written by the teachers;
3) the DET units designed by the teachers;
4) interviews with the participant teachers.

Pre/post data were answers to six questions about the design process, tinkering and technical expertise, the relationship of science and technology and ways to modify the curriculum to include DET. Students answered the following pre/post course questions at the beginning and at the end of the course:

1) Describe the design process, as you understand it.
2) Define what you think 'tinkering' is and describe how much self-confidence you have in your ability to tinker.
3) Define what you think 'technical expertise' is and describe how confident you are in your technical expertise.
4) How are science and technology (engineering) related?
5) What fraction of time should design, engineering and technology be allocated in K–12 curriculum? Why?
6) How might you modify existing curriculum/lessons to include design, engineering and technology? Give an example.

The second set of data was students' weekly reflections on course readings. The readings consisted of primary research articles on the impact of DET in the classroom. Students wrote seven reflection papers.

For this class, students also created and taught a DET unit in their classroom. As a final assignment, students wrote a report on the impact of their teaching on students' learning. The unit and the report that evaluated the impact of the unit on students provided rich data sources on how teachers were able to apply their learning to the lesson plans they designed and taught.

The fourth set of data included interviews with the participants that are conducted though two focus group reports, classroom discussions and email correspondence.

DATA ANALYSIS

Exploratory case studies of three graduate students were examined using Miles & Huberman's qualitative data analysis methods [18]. This data analysis method revealed meaningful patterns in the data that evolved during the main phases of analysis which involved data reduction, data display and conclusion drawing and verification.

During the data reduction process, all data was organized and reduced into categories to reveal patterns. This process also involved the selection and simplification of rich data into meaningful categories. Initially, data from all sources were compiled into electronic word-processed files. Then, all text referring to teaching was extracted from the data. The text was initially coded using a fine grained analysis (e.g. teaching with models, awareness of gender issues) by one of the researchers. This proved to be idiosyncratic to each teacher so a second pass was made through the data by a second researcher and the initial codes were replaced by common themes that subsumed large categories of data. The four categories that emerged were:

1) Reflections on Practice;
2) Changes in Practice;
3) Intentions to Change Practice;
4) Changes in Knowledge.

All text was then coded and examined using these new categories.

The next step, data display, involved the compressed assembly of the reduced data in a form that would demonstrate the patterns and interrelationships. The final stage involved conclusion drawing and verification. During this stage, the implications of the findings for the research question that was posed were explored and assessed. This process also involved re-examination of the data with the emerged categories and a re-evaluation of the data to verify these categories.

RESULTS AND DISCUSSION

All three students learned more about DET and were able to incorporate DET into their science lessons. However, they had different outcomes from the course and faced different challenges based on their teaching situation, background and experiences. Table 1 provides a summary of teacher's learning. The emergence of these changes in teachers' knowledge and practice are described in detail in the following sections.

Alice*: changes in knowledge*

Having a good knowledge base initially, Alice's understanding of the design process became more precise and she acquired vocabulary that promoted this precision. Since she already understood the pervasiveness of technology in our everyday lives, there was little change in this area. The biggest knowledge change was a move from describing science and technology as two parallel endeavours to seeing the reciprocal nature of science and technology. According to Alice, 'Technology is applied science. Science concepts are the backbone for artefacts made to improve everyday living (technology). A good understanding of many specific technologies should include an understanding of science concepts that make technology possible.' She realized that, to foster children's understanding of DET, she would have to plan it systematically in each lesson. She moved from thinking about DET lessons as 'Giving kids a hand in deciding what they are going to do to discussing what might work or might not work and writing design plans' to planning it systematically as part of each lesson by 'adding pieces where possible, tinkering into one lesson, designing something that requires the background science content from another lesson'.

