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Professional Development for the Integration of Engineering in High School STEM Classrooms

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Abstract

Science, Technology, Engineering, and Mathematics (STEM) education in the U.S. is in transition. The recently published *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* as well as the *Next Generation Science Standards* are responsive to this call and clearly articulate a vision that includes engineering practices as key components. This shift presents significant challenges to school districts owing to a stark lack of research-based engineering-focused instructional materials and corresponding teacher professional development. The purpose of this study was to investigate the impact of a professional development program on high school STEM teachers' ability to enact design-based pedagogical practices associated with the pre-selected engineering design curriculum (INSPIRES Engineering in Healthcare: A Heart-Lung System Case Study). Data were generated through evaluation of teacher practice using the Reformed Teaching Observation Protocol (RTOP). Findings demonstrated that RTOP scores were statistically significant.

Keywords: Engineering, HS professional development

Introduction

The reports entitled *Rising Above the Gathering Storm* and *Rising Above the Gathering Storm Revisited: Rapidly Approaching Category 5* issued by the National Research Council (NRC) and the National Academy of Sciences (NAS), National Academy of Engineering (NAE), and Institute of Medicine (IM), highlight the need to develop rigorous new K–12 curriculum materials and strengthen the skills of current Science, Technology, Engineering, and Mathematics (STEM) teachers as highest priority actions (NAS, NAE, & IM, 2010; NRC, 2007). This need was heightened with the 2012 publication of *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (Frameworks)* that incorporates ideas and practices of engineering into mainstream science education for the first time (*Next Generation Science Standards* [NGSS], 2012). Indeed, the newly released *Next Generation Science Standards* (2012) include four performance expectations for engineering design at the high school level (HS-ETS1) that integrate engineering and science “Practices,” “Disciplinary Core Ideas,” and “Cross-cutting Concepts.” As a result, there is a significant and growing need for innovative curricula that integrate engineering design concepts and practices with science learning.

Although the development of innovative curricula is necessary, it is not sufficient for affecting change in STEM classrooms. In order to integrate engineering into STEM classrooms, teachers must have knowledge of engineering core ideas and practices and develop the pedagogical skills to teach engineering design in a way that integrates science and mathematics principles. In particular, teachers must develop pedagogical practices to support student groups as a “facilitator” or “coach” during open-ended design exercises and to probe students to provide rationale for design decisions

that are based on underlying science, mathematics, and engineering fundamentals. These integrative pedagogical skills represent a new and different way of teaching for most practicing STEM teachers and therefore require significant development and support. One promising strategy for supporting teachers in the integration of new pedagogical skills is a professional development system constructed around the use of aligned educative curriculum materials (Ball & Cohen, 1996; Schneider, Krajcik & Blumenfeld, 2005; Singer, Lotter, Feller, & Gates, 2011). Curriculum that is educative “can offer concrete illustrations of the nature of student understanding important at a given point and how other teachers have reached this level” (Ball & Cohen, 1996, p. 8).

This study sought to develop and describe an educative-material-aligned professional development (PD) system for high school technology education teachers. We hypothesized that such a PD system would improve teachers’ ability to enact pedagogical strategies and materials consistent with recent STEM reforms advocated by the NRC (2007) and NAS, NAE & IM (2010). These reforms include such practices as integrating engineering and science practices, being technology-rich, and focusing on meaningful content.

Design and Procedures

Participants

The professional development program described in this study involved a total of 12 teachers. Three of these teachers did not return to a technology education classroom after the conclusions of the summer PD experience and so were excluded from the study. The nine remaining teachers consisted of eight males and one female and ranged in teaching experience from 2 to 25 years. The teachers were recruited from a large school district located near a mid-Atlantic urban center. A member of the central administration of this school district recruited the teacher participants. The nine teachers were each from a different high school and represent a combination of urban and suburban environments.

Program Overview

In designing the professional development program, we drew upon the latest professional development literature including recent works of Darling-Hammond and McLaughlin (1995); Garet, Porter, Desimone, Birman and Yoon (2001) and Singer et al. (2011). From this research base, we designed an extended summer institute (SI) followed by academic year classroom support. The summer institute (SI) consisted of 105 contact hours (15 consecutive days, Mon–Fri., for seven hours per day).

The first two authors of this paper provided significant leadership in the design and implementation of the reported SI.

Each day of the institute consisted of three main components: (1) a morning content portion focusing on specific STEM-related practices and core concepts; (2) a pedagogical portion consisting of practice teaching to high school students (approximately 90 minutes per day, Mon–Thurs) and; (3) a critical reflection and analysis of instructional practices. The lead authors (J. Singer and J. Ross) served as two of the three main facilitators associated with these three components of the SI. They both lead instruction associated with STEM practices as well as facilitated post-practice-teaching reflections. In addition to these three components, the use of pre-selected curricular materials (INSPIRES Curriculum module) was utilized to provide cohesion among the different portions of the day and is considered as a fourth component of the model. The INSPIRES materials utilized were initially developed through prior NSF support (DRL 0352504) under the leadership of J. Ross.

