ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans JAZZED about Engineering Education

Paper ID #17443

Using Engineering Design Teaching Portfolios to Gauge Design Teacher Performance and Infer Design Pedagogical Content Knowledge

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Fundamental – Using Engineering Design Teaching Portfolios to gauge design teacher performance and infer design pedagogical content knowledge

Abstract

This paper reports on the creation and use of an Engineering Design Teaching Portfolio system created for the NSF-funded DRK-12 project Engineering for All (EfA). In this project two middle school engineering design-based instructional units were developed. The instructional units were designed to depict engineering as a social good. One EfA unit is focused on urban vertical hydroponic farming and the other on providing safe drinking water through water purification. The research portion of this project included the development of Design Teaching Standards (DTS) and guidelines for teachers to create their own Design Teaching Portfolios (DTP). Data from the portfolios would be used to describe teachers' pedagogical content knowledge (PCK) when using design activities with students. Review of the teaching portfolios in light of a set of Design Teaching Standards provided information on teachers' pedagogical content knowledge. The developed portfolio system (i.e., teaching standards, portfolio guidelines and evaluation rubrics) can be used both for teacher evaluation and for teachers' self-assessment.

Introduction

The Engineering for All (EfA) project is a three-year project funded by the NSF. The main goal of this project was to develop middle school technology education unit that emphasize the role of engineers in solving global problems. Through contextual design challenges, the students are asked to explore solutions to current issues. One unit is focused on the development of sustainable cities through the inclusion of urban vertical hydroponics farms. The other unit is focused on the development of water filtration systems for third world countries. Both units are incorporating the "informed design" curricular structure (Burghardt & Hacker, 2004), which includes first introducing the major design challenge, followed by "Knowledge and Skills Building" (KSB) activities that provide the students with pre-requisite experiences and skills to deal with the design challenge.

The units were developed by technology education teams and were tested by public middle school teachers who have received specific professional development on how to teach one of the two EfA units. Information about teachers' practice and students' performance were collected through structured teaching portfolios. The units were revised twice based on the review of teacher portfolios. The portfolios were also used to elicit specific teaching behaviors and their impact on students' performances on various units' activities.

This paper will describe the developed Design Teaching Standards (DTS), the Design Teaching Portfolio (DTP), and the creation of profiles of Design Pedagogical Content Knowledge (D-PCK) based on the review of data collected by this project.

The Design Teaching Standards

Teaching Standards describe what teachers need to know and be able to do in order to support students' learning. Currently, there are no published teaching standards for K-12 engineering design in the US, although there have been teaching standards in other countries (DATA, 2003), and teacher professional development standards in the US (ASEE, 2014). As a result, we had to develop teaching standards of our own, and did so based on an extensive review of the design cognition, teaching and learning literatures related to engineering design (Crismond & Adams, 2012; Cross, 2001; Hacker, 2014), standards for teacher preparation (DATA, 2003) and engineering teacher professional development (Farmer & Klein-Gardner, 2014). Teaching standards, much as content standards have been used previously (see Kesidou & Roseman, 2002), can also be used to determine whether classroom curricula provide adequate support to teachers in creating learning opportunities for the students they teach.

Knowing how to teach engineering involves a quite different knowledge and skill set than knowing how to do engineering. Like engineers, teachers using design tasks need content knowledge, but they also need pedagogical content knowledge (PCK), which is domain specific and contextualized. The work of Shulman (1986) on science PCK as well as others (e.g., Ball, Lubienski & Mewborn, 2001, Magnusson, Borko and Krajcik, 1999), influenced our efforts to develop the teaching standards used for this project. In addition, a framework that articulates what informed design thinking entails – students using design strategies effectively; making knowledge-driven decisions; conducting sustained technological investigations; working creatively; and reflecting upon their actions and thinking – was another foundation upon which this work was built (Crismond & Adams, 2012). The final set of the design teaching standards (see Table 1 for details) created for this project is organized around three dimensions:

Dimension I – *STEM Concepts* – Teachers' understanding of science, technology, engineering and mathematics (STEM) concepts that are unit-specific, and themes that are cross-cutting (e.g., modeling, systems, materials, values);
Dimension II – *Design Practices* – Teachers' knowledge of how to engage students in learning and using engineering design processes; and
Dimension III – *Classroom Instruction* – Teachers' knowledge of classroom practices that have the potential to engage and support student learning.

The DTS were vetted by many science, engineering and technology educators who were asked to comment on the quality of the standards in face-to-face meetings, at national conferences, and via on-line surveys. Most participants agreed that these standards are feasible, important to engineering design teaching, and written in a concise and clear manner.

The Design Teaching Portfolios

Teaching portfolios have been used by educators for more than two decades. Why use portfolios?