Reflections on practice

Alice's reflections on her practice were very self-critical. For example, after reading about and discussing an article about children building functional models of elbows, she wrote 'I stopped and thought about the models I have used and made with the children in my class in the past and I am ashamed to admit that I couldn't come up with any examples of models that would do anything but reinforce the view that models are physical copies of reality'. She also noted that she would have to redesign her lessons to allow for multiple solutions. She saw how she could use the iterative DET design process to help students understand why they had to write and rewrite in language arts. She described using DET in her classroom as trying 'to incorporate the iterative process in my classroom in a very explicit manner across the curriculum. I have realized most academic and other projects in life follow this model. I believe that teaching children that the process of making revisions is not only O.K., but actually desirable. Hopefully, this will help to reduce the common stigma asso-

Table 1. Summary of the Effect of the DET Course on Teachers' Knowledge and Practice

	Alice	Denise	Dana
Description of the Student	Third grade teacher at a private school	Curriculum developer at a science museum	High school honors chemistry teacher at a public school
Description of Unit	Tortoise Habitat	Bridges	Calorimeters
Changes in Knowledge	• Described DET and the design process with technical vocabulary • Recognized reciprocal nature of science and technology • Realized the need for systematic planning to teach DET to reflect the iterative design process	• Learned that design process is iterative and science and technology are reciprocal • Recognized that technology is not merely computers • Learned that tinkering is not just playing • Noticed the challenges teachers face in teaching DET	• Described DET with technical vocabulary • Learned the iterative design process • Developed a reciprocal view of science & technology
Reflections on Practice	• Critiqued her own use of models in her teaching • Reflected on the design approach as a better method than the crafts approach	• Formally shared what she learned with the museum staff to begin an examination of current activities.	• Providing everyday context was important but hard with chemistry. • Initially the iterative process was hard for her students but at the end they learned everything intended
Changes in Practice	• Designed and built a desert habitat unit based on DET concepts • Focused on the design process, constraints, and requirements • Redesigned her lessons to allow multiple solutions • Included discussion on ethnics and safety	• More attention on gender equity • Integrated design process and tinkering in lessons • Her unit changed from being fun building activities to activities exploring the science behind technology	• First struggled to use DET in her classroom until she noticed the parallels between the design process and the scientific method • Incorporated DET into her unit in various ways • Designed her lessons to allow multiple solutions.
Intentions to Change Practice	• Plans to teach design process explicitly • Plans to use the iterative design process in language arts • Plans to learn more of science supporting technologies and use more everyday context for DET • Plans to teach a model building unit on body systems	• Plans to develop a DET workshops focusing on properties of materials • Plans to include women inventors in lessons and systematically observe gender interactions during team work. • Plans to focus on collaboration, communication, and team experience	• She made changes and wrote about outcomes and challenges of what she was changing • Will help other teachers incorporate DET into their classes

ciated with not getting something "right" the first time you try it.'

Changes in practice

She realized early in the course that her project's time could be a more productive learning time if she changed from a crafts approach to a design approach and that the problems to be solved should be linked to the everyday lives of her students. She wrote 'The craft-based approach is what I provide for my students during their Friday projects time. This is the only view I am currently employing, although I hope to be a teacher that also employs the design approach and the science technology society approach'. She realized that, if she had a model for the tinkering that students engaged in during project time, she would be better able to assess their work. She wrote that, 'The general idea of developing a model of tinkering was interesting in part, to me because, once a model is established, it is easier to establish guidelines for assessment'. Alice had a long list of things she intended to change:

a) to teach the design process explicitly;
b) to learn more of the science that supported various technologies and engineering concepts;
c) to learn more about what kinds of DET activities that were appropriate for young children;
d) to use more everyday contexts for DET projects;
e) to plan a unit for summer school that included building models of the functioning of body systems.