Component 1: STEM practices

This component was (1) team taught by STEM faculty members (Engineering faculty) and an inquiry-based pedagogical facilitator (Education faculty); (2) focused on related STEM curriculum standards; (3) instructed using an inquiry/design-based, phenomena first approach; and (4) designed to use activities and learning technologies from the same reform-based curriculum materials (INSPIRES) recommended to the participating teachers.

Component 2: pedagogical practice

Core elements of the pedagogical practice component focused on providing the teacher-participants opportunities to implement the various pedagogical strategies, STEM practices, and curriculum materials with high school students. The use of a content course alignment chart allowed for similar pedagogical practices to be emphasized on the same day, despite the teachers being divided into three practice teaching groups. Example practices emphasized: (1) “Phenomena first,” general inquiry and design-based learning (e.g., Predict, Observe, Explain; integration of an engineering design loop and integrating process skills); (2) Collaboration (e.g., jigsaws and Think, Ink, Pair, Share); (3) Context (e.g., driving questions, KWL charts, PBL); (4) Technology integration (e.g., simulations, data collection, visualization) and; (5) Sense making and assessment (e.g., wait time, probing questions, multiple representations, prior knowledge).

Component 3: reflective critiques

The final component of the SI was a critical reflection focusing on the day’s pedagogical practice. The general structure of the reflective critiques involved the use of short

video clips (15–75 seconds) recorded from previous pedagogical practice sessions (either earlier from the day, or previous days). The critiques focused on positive exemplars as well as “missed opportunities” regarding specific pedagogical strategies (e.g., context, making meaning, etc.). The presentation of each clip began with a brief description of the general lesson followed by the short video segment. At the conclusion of the clip each of the teachers individually records their thoughts. Next the individual thoughts were shared with nearby peers followed by a whole group discussion. The authors served as discussion facilitators by probing the participants to support their critiques with either observations or explanations.

Component 4: pre-selected materials

The pre-selected materials utilized in our program (INSPIRES) were developed with prior NSF support (DRL-0822286) and aligned with content and pedagogical strategies promoted by such leading national science education reform documents as the *Frameworks for K–12 Science Education: Practices, Crosscutting Concepts and Core Ideas* (NRC, 2012). The INSPIRES curriculum materials were used in the PD to provide coherence among the three other components. During the morning content courses, specific activities from the materials were used by the instructors to illustrate key ideas or as “jumping off” points for deeper discussion. Later in the day the teachers utilized these same strategies and materials as they formed small teams to plan and practice teach. In this situation the innovative materials were used as a mechanism to “engage teachers in concrete tasks of teaching, assessment,

observation, and reflection that illuminate the processes of learning and development” and grounds the professional development “in inquiry, reflection, and experimentation that are participant-driven” (Darling-Hammond & McLaughlin, 1995, p. 598). By threading the materials throughout the entire institute, the participants learn far more than just the mechanics of a new curriculum.

Collectively these four components were intended to situate the professional development in a learning environment that effectively resembles the teacher’s classroom, thereby providing a “situative” perspective. Putnam and Borko (2000) argued that studying teaching and teacher learning from a situative perspective allows us to “see more clearly the strengths and limitations of various practices and settings for teacher learning” (p. 12). Applying a situative perspective to the professional development allowed us to maximize the potential growth in professional knowledge of teachers and the likelihood that participants would carry their learning back to their classrooms.

The INSPIRES curriculum, consisting of five units, was designed to be flexible and low cost to maximize potential usage. INSPIRES units are independent of one another, so they can be implemented individually in an existing science or technology education course or together in a cluster to comprise a full course. Each unit is approximately six weeks in length, assuming a 45-minute class period. Each curriculum unit emerged from a common set of design principles (Table 1), follows a common structure, and focuses on integrating engineering design with STEM learning. The curriculum is aligned to the ideas and practices of engineering articulated in the *Framework for K–12 Science Education: Practices,*

Table 1.
INSPIRES curriculum design principles.

Curriculum design principles	Learning theory	Instructional strategies
1. Context: Meaningful, defined problem space that provides intellectual challenge for the learner	Situated cognition ^a	<ul style="list-style-type: none"> • Initial video • Design challenge • “Just in time” content
2. Standards Based: Publications that define the language and methods of the larger community (NSES, ITEEA Standards for Technological Literacy, Common Core, NGSS)	Situated cognition ^a	<ul style="list-style-type: none"> • Alignment charts • Pre-/Post-achievement measures
3. STEM Practices: As defined by <i>A Framework for K-12 Science Education</i>	Situated cognition ^a	<ul style="list-style-type: none"> • Inquiry and design-based activities • Argumentation • Models/Simulations
4. Collaboration: Interaction between students, teachers, and community members to share information/designs, negotiate meaning and build consensus	Making thinking visible ^b	<ul style="list-style-type: none"> • Inter- and intra-student group sharing • Think, Pair, Share • Group presentations
5. Public Artifacts: Public representations of ideas or practices that can be shared, critiqued, and revised to enhance learning	Making thinking visible ^b	<ul style="list-style-type: none"> • Daily artifacts of key ideas • Design loop • KWL posters, target poster
6. Metacognitive: Opportunities to explicitly recognize the nature of STEM practices, interpret key STEM concepts individually and revise designs/reports based on feedback	Making thinking visible ^b	<ul style="list-style-type: none"> • Design notebook set-up • Targeted discussions emphasizing rationale for design decisions

Note. Learning theories grounding design principles. a = theory of situation cognition, that knowing is inseparable from doing, and that knowledge develops in social, cultural and physical contexts (Linn & Hsi, 2000; Singer et al., 2011). b = theory that making thinking visible by encouraging meaningful dialogue focused on science content will help students not only increase subject matter knowledge, but also improve their reasoning abilities (Garet et al., 2001; Lotter, Singer, & Godley, 2009; Rushton, Lotter, & Singer, 2011).