> *"Although portfolios can be time-consuming to construct and cumbersome to review, they also can captures the complexities of professional practice in ways that no other approach can. Not only are they an effective way to assess teaching quality, but they also provide teachers with opportunities for self-reflection and collegial interactions based on documented episodes of their own teaching." (Wolf, 1996)*

Indeed, a well-structured teaching portfolio can provide rich information on educators' classroom practices and the performance of their students. Typically, teacher portfolios are used as a tool for teacher evaluation. Teacher portfolios were used by the CT State Department of Education for two decades for the evaluation and support of beginning school teachers (Lomask et all, 1995). Teaching portfolios are still used by the National Board for Professional Teaching Standards (Darling-Hammond, 1999) as a major component of their comprehensive assessment of quality teaching. Lately, many states adopted the teaching portfolio as a tool to assess the qualification of pre-service teachers (e.g., edTPA, Sato, 2014). In all these examples, the portfolios were designed to evaluate the quality of the teachers.

While teaching the unit, the technology teachers compiled their portfolio that had materials described in Table 2. The DTP's general structure is based on a portfolio-based teacher certification program used in the Connecticut's BEST program during the years 1995-2009. Portfolio-required entries and videos were uploaded on line or sent to the research team via regular mail.

Table 1 – The Design Teaching Standards

Standard 1. STEM Concepts **When teaching engineering design, teachers facilitate students' learning and use of relevant science, technology, engineering and mathematics (STEM) concepts.**	**Standard 2. Informed Design Practices** **When teaching engineering design, teachers facilitate students' development of engineering design thinking and practices.**	**Standard 3. Classroom Instruction** **When teaching engineering design, teachers use appropriate instructional strategies to engage all students in the design process and monitor their progress.**
In doing this, teachers provide students with opportunities to: **1.a** *Unit-Specific Concepts* – Learn and apply relevant science, technology, engineering and mathematics (STEM) concepts relevant to the specific design task. **1.b** *Representations & Models* – Use sketches/drawings to represent and visualize ideas, and use models to make predictions and develop explanations. **1.c** *Systems* – Use systems thinking to describe and analyze inputs, processes, outputs, controls and feedback loops of a product and its sub-systems. **1.d** *Needs, Impacts & Values* – Consider human needs, values, and impacts on people and the environment and when designing. **1.e** *Resources & Materials* – Explore efficient use of limited resources appropriately while learning about materials and their properties. **1.f** *Engineering & Careers* – Introduce the engineering professions and explore aspects of the nature of engineering.	In doing this, teachers provide students with opportunities to: **2.a** *Understand Challenge* – Understand the design challenge by identifying desired performances, criteria and constraints. **2.b** *Research & Investigate* – Do research and hands-on investigations to gather insights/information about the challenge. **2.c** *Generate Alternatives* – Produce several different possible design solutions. **2.d** *Decide & Build* – Balance benefits and tradeoffs in choosing a solution to build; use tools safely when making a prototype. **2.e** *Test Prototype* – Design and perform experiments to test how the prototype works and meets the design criteria. **2.f** *Revise & Iterate* – Use feedback from tests and ideas from others to refine and improve the prototype iteratively. **2.g** *Communicate & Reflect* – Share design ideas and solutions and reflect on the design work, the processes used and decisions made.	In doing this, teachers: **3.a** *Plan and adapt lessons* – Set appropriate learning goals and adjust curricula to create lessons that address students' specific learning needs. **3.b** *Support Academic Learning* – Incorporate literacy and numeracy tasks, and education technology into instruction. **3.c** *Support Practical Learning* – Teach students to safely use tools, materials and fabrication methods. **3.d** *Encourage Team Work* – Encourage all students to work collaboratively in teams, and share ideas and resources with peers. **3.e** *Use Formative Assessments* – Use formative assessments to gather evidence of students' learning, provide timely feedback, and adjust daily instruction. **3.f** *Use Summative Assessments* – Use assessments and performance rubrics to evaluate students' design practices, final prototypes and mastery of relevant STEM ideas.

Table 2 – An Overview of the EfA Design Teaching Portfolio

In your portfolio please include the following entries and materials:
1. Instructional logs written at the end of each KSB. These logs should address the following issues: a. Main STEM concepts that were taught b. Main engineering practices that were practiced by students c. Findings about students' general learning strengths and challenges during this KSB d. Challenges in teaching this KSB
2. Student work done by one male and one female student, for each KSB's formative assessment task. The work should be reviewed, evaluated and clear feedback written by the teacher should be added to the submitted student work.
3. Three unedited instructional video clips, each 5-10 minutes in length, depicting the following: a. Teaching a STEM concept b. Teaching an engineering design practice c. Students' oral presentations of their final project with oral feedback from the teacher.
4. Written reflection on curricular revisions needed in order to improve the unit and enhance student learning

Performance Rubrics

Performance rubrics were developed in order to review the submitted teachers' portfolios (N=21). Table 3 provides an example of a performance rubric based on the first disciplinary content teaching standard (1.a). Table 4 describes where evidence in the teaching portfolios were available for assessing teacher performances. The development of the rubric was an iterative process in which various portfolios were reviewed in light of the design teaching standards. The rubrics were designed to provide a framework for the research and to provide feedback to teachers. Since the rubrics were not used for assessment, no attempt was done to explore the reliability of the rubrics as a scoring tool. Based on the portfolio review, the authors identified areas of strengths and areas of needed improvement in the instructional practice of the participating middle school technology education teachers, which are described in the findings section of this paper.