Changes in her practice had a positive impact on her enrolment. Because Alice had replicated, with modification, activities explored in the graduate course, an increased number of parents enrolled their children in her class for the next year. In an email to us, she said, 'I employed some of the activities learned in BEE 2 and parents have asked about what I am doing? More kids have signed up for my class.' Specifically, Alice taught the design process as a way to solve everyday problems and focused on the process rather than the end product. She said 'This is the type of student driven project I like to engage my class in, coming up with a solution for a problem they encounter everyday' and she went on to write 'The expectations that I have for the planning and building have changed. I have been doing a lot of group work, requiring written plans and drawings, and revisions of original plans before construction begins. In the past, I often let kids just jump in, and I have found that when they are better prepared, they are more successful.' She also helped her students explore requirements and constraints before jumping into designing solutions. Furthermore, she included discussions of ethics and safety as important aspects of DET. She reported addressing 'The concept and importance of ethics and safety during design in a discussion we had in class this week during our study of geology and mercury that used to be in thermometers'.

Intentions to change practice

Her unit included everything she had learned as well as her intentions to change her practice. Her students were given two desert tortoises to keep as long as they had a proper living environment. Consequently, she focused her unit on guiding students to design and build a tortoise habitat on the school grounds. This was a real world problem in which the functional requirements of keeping the animals alive and the constraints of budget were paramount. Her third grade class did a great deal of research using the internet and also visited a desert tortoise rescue centre to interview the staff in order to understand the nature of their problem. They built models of possible habitats based on their research and selected the design that best addressed the budget constraints and functional requirements. These models were then presented to the groundskeeper who, with the help of the children, built the tortoise habitat on the school grounds which then became a permanent part of the school's environment. The level of students' enthusiasm for the project was quite high, as demonstrated by the fact that they skipped some recess periods and shortened lunch periods to spend more time working on the project. Alice described the impact of the unit on her practice in the following way: 'In the project I did with my class [3rd grade] for the engineering course (designing and constructing a tortoise habitat), we talked a lot about the requirements for the design and the constraints. Since then, I have found that these terms apply to many classroom projects and activities, and I find myself using them to better explain to students my expectations for projects.'

Denise: *changes in knowledge*

Denise's understanding of DET and related issues changed significantly. She went from thinking of technology as computers and their components to realizing that technology was pervasive in all aspects of life around her. Viewing the design process as less formulaic and more iterative, while also realizing that tinkering was not just playing but included experimentation, she no longer separated science and technology but saw them as reciprocal. She first wrote that 'technology utilizes scientific laws and processes' but by the end of the course wrote that 'at times scientific knowledge is gained from technology and times when technological innovation results from science. I see it bidirectional now'. She also gained a greater understanding of the challenges faced by teachers trying to integrate DET into their classrooms and no longer expected as much from them in her work at the Science Centre. Her reflections included the comment 'Because I am not in the classroom, I was not aware of all the time and curricular constraints that are imposed on teachers. However, I do think DET should be integrated with curriculum when possible.'

Reflections on practice

Reflecting on her practice, Denise questioned the grade level appropriateness of topics and the kinds of curriculum and workshops she was developing. She wondered how students were understanding the museum activities after reading about the naive conceptions children hold about models because 'The Science Centre uses both models and analogies to help children explore and understand a topic'. Furthermore she wrote, 'Now I am very curious about how my seventh grade students view the models and analogies'. In rethinking her workshops, Denise intended to 'Plan to add design or redesign elements to my workshops. I will attempt to integrate the four skill categories—decision making, project management, communication and collaboration—into team experience.' Finally, she remembered past instances when she saw students engaging in inequitable gender interactions and had not intervened because she did not recognize them as inequities. She wrote that, 'As I thought back on how my students have behaved in team situations, I realized, though not at the time, that they were exhibiting many of the behaviours described in the study. I remember seeing the boys completely take over various activities . . . Most of the girls just handled the journal entries or just watched.'

Changes in practice

Denise changed her practice at the Science Centre by paying more attention to gender equity because, when she reflected on planning her assignments, she said, 'Wow, this piece isn't really girl friendly. I really want to stay neutral'. She also integrated the design process and tinkering into her lessons and included an examination of the properties of materials used in lessons whenever possible. In addition, she added a discussion of technology to her lessons. Before this addition, she said, 'Students view technology as computers. Until a discussion was introduced about what technology really was, they did not begin to see the bigger picture.' In addition, she formally shared what she had learned with the other museum staff to begin an examination of the current activities in their school programme.