Crosscutting Concepts, and Core Ideas (NRC, 2012). As a result, each INSPIRES curriculum module targets all four NGSS Engineering Design performance expectations (HS-ETS1) and all eight Science and Engineering Practices (NGSS, 2012).

The specific INSPIRES module utilized in this study was the INSPIRES *Engineering in Healthcare: A Heart-Lung System Case Study*. A brief description of this module with examples of how each design principal is integrated can be found in the Appendix immediately following the conclusion of this paper.

Data Collection and Analysis

Data Collection

Two main sources of data were utilized in this study: evaluations of video-recorded lessons and teacher reflective journals. The videotaped lessons were collected before and after the summer institute. As part of the professional development program application each teacher-participant was asked to submit a videotape of an inquiry-based or design-based lesson. Eight of the nine teacher-participants submitted videos. During the following fall semester, the nine teachers were videotaped teaching two lessons from the curriculum unit on which the SI focused. The two lessons were pre-selected by the authors. The first lesson was a “hands-on” inquiry-based activity focused on the introduction of concepts associated with heat transfer. The second lesson was a multiple day lesson in which students “plan, build and test” their Heart-Lung systems. The first day of this lesson, which had the primary goal of “planning,” was targeted for this study.

The second data set was generated from daily reflective journals. Each day the teacher participants were asked to complete a daily reflection form that represented each of the first three components of the PD system as previously described. Section one of the daily reflection form prompted teachers to record their thoughts regarding the morning content phase, section two focused on the planning portion of the controlled pedagogical practice phase, and section three focused on the post pedagogical practice reflection. Teachers were provided opportunities to complete the daily reflections prior to the day’s lunch break and again at the conclusion of each day. Teacher participants included their names and dates on each form prior to turning them in at the conclusion of each day. Reflection forms were photocopied and originals were returned to the teachers the following day.

Data Analysis

Quantitative

Analysis of teacher practice was conducted using a mixed quantitative/qualitative methodology. Initially

each of the videotaped lessons was reviewed and detailed notes regarding classroom activities (including time stamps) were recorded. Next the tapes and notes were reviewed using the Reformed Teacher Observation Protocol (RTOP) developed by the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) project (Sawada, Piburn, Judson, Turley, Falconer, Benford, & Bloom, 2002). The RTOP contains three scales: lesson design and implementation, content, and classroom culture. Five items each measure the lesson design and implementation scales. Content is divided into two subscales: propositional knowledge (five items) and procedural knowledge (five items). Classroom culture is also divided into two subscales, communicative interactions (five items) and student-teacher relationships (five items). A teacher’s performance on each performance element can be rated using a 0 (never occurred) to 4 (very descriptive) scale (Piburn, Sawada, Turley, Falconer, Benford, Bloom, & Judson, 2000). The total points possible sums to 100.

Paired raters independently scored 50 percent of the sample (involving approximately 500 individual items) supported with the use of a detailed rubric for each RTOP item (Gates, 2008; Ruth, 2007). Owing to the small sample size of the study, inter-rater reliability was assessed by means of an item by item comparison method showing the percent of questions on which the researchers assigned the same score, an adjacent score (+/- 1), or a non-adjacent score. Descriptive and repeated measure statistics were generated for total RTOP as well as each of the five RTOP subscale scores associated with each of the nine teachers for the three conditions (before and two post-institute enacted lessons). Follow-up post-hoc analysis (when appropriate) was conducted using a Least Significant Difference Comparison. Any missing data points (one tape was missing for each of the three distinctive time periods; for example, six teachers had three tapes and three teachers had two tapes) were generated by SPSS through Expectation Maximization (EM) methodology, a maximum likelihood function that has been shown to minimize bias in the imputed values (Dempster, Laird, & Rubin, 1977).

Qualitative

Following the completion of the RTOP analysis, the videotape notes were once again reviewed utilizing a domain analysis approach defined by Spradley (1980). In this process initial cover terms are more clearly defined through inclusion of subordinate terms (included terms) as well as the relationship between the cover and included terms. This step was repeated for each successive set of videotape notes. The next phase of the analysis involved transcribing “chunks” of data from sections of individual tapes into a table. The third phase of the analysis involved

Table 2
Summary RTOP statistics of scores from before and after summer institute.

RTOP scale	Pre-institute mean (SD)	Post-institute Lesson 1 mean (SD)	Post-institute Lesson 2 mean (SD)
Total	62.9 (11.9)	69.9 (11.5)	75.6 (11.8)
Lesson design	13.1 (3.4)	14.0 (2.2)	15.2 (3.3)
Propositional knowledge	9.2 (2.7)	15.7 (2.8)	15.8 (2.3)
Procedural knowledge	11.8 (2.0)	13.7 (1.7)	14.1 (2.6)
Classroom culture	12.0 (3.5)	12.9 (3.1)	15.4 (2.0)
Teacher–student relationships	13.9 (3.3)	13.9 (2.0)	14.9 (1.9)

Table 3
ANOVA summary for RTOP subscales.