Research

All in all, 21 teachers participated in this study. Eleven teachers taught the "water filtration" unit and the others taught the "urban hydroponic vertical farm" unit. These units were implemented by teachers over an 8-10 week period. Students enrolled in these technology classes were from grades 6, 7, 8 and 9. The teachers submitted logs periodically while teaching the units, as well as short videotaped vignettes. At the conclusion of the unit, the teachers submitted annotated student work and personal reflections. All the written materials were printed out and bound as a portfolio, to make the portfolio review more accessible.

The research focused on the following questions:

1. What aspects of design PCK do technology teachers use in the classroom while engaging their students in engineering design projects?
2. What specific challenges do teachers face while implementing the EfA units?
3. How can we use teachers' portfolios to create materials for future professional development for technology teachers?

Table 3
Sample Rubric for Design Teaching Standard 1.a: STEM Concepts

Standard 1.a *Unit-Specific Concepts* – Teachers provide students with opportunities to learn and apply relevant science, technology, engineering and math (STEM) concepts relevant to the specific design task.			
	Novice-1	**Progressing-3**	**Advanced-5**
Standard 1.a STEM Concepts	AEB* **1st video**, the teacher makes mistakes in describing design-relevant STEM concepts.	AEB 1st video, the teacher mentions STEM concepts relevant to the design tasks, but doesn't explain them well.	AEB 1st video, the teacher explains design-relevant STEM concepts in a clear and accurate way.
	AEB weekly **logs**, the teacher makes limited connections between STEM concepts and the specific design challenge.	AEB weekly **logs**, the teacher describes direct connections between STEM concepts and the specific design challenge.	AEB weekly **logs**, the teacher describes direct and indirect connections between STEM concepts and specific design challenge.
* AEB = As evidenced by…	AEB submitted student work, the teacher doesn't identify major misconceptions presented in student work.	AEB submitted student work, the teacher identifies major misconceptions in students' work and addresses them mainly by scores and/or praises.	AEB submitted student work, the teacher identifies major misconceptions in students' work and addresses them with accurate and informative feedback.

Table 4
Sources of Evidence from Teaching Portfolios for Evaluating Dimensions of Design Teaching

Standard 1. STEM Concepts — When teaching engineering design, teachers facilitate students' learning and use of relevant science, technology, engineering and mathematics (STEM) concepts.	
Sources of Evidence:	
• Quality of teacher/student interactions during instructions about a disciplinary concept (See 1st video – Supporting Concept Development) • Students' work on KSB performance tasks • Students' work in Design Journals	• Students' explanations for design decisions in final presentation and teacher feedback (See 3rd video – Team Presentations) • Teachers' descriptions of science and engineering concepts in Teacher Logs
Standard 2. Informed Design Practices — When teaching engineering design, teachers facilitate students' development of engineering design thinking and practices.	
Sources of Evidence:	
• Quality of teacher/student interactions during instructions about the design process (See 2nd video – The Design Process) • Quality of students' work on the design challenge (drawings, photos of models, • Students' work in Design Journals	• Experiments and reflections in design journals. • Students Design Journals • Students' presentations of final products (See 3rd video – Team Presentations) • Appropriate use of Design Feedback Rubric to evaluate quality of students' design journals
Standard 3. Classroom Instruction — When teaching engineering design, teachers use appropriate instructional strategies to engage all students in the design process and monitor their progress.	
Sources of Evidence:	
• Quality of teacher/student interactions during instruction (See all three submitted videos) • Quality of learning activities	• Quality of feedback given to student work • Teacher reflections on the teaching/learning process during the unit

Findings

This section organizes the findings by the paper's three research questions.

Question 1 – What aspects of design PCK do technology teachers use in the classroom while engaging their students in engineering design projects?

Dimension I of Design PCK – Understanding STEM concepts and themes

Teachers' grasp and depth of portrayal of key disciplinary concepts, including modeling, systems, and working within constraints when proposing optimized solutions, was varied. Videos of instructional segments showed that some teachers addressed students' misconceptions, based on their own understanding and grasp of these ideas. Others did not know how to elicit student' understanding and therefore couldn't address students' shortcomings. The ways that teachers adapted (or not) the EfA original materials served at times as an indicator of their grasp of concepts. For instance, one teacher augmented the original curriculum's treatment of hydroponics systems and systems thinking, by having students compare six main types of hydroponic systems, instead of just the two that were included in the EfA curricula.