The progressive work on her bridge building unit indicated that she was more aware of the time students need to engage in hands-on exploration and discussion and that activities needed a real-world context. The number of unit topics decreased as Denise focused on the key DET concepts she wished students to learn. A unit activity on bridge building was originally a series of short activities disconnected from science where students had fun building bridges without knowing why some bridges held up the toy cars and others did not. As Denise's design knowledge, skill and self-confidence grew, the unit shifted to a series of activities building upon one another that explored the science behind building bridges by systematically exploring concepts such as load and the function of arches and spans. The readings and peer critiques changed the way Denise thought about curriculum development. She wrote that 'What I have discovered will redefine my approach to creating content for future workshops'. And she used the peer feedback to help her reframe her unit saying 'I think the information [from classmates] will have a favourable impact' on her work.

Intentions to change practice

To change her practice, Denise intended to create a DET workshop focusing on properties of materials and include women inventors in lessons. Denise wrote that 'This is something I would love to share with students to help them gain an appreciation of what early women inventors faced in their endeavors'. All future workshops would also include decision making, project management, communication and collaboration to create a team experience. She wanted to do systematic observations of gender interactions in her teams and determine how students conducted investigations with the intent of making changes where needed. Denise wrote that 'Since I put students in teams of three and four, I am very interested to see how the same gender teams learn and explore compared to mixed gender teams'. Nevertheless, Denise still struggled with resources to use in her informal science programme. She was frustrated because she 'found that most of the technology-related educational materials available are written about computers. It's been a challenge to find reference sources for my programme.' After the end of the course, Denise also reported informally that other Science Centre staff were interested and enthused about the prospect of learning how to shift more of their activities from a crafts approach toward a design approach, thus indicating that the knowledge of design this individual acquired had impact that extended beyond her own professional activities.

Dana: *changes in knowledge*

Dana's change in understanding of the design process shifted from describing it as a short process without technical vocabulary to a more iterative process with appropriate vocabulary. She developed a better understanding of the reciprocal relationships between science and technology. Her first thoughts on this placed technology in a subordinate position, i.e. 'I think of science as a means of solving problems through understanding the organic and inorganic world we live in. Technology is part of that world and we use science to understand technology and further it.' At the end of the course, she thought about the relationship in the following way; 'Science and technology go hand in hand, one does not drive the other but they are a couple. Technology is necessary to understand and apply science and vice versa.' Her biggest change in understanding was from having no idea of how to incorporate DET into her curriculum to 'allowing students to design a lab procedure incorporating DET where students must consider the constraints, design a procedure (and sometimes even the artefact to test the procedure) and test it.'

Reflections on practice

Dana's reflections on her practice indicated that she was struggling to incorporate design in her classroom. She wrote 'We are learning it in a pure form. How can I apply philosophy of the design process to other things and to design an artefact for chemistry? I was struggling trying to input or incorporate this design process in my own classroom.' She saw parallels in the design process and the scientific method i.e. 'The process of design in general and "Technological design" seem to parallel the steps typically associated with the scientific method which is widely taught in most if not all science lab-based classrooms' and thought this parallel approach might be a way to incorporate design.

Dana also struggled with another concept introduced in the course. She thought that science teachers should also teach problem solving; however, she was frustrated because the readings indicated that there was a debate about general problem solving skills. In her reflections she said 'I want to believe that the ability to solve problems can be taught and transferred; if this is indeed not the case then I've entered a career for the wrong reasons, or at least for very idealistic reasons'. She also took issue with the need for everything to be in an everyday context and again struggled to think about ways to do this with the abstractions of chemistry. Her position was that, 'Every concept taught does not have to be for the ultimate outcome of using it in everyday life. If something has to be relevant to everyday life before it is important enough to learn, we may never learn.'