RTOP scale	Degrees of freedom	Critical value (F)	Significance (P)
Total Score	2	3.239	P = 0.067
Lesson design	2	1.179	P = 0.333
Propositional knowledge	2	16.847	P < 0.000
Procedural knowledge	2	4.235	P = 0.033
Classroom culture	2	4.544	P = 0.027
Student–teacher relationships	2	0.639	P = 0.541

Table 4
Post-hoc pairwise comparisons.

RTOP scale	Pre vs Lesson 1	Pre vs Lesson 2	Lesson 1 vs Lesson 2
Total score	NS	P < 0.01	NS
Lesson design	NS	NS	NS
Propositional knowledge	P < 0.01	P < 0.01	NS
Procedural knowledge	P < 0.01	P < 0.05	NS
Classroom culture	NS	P < 0.05	NS
Student–teacher relationships	NS	NS	NS

Note: “NS” refers to Non-Significant

assigning codes to the transcribed chunks of data using analytic coding techniques described by Coffey and Atkinson (1996). The final phase of the analysis involved identifying patterns and/or themes that emerged from the coded data chunks.

The qualitative analysis of the teacher daily reflections utilized four basic steps. The first phase of the data analysis involved reading each of the reflections. After reading each essay, the first section (reflection on morning content session) of each essay was read to identify preliminary cover terms. Cover terms include terms, and semantic relationships, and are a component of domain analysis as suggested by Spradley (1980). This step was repeated for each successive section of each essay. The second phase of the analysis involved transcribing “chunks” of data from each essay into a table for each section of the essay. The third phase of the analysis involved assigning codes to the transcribed chunks of data using analytic coding techniques described by Coffey and Atkinson (1996). The final phase of the analysis involved identifying patterns and/or themes that emerged from the coded data chunks.

Findings

The findings section is organized into two distinctive portions with quantitative RTOP results reported first, followed by the descriptive qualitative findings. The quantitative section provides general patterns and differences between the pre- and post-SI conditions. The qualitative section presents results in a sequence that is intended to demonstrate a chronology of the teacher-participants experience. The qualitative section begins with baseline findings associated with their pre-SI lessons, continues with evidence collected during the SI (daily reflection journal data), and then concludes with video-tape data from the post-SI enactment of Lessons 1 and 2 of the INSPIRES Heart-Lung curriculum.

Quantitative RTOP

The mean RTOP scores associated for the total as well as for each of the individual subscales demonstrated the same increasing pattern. This pattern is representative of an

increasing classroom use of reform-based pedagogies. The largest “Pre” and “Post” institute gains are associated with the “Propositional Knowledge,” “Procedural Knowledge” subscales.

Deeper analysis to determine whether these differences in RTOP scores were statistically significant was determined using a repeated measures analysis of variance. Findings reported in Table 3 demonstrated that RTOP subscale scores were statistically significant among the three various lessons.

A post-hoc analysis utilizing a *Least Significant Difference Comparison* demonstrated that the scores were significantly different for multiple RTOP subscales between the pre and the two post lessons. The “planning” portion of Lesson 2 demonstrated significant differences on three subscales (Propositional and Procedural knowledge as well as Classroom Culture). The post-hoc analysis also demonstrated that the “pre” and “Lesson 1” scores were significantly different for two of the RTOP subscales (Propositional and Procedural Knowledge.)

Qualitative Data

Emergent themes from teachers’ pre- and post-summer institute videotaped lessons and daily reflective journals are presented in chronological sections. The first section discusses findings from teachers’ “Pre-taped” lessons, the second section captures findings from teachers’ “Daily Journal Entries,” and the third and fourth sections illustrates teachers’ instructional shifts during “Lesson 1 and Lesson 2” enactments.

Pre-taping

Qualitative analysis of teachers’ pre-institute lessons provided a baseline for teachers to demonstrate nascent reforms in science and mathematics instruction. Pre-institute data revealed teachers’ lessons were structurally different but centered on one echoing theme: teaching students steps in the engineering design process. For example, Mr. A’s lesson objective asked students to plan, design, and build a prototype of an educational board game that included rules and game pieces in order to immerse students in the engineering design process. Ms. K chose to expose her students to the engineering design process by instructing them to construct a windmill capable of using renewable energy to lift a cup vertically from its initial position, whereas Mr. D’s lesson focused on students building a vehicle prototype capable of moving up a ramp with the most efficient gear train and mechanical advantage. This baseline analysis demonstrated that teachers struggle with four main pedagogical themes: (1) fundamental mathematical and scientific concepts; (2) model building; (3) scientific discourse; and (4) conceptual coherence.