Dimension II – Engaging in the informed design practices

Teacher logs and videos showed that EfA teachers grasped the steps of the informed design process and made references to it during instruction. The informed design model was introduced in the EfA's first sub-unit materials, and it was used to structure the learning activities as a preparation for the Grand Design Challenge (GDC) at the unit's end. Teachers, however, noted that despite the early introduction of the informed design process at the beginning of the unit, students had problems using this model when they were faced with the design challenge at the end of the unit.

The infusion of scientific inquiry into the design process challenged both students and teachers. For example, the lessons in which students were asked to design fair-test experiments to explore key variables influencing the growth of plants in hydroponics systems (e.g., pH, lightening length, composition of nutrient solution) required teachers to distinguish and explain to their students the concepts of controlled experiment, independent and dependent variables, and how to measure effectively the outcomes of the experiment. Classroom videos of several teachers conducting these lessons showed that although the teachers may have known what the components of good experiments are, they lacked the specific pedagogical knowledge of how to help students understand these concepts without turning the inquiry into a cookbook activity.

Dimension III – Classroom pedagogy

The teachers' portfolios contained evidence that teachers were capable at classroom management and they use of general pedagogy skills to engage students and manage the classroom. Teachers used whole-class presentation, as well as small-group discussions to present the unit's content and activities. The teachers excelled when it came to teaching procedural knowledge relevant to their field (see DTS 3.c), such as the use of tools for fabricating prototypes, and the use of Computer-Aided Drawing (CAD) system, specifically Google's *Sketchup* program. Teachers' annotations written on student work showed that the teachers are not accustomed to provide meaningful feedback to students about the quality of their performance. Most written feedback included praises and encouragements (e.g., "I love your answer", "good work" or even smilies). Instances where teachers overlooked student misconceptions, or did not comment on a feature of a design that would not work if built (e.g., a gravity fed filtration system where the source of water was lower in height than the filter itself), were noted. A few teachers used feedback as a tool to support students' conceptual understanding.

Question 2 – What specific challenges did teachers face while implementing the EfA units?

Fidelity of Implementation – Teachers found that they needed more time to implement the units of instruction. The EfA materials attempt to include many important and key concepts, including modeling, systems thinking, and engineering as a social good. Teachers found that more time had to be devoted so that students could grasp concepts being addressed by the instructional materials and the design challenges.

Filling in the Gaps – Gaps in student knowledge were noted during instruction that teachers felt needed to be addressed. For instance, one teacher added a review of the Periodic Table after realizing that students are not familiar with the chemicals mentioned in a brief reading segment that included the names of common mineral contaminants in drinking water.

Question 3 – How can we use teachers' portfolios to create materials for future professional development for technology teachers?

Training for teachers in the Design Teaching Standards during the two-day summer workshop was limited. A review of the rubrics that were used to provide feedback to teachers during future workshops would help teachers gauge what would best be included in the portfolios. Exemplar teacher portfolios were provided by the Connecticut's BEST program to give CT teachers a sense of what an effective portfolio could include, and which was part of the state's permanent teaching certification requirement.

The use of sample classroom teaching videos has been used to enhance teachers' classroom practices in a variety of STEM disciplines, including math and engineering design (Sherin, 2001; Crismond, 2003). Providing teachers with an "illustrated" version of the Design Teaching Standards, one with videos that show standards being met by different teachers using the *Engineering for All* curriculum is a planned part of the last year's work for the EfA project.

Teaching portfolios can provide contexts for peer coaching and mentoring, where teachers analyze their own and others' classroom work via portfolios they create. A recent study of Harvard's Best Foot Forward program, a video-based teacher evaluation portfolio system, showed improved both instruction and increased peer observation and support among teachers (Quinn, Kane, Greenberg and Thal, 2015). Peer planning and review sessions by teachers from different STEM disciplines, which can help teachers achieve integrated STEM learning objectives as when technology and math education teachers collaborate on curriculum planning (Pearson, Richardson and Sawyer, 2013) – such work could be enhanced via the use of teaching portfolios.

Conclusions

The EfA teaching portfolios developed in this project can provide authentic evidence for the instructional practices of middle school technology teachers. The performance rubrics that were used can help professionals in their efforts to improve classroom instructions. The rubrics can also be used for self-assessment as well as for professional development purposes. These rubrics are not content-specific, therefore they can be used with a wide range of engineering design-based K-12 STEM curricula. Providing teachers with Teaching Standards and performance rubrics can guide and improve instruction in technology education settings.

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