Dana also reflected upon the struggles of her students who were in advanced placement chemistry and had been academically successful all of their school careers. It was especially hard for them to learn that an iterative process was good and that initial failure was not bad. She felt that, 'It must be a reasonable thought to not be successful on the first try and that the need to redesign is not a mark of failure but a point of learning'. She wanted to help her students develop another view of learning, writing, 'I believe that educational development surrounding "technological design" instruction is less about developing new techniques for solving problems and more about allowing the learner to feel free to "play" with an artefact in question. We must first make it acceptable practice to play with or experience first hand the task or artefact.'

Changes in practice

Dana exhibited the most dramatic changes in practice. She had her students write about science and technology to determine their prior knowledge and was surprised by their responses. She said, 'I was curious as to how my own students related science to everyday life and more so, their idea or definition of technology. So I asked. I had the students write a short paragraph that gave me an understanding of technology and how science was part of their everyday lives. An astounding numbers of students, these are high school honours chemistry students, had the misconception that technology is simply computers.'

Worried about covering the required curriculum, Dana did not create an extensive unit. Instead, she described what she did as follows: 'Students were introduced to the technological design process and used these concepts to design two labs. One tested the heat of fusion of ice and the second to determine the specific heat of an unknown metal thus allowing the metal to be identified. In addition, students designed and built their own calorimeter to use in the lab.' Students investigated ways to build a calorimeter outside class time and presented Dana with a list of construction materials that would fit her budget, which she provided. Watching her students build their own calorimeters to meet the needs of their chemistry labs, she came to the conclusion that 'Invention and the process of inventing should be incorporated into the curriculum at all levels'.

Intentions to change practice

In creating her unit, Dana used the steps in the design process and included a substantial evaluation component. The evaluation of the unit (including a delayed post test) indicated that the students had learned everything she had intended. Furthermore, students retained that knowledge on the delayed post test and were enthusiastic about taking it because they felt they had learned the most when doing the activities in the unit. When Dana told her class they were having a quiz on this unit (the delayed post test), one of her students said, 'Oh, good, that's the unit I really understood'.

The impact of the project extended beyond Dana's own classroom. As department chair, she began to help the other science teachers incorporate DET into their instruction. Since she felt that the course 'changed the way I teach, also making me take steps to change how others teach, particularly freshmen teachers'. Dana was a person of action and put her intentions to change practice into action. She did not write about what she was going to do but instead concentrated on the challenges and outcomes of what she was changing. Her overall evaluation of the experience of trying to infuse DET into her practice was: 'I never would have attempted what I did in the course. That's cool . . . Long lasting effects on my students too'.

SUMMARY AND CONCLUSIONS

Our work with teachers suggests that the responses of Denise, Alice and Dana are fairly typical. Teachers come to experiences, such as the DET course, with limited understanding of DET, but are willing and eager to learn new ideas and new ways to improve their practice and motivate their students. However, helping teachers infuse DET into their current practice is not a simple matter of a short workshop or other band-aid approaches, but it can be accomplished under the right conditions. Teachers need a sufficient amount of time to read, discuss and reflect, as well as try out small DET lessons and then take on more ambitious changes in their curriculum. Teachers also need support in seeing how DET already exists in their own curriculum, although often hidden or unacknowledged, and in the science standards. Consequently, we recommend that issues of scalability be addressed by rethinking teacher preparation for both elementary and secondary teachers and that course work in science education graduate programmes address the issue of infusing DET into the curriculum explicitly. Such has been our approach for graduate students, and we are currently including the design process in our elementary science methods courses.

The three cases presented are indicative of the kinds of changes that can be made under varying conditions of context and teacher background knowledge when there is the right kind of support. Alice, Denise and Dana were able to improve their practice because they were provided with opportunities to participate in a variety of activities that enhanced their knowledge, skill and understanding of DET. These activities included:

1) reading and discussing the research on classroom applications of DET;
2) discussing possible changes in their own practice;
3) developing lessons and trying them;
4) sharing their successes and failures on the lessons with one another;
5) continually refining their lessons throughout the 15-week period of the course.