Theme one: fundamental mathematics and science concepts. All but one of the teachers struggled to articulate and contextualize underpinning STEM concepts associated with design tasks from their pre-institute lessons. Teacher lessons provided limited opportunities for students to build knowledge in fundamental science, mathematics, and engineering content. Ms. K’s class, for example, was tasked with constructing a windmill to lift a cup (vertically) and explain how renewable energy was converted in the process. Most of the lesson centered on students’ constructions with little to no time discussing fundamental scientific and/or mathematical ideas related to students’ windmill designs. Ms. K focused more on student constructions rather than students’ scientific ideas. Salient scientific concepts, such as force, rotational motion, conservation of energy, and energy transformation were not apparent in her lesson. The lesson allowed students to sporadically interact with a few engineering design steps but did not discuss the rationale behind the design process or discuss its importance in the windmill construction. Similarly, Mr. A’s lesson, engaged students in the design process by allowing them to develop an educational board game, but fundamental science and mathematical ideas were not at the heart of the lesson. Mr. A asked his students, “What kinds of games did you play growing up?” and “What games do you like playing?” Mr. A insisted, “Make [your] game adventurous?” and “Color the box.” Mr. A focused more on structural and aesthetic components of the game and less on scientific, mathematical, and engineering ideas.

Although the majority of teacher pre-taping lessons focused mainly on superficial knowledge, Mr. D’s questions and student discourse illustrated fundamental science and mathematical concepts. From the outset Mr. D’s pre-taping lessons delved into fundamental concepts of the lesson. His probing questions and feedback involved fundamental science and mathematical ideas coherent in the lesson. Mr. D announced and questioned, “The formula for calculating power is force times distance divided by time... how will these be used or applied?,” “Remember force is equal to weight times sin theta.” A student chimes in, “[sin theta is] opposite over hypotenuse.” Mr. D asked, “What is the angle you will climb?” A student replies, “20 degrees.” Mr. D provided students with four different scenarios of work on an object and probes his students, “Is work being done ... why ... what’s pushing it ... gravity?” Mr. D’s questions and comments prompt students to engage in core ideas of the lesson. “What’s the minimal angle you’ll be asked to climb with the cargo?,” “Use this information to determine how much power your vehicle produces.,” “Measure the diameter.,” “Write out your formula too.,” “How much is your mechanical advantage?:”.

All other teachers performed low in this subcategory because their lessons mainly scratched the surface of scientific concepts, contextual understanding, and made little to no connections within and across content disciplines. Teachers prefaced a large portion of their content with lower level questions and did not focus on helping students develop a deeper understanding or application of the content. Teachers provided directives and asked questions like, “Write in your own words the difference between problem and opportunity.” and “What are the steps in the solving problem process?” instead of asking students to tackle higher order questions and core concepts in science, mathematics, and engineering.

Theme two: model building. Most teachers asked students to build models to represent their ideas. Although student ideas were developed by either teacher directed instructions (commonly known as cookbook recipes) or lacked scientific evidence students were asked to generate mental or pictorial models while others were asked to build physical replicas or prototypes. Teachers, however, did not allow students to use these models to develop explanations, make predictions, or test and compare conjectures. Students simply presented models devoid of scientific theories, laws, and phenomena.

For example, Mr. C asked his students to pictorially represent a technological device of their choice that students felt could be utilized to solve a technological problem. Students came up with examples such as building a comfortable chair with a refrigerator, a supersized cushioned desk, and a form of transportation to transport humans to other countries quickly (faster than an airplane). Similar to Ms. K’s class, students were neither asked to articulate nor corroborated their designs with scientific evidence. Thus student designs lacked scientific and mathematical explanations. In addition, students were not encouraged to collect data, use multiple designs to determine their models precision and limitations, or utilize simulations to substantiate, validate, or test their models.

Theme three: scientific discourse. Pre-taping data provided little evidence of teachers engaging students in scientifically oriented questions, explanations formulated from evidence, or discourse warranting justification of proposed explanations. Teachers asked questions, but questions did not ameliorate students’ understanding of core ideas or encourage students to provide explanations. Teacher–student discourse was visible but scientific ideas were not the main focus. Teachers did not address students’ misconceptions and demonstrated little support in aiding students in developing conceptual understanding. Students asked questions but these questions were not based on connecting content to phenomena or stimulating reflective and critical analysis of their work.

For instance, Ms. K provides an example of a typical classroom exchange. She asked her students to read directions from a packet that provided instructions on how to construct a windmill. She explained, “Write solutions to how you will use materials to do this?” However, students were not given the opportunity to share their ideas. Ms. K questioned, “Which template did you choose and why?” One student answered, “I will use the five-inch template because it is small.” Once more, the conversation ceased with no further explanation from the student or questions from Ms. K as to why the student selected a smaller diameter for his windmill. Ms. K’s conversations placed more emphasis on the windmill’s construction and aesthetics as opposed to developing student’s scientific discourse in fundamental concepts of energy transformation and conservation.

The RTOP scores in this subcategory were low because teachers demonstrated very little academic press or confidence in eliciting scientific responses and elaborating on students’ questions to develop a greater conceptual understanding of the content. Teacher questions and comments focused on procedural knowledge and structural aesthetics rather than core scientific concepts and ideas.

Theme four: conceptual coherence: realworld applications. Teachers’ pre-taped lessons revealed teachers presenting scientific concepts and procedural knowledge in isolation instead as a cohesive unit. The interdependence of practices and core ideas were not at the forefront of teachers’ lessons. Students were involved in several aspects of the design process but the significance, rationale, or reasoning for their involvement was not coherent. For example, Ms. K’s lesson related the idea of constructing a windmill to harness renewable energy but did not encourage students to develop understanding of the interrelatedness or relevant scientific concepts supporting both these ideas. Her lesson did not provide a coherent conceptual understanding of renewable energy, energy transfer, and/or the mechanics of windmills. Instead, the lesson provided students with unconnected pieces of knowledge while omitting several steps in the engineering design process.

Contrary to other teachers in this cohort, Mr. D’s lesson emphasized the interrelatedness of mathematical and scientific thinking and provided students with several real-world examples. Mr. D asked students to “write out the formula for the best mechanical advantage? What is power? How far is it traveling?” Mr. D anchored his lesson with a previous activity that students could relate to as he explained, “when we first made this (pointing to the Lego vehicle) ... what was one of the first problems? ... this gear remember was touching the ground ... so the way we fixed that is we put on two more wheels that were a little bit larger.” Mr. D. continued, “I saw a truck trying to go up a ramp with an elevator lift...the lift hit the back of the ground and got stuck... what is the problem?”

With the exception of Mr. D's lesson, all other teachers' RTOP scores echoed similar patterns as presented in Ms. K's lesson. Most teachers in this cohort presented scientific ideas in isolation. Teachers' RTOP scores revealed teachers' limitations in coupling scientific practices with core scientific and mathematical ideas.

Summer institute daily journal entries

Teacher, summer institute, daily journal entries provided another triangulation data point to our quantitative and qualitative findings. From teachers' detailed analysis of their morning content sessions, controlled pedagogical practices, and afternoon post-pedagogical practice reflective time two main overarching themes emerged.

Theme one. The first theme, content knowledge, which relates mathematics and science concepts specifically to the design, build, and testing stages of the Heart-Lung Machine (HLM) curriculum, was discussed frequently in teacher journal entries. Concepts included mathematical calculations, conversions, and interpretations as well as scientific analysis regarding the physiology of the heart, circulatory system, and parameters that affect blood flow in the HLM. Teacher responses coded as "Content Knowledge" included such comments as "I learned a lot about the flow rate and math," "I learned about metabolism and oxygenation," "I learned about the exchange of oxygen and carbon dioxide with the heart and lungs." Many of these codes were associated with phrases that demonstrated the magnitude and importance of the content learned. Examples like, "this was huge for me," "gaining insight was amazing," and "I was surprised at how much information I gained" are snapshots of teachers' most salient moments in grasping mathematical and science concepts.

Theme two. Pedagogical content knowledge, the second emergent theme, included three distinct subcategories that further explained the theme. Pedagogical strategies teachers learned the most is the first subcategory followed by strategies employed in both the planning and enactment stages of training with critiques of their summer controlled practice enactments as the third and final area of reflection. Teacher responses related to pedagogical content knowledge as it pertained to learning generated phrases such as, "pass it on strategy to close the lesson," "artifacts are good use of memory recognition," and "effectively connect the lesson." Planning/ implementation sections in the training captured teacher responses such as, "engage students, encourage answers, and give clear directions" and "kids must justify reasoning and connect to their design-make it real for them." Finally, teacher critiques after teacher summer enactments elicit reflections that indicated teachers were thinking about pedagogical strategies that were either

present or missing during their summer enactments. The terms "I should have" is associated with or linked to phrases such as "refine," "communication," "culmination," and "probing questions" to reflect teachers' thought on their overall content and pedagogical knowledge. Findings from teacher journals demonstrate that teachers' acquisition of "content and pedagogical knowledge" was significant throughout the professional development particularly during the first two weeks. Qualitative emergent themes support Quantitative RTOP findings which indicate teachers were able to model, embed, and implement content and pedagogical knowledge from the INSPIRES heart-lung curriculum into their classroom practices.

Fall enactment lesson 1

Teacher Lesson 1 enactments demonstrated major shifts compared to their pre-institute lessons. Lesson 1 provided a platform for teachers and students to engage in greater scientific discourse. Teachers' ideas became centered on students' construction of scientific knowledge instead of completing activities with a paucity of scientific inquiry. Lesson 1 also demonstrated significant shifts in the integration of student centered data collection to support various explanations and design rationale. Teacher pre-taping lessons neither asked students to collect data nor conduct an investigation to describe phenomena. Instead, most teachers asked students to offer an explanation to a technical or societal issue by which they could employ the problem solving process. Unlike teachers' pre-taping lessons, Lesson 1 presented students with phenomena-first activities and concepts associated with heat transfer, fluid flow, and system volume. Qualitative analysis of teachers' pedagogical transformations in this lesson revealed three emergent themes: (1) Increased Scientific Discourse; (2) Data-Driven Explanations; and (3) Real-World Connections.