In short, the course participants became a community of learners who provided support for one

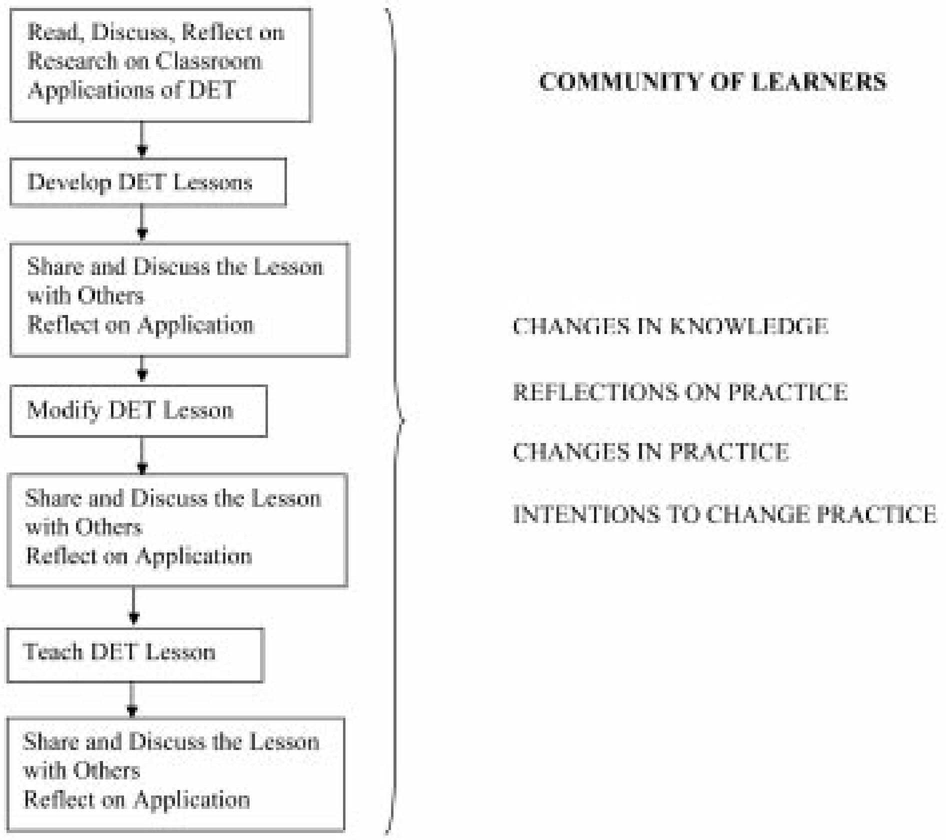

Fig. 1. Structure of the course that created a community of learners and the changes in students' knowledge and practice

another as they tried to infuse DET into their practice. It is also important to understand the impact of the course beyond the teachers' own practice. For Alice, her next year's enrollment more than doubled because of the parents' interest in her changed practice. For Denise, her fellow staffers at the Science Museum looked toward the design process as a more effective way to engage students in better understanding science and technology activities. For Dana, her change in practice provided an opportunity for other science teachers to consider a potentially more effective approach to teaching in their own practice.

We believe that we were successful in bringing about change in all of the class participants because of the structure of the course. In this course, teachers experienced changes in their knowledge and practice by being part of a community of learners that provided timely feedback and reflection (See Fig. 1). We recommend that others seeking to infuse DET into the K–12 curriculum take a similar approach. We also recommend that engineering educators who wish to infuse DET into the curriculum familiarize themselves with the curricular and testing constraints that teachers face. Alice was the most successful because she had fewer constraints than Denise and Dana.

Follow-up research with Alice, Denise, and Dana is planned to determine whether they continue to infuse DET into their practice without the support that the course provided. All three teachers intended to make additional changes, but whether intentions become actions will depend upon contextual factors such as administrator and parental responses, school rankings in statewide tests and the resources (time and supplies) to develop activities that employ DET.

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