Theme one: increased scientific discourse. Shifts in student-teacher conversations were evident throughout Lesson 1 enactments. Discourse moved from, "... how would you like your phone or camera ... square or rectangular ... diamond shaped ... how large?" to discussions involving, "Metabolism ... chemical reactions ... the warmer the molecules are the faster they vibrate...energy of vibrations can be transferred to neighboring molecules ... heat movement [is being transferred] from inside the water bottle to outside the water bottle ... the metal container had no insulator ... so [temperature change occurred] much faster ... larger change...verses the plastic ... plastic had a cavity of air ... temperature [change occurred] slower." Students were allowed to build prior knowledge, connect concepts from previous lessons to subsequent ideas, construct explanations to investigations, and extrapolate data to design,

build, and test a functional HLM based on its criteria and constraints.

Teacher questions pursued student's thoughts and ideas pivotal to core concepts in the lesson. For example, Ms. K's lesson discussed fundamental scientific concepts of heat transfer and connects these concepts to physiological characteristics of the human body and to students' HLMs. Ms. K asked, "Is oxygen-exchange in the body slower or faster when the body is cooled?" Student's replied, "Slower molecules do not move as fast" Ms. K reiterates, "As the body cools, the metabolism slows down the oxygen exchange." Ms. K asked, "If you had a choice to insulate the blood (in the heart-lung machine) which would you choose?" Furthermore, Ms. K asked questions regarding the engineering design steps, "Where are we in the engineering design loop? ... does anyone agree or disagree? ... refining ... okay you're adding new things to your design."

Contrary to the aforementioned lesson, Ms. K's pre-taping lesson mainly asked questions tangential to the lesson's objective, skipped through stages of the design process, and provided students little to no time to expound upon their ideas, whereas her Lesson 1 related questions to core scientific ideas, steps in the engineering design loop and allowed students opportunities to provide explanations.

Similar shifts were noted throughout teacher enactments in this cohort. Mr. A for example asked his students to, "make predictions...which one will have the greatest temperature change after 10 minutes... the metal or plastic?" Mr. A continued "let's share our predictions." Students employed, "the plastic bottle is lower [will have the lowest change] ... the plastic container has space in between..." Mr. A continued, "Let's explore this idea about ... air pockets around the plastic container." Similarly, Mr. J's lesson allowed students extra time to explore concepts of heat transfer such as conduction, convection, and radiation. Mr. J instructed the class objective, "What different factors affect heat transfer? Identify three methods of heat transfer?"

Most teachers in this cohort as demonstrated by Ms. K, Mr. A and Mr. J converted from asking students superficial questions not central to the lesson's objective to probing students' prior knowledge and extracting ideas regarding scientific concepts. Although teachers mainly initiated questions, scientific discourse was not one-dimensional. Students asked questions in order to construct knowledge and make sense of scientific concepts embedded in the lesson. Students asked, "Does the entire five milliliters of blood need to be cooled?," "can we just put ice in the patient?"

Despite teachers' increase in scientific discourse by way of questioning, teacher-student conversations in some classes did not fully allow students to obtain deep conceptual understanding. Most teachers allowed students to complete Lesson 1 activities by making predictions, and

providing rationales, but few teachers elaborated or solidified students' understanding at the conclusion of the lessons. Mr. J for example asked his students to, "predict and rate which [medium] will result in the largest temperature change in ten minutes...what you think?" Students made predictions as to the medium that would result in the largest temperature change but did not elaborate or provide rationale to their predictions. Mr. J quickly moved on to the next part of the lesson and completed the next activity with similar sentiments; increased questioning but very little scientific discourse based on laws, theories or evidence. One student asked, "Is there no blood in the lungs?" Mr. J responds "Absolutely there is" and quickly moved on to closing statements without further questions or explanations to decipher students' understanding or lack thereof. Mr. J did not make clear his response as either the affirmative or negative. His statement could imply "absolutely there is no blood in the lungs" or "absolutely there is blood in the lungs." Thus either the latter or former statement could be misconstrued by students and would require further explanation.

Theme two: data collection and analysis. Teacher Lesson 1 enactments provided an arena for students to conduct investigations that served as evidence for student ideas in designing, building and testing their HLMs. During the lesson teachers utilized data to help students recognize similarities and difference in water containers and explore patterns of various cooling environments used in heat transfer. Data collection and analysis equipped students with a deeper understanding of heat transfer and allowed teachers to scaffold student learning. Heat transfer data provided students with evidence to support scientific claims

The integral use of data collection and analysis were evident from the outset for many teachers. Students made predictions as to which cooling medium would cool the water fastest and supported their explanations with scientific rationale. Teachers asked students to collect data on initial temperatures of several small bottles prior to placing them in different cooling environments. Students were later directed to record final water bottle temperatures after ten minutes, and calculate temperature changes in each environment. Data collection set the stage for teachers to build students' knowledge in potential blood cooling methods, delve deeper into core scientific ideas, and provide evidence for students expanding ideas of heat transfer. Mr. J and Ms. K highlight examples of these instructional changes below.

Predict and rate which will result in the largest temperature change in ten minutes ... what you think? What was observed? ... Were your predictions accurate...what about

[the] guys with ice packs? Walk around and look at other bottles and make observations (Mr. J).

As most teachers focused students' attention on "which environment would have the biggest temperature change?" and "Which treatment worked best?" One teacher proposed, "Nobody said cool water ... why?" Mr. C, in this instance, attempted to get students to think about all cooling environments and delve deeper into why each medium would or would not be a suitable match for cooling blood in a HLM.

Theme three: real-world connections. Teachers pre-taping lessons presented scientific concepts in isolation, whereas Lesson 1 enactments allowed teachers to make connections within and across the curriculum. Common threads in Lesson 1 enactments revealed teachers fervently linking concepts of heat transfer with students' HLM designs and real-life experiences. These connections elicited ideas, generated questions, and supported students' explanations in their attempt to design, test, and build a HLM.

Instead of eschewing scientific concepts and focusing on superficial topics teachers embraced ideas and directives directly from the curriculum. For example, Lesson 1 connoted "Begin class with a student or group presenting an artifact that captures the key ideas." (UMBC INSPIRES) Most teachers allowed students to present at least one artifact and discuss the nexus between their artifacts and heart lung machine designs. Students presented artifacts and provided explanations. One student presented a picture of a shower, whereas other students tried to guess how this particular artifact connected to a heart lung machine, "water flow is like blood ... you can regulate temperature." Another student brought in a straw and explained "[it's like] a closed system ... like the tubing on the machine that transports the blood"

Many teachers went beyond connections made within the lesson, and drew upon students' previous experiences coupled with core scientific ideas from the curriculum. Mr. A for example connected students' previous experiences in maintaining temperatures of food and beverages with developing students' conceptual understanding of heat transfer. Mr. A explores, "Remember ... thermoses we used to have in elementary school? ... Remember the super hero lunch buckets with thermoses in it ... if you put in cold drink you had cold drink at lunchtime. If you put in hot soup you had what at lunchtime? ... key point...it wasn't cold."

Mr. A continued to connect Lesson 1 to real experiences when he differentiated between properties of a metal and plastic container. Mr. A compared insulation found in homes to the plastic container in their investigation. A student commented, "That is what you put in a wall," Mr. A commented and suggested, "Yes ... and why do we keep insulation in there?" and goes on to explain, "same thing with insulation [in the winter], it keeps the cool air out and

warm air in." Mr. A connected the activity to the overall theme as he suggested, "We just learned what material will [transfer heat faster] ... How would you use that inside your project to cool the blood ...? That's what I need you to start thinking about."

Several teachers briefly connected heat transfer with cooling student's HLM by using a KWL chart. One teacher asked students, "What do we want to know about cooling [the blood] Is there anything we've learned in the past few lessons? ...any ideas on regulating or cooling the blood of your heart-lung machine?" (Mr. D) Another teacher articulated concepts of heat transfer by referring to a hot air balloon. He mentioned, "As the balloon went up it cooled and came back down. It heats ...[goes] upas it cools it comes down. It created a cycle of convection." (Mr. B)

Although most teachers made meaningful connections to the HLM, some teachers focused solely on heat-transfer and struggled with helping students connect both ideas. For example, Mr. J's lesson involved scientific concepts, but content was mostly articulated in isolation. Mr. J asked "identify the three applied methods of heat transfer" can you give me an example of convection? ... Can someone give me an example of conduction...radiation?" Mr. J intermittently discussed concepts in isolation and did not connect them to students' HLM until the end of the lesson. At this point Mr. J superficially connected heat transfer to students' design and did not delve deep or elaborate into how heat transfer was applied, used or impacted students' HLM design. Mr. J suggested students construct groups and discuss and sketch models for cooling the blood. Mr. J asked and commented, "Have you sketched your design yet? What will you do? Draw your idea."

Overall, teachers made statistically significant shifts in Lesson 1 enactments compared to teachers' pre-taping lessons. Although few teachers struggled to make meaningful connections most teachers challenged students to increase discussions grounded in scientific ideas, use data to generate evidence for explanations, and connect heat transfer to core ideas within and across the curriculum.

Fall enactment lesson 2

Teacher Lesson 2 enactments continued to demonstrate different shifts in teachers' pedagogical strategies as compared to teacher pre-taping and Lesson 1 enactments. Overall Lesson 2 provided students the autonomy to design their own HLM within the criteria and constraints embedded in the lesson. Teachers encouraged students to use an eclectic mix of materials, put their ideas in motion, and incorporate quintessential scientific concepts from previous activities to construct an operable HLM. Lesson 2 enactments demonstrated a significant increase in student ideas, the use of models, and connections within the lesson. Few classrooms in previously described pre-taped lessons asked students to design or build a model to represent or test student ideas. Lesson 2 presented

students with the challenge of designing, building, and testing, a heart lung system. Although teachers videotaped lesson only captured student designs stages, Lesson 2 illustrates a unique set of differences compared to Lesson 1 and from which three distinct themes emerged: (1) Divergent Modes of Thinking; (2) Student Models; and (3) Intra-Curriculum Connections.

Theme one: divergent modes of thinking. Contrary to teachers' pre-taping lessons, Lesson 2 enactments allowed students' opportunities to explore various ideas and designs. As students transitioned from guided inquiry activities to more open inquiry tasks, teachers allowed students time to formulate their own ideas and strategies in pursuit of building an operable HLM. For example, students in Mr. D's class presented different artifacts, whereas other students provided their explanations how these artifacts resembled their HLM. Students explained, "[A] power generator ... keeps going like the HLM keeps pumping blood through the body [and is a] power source for [the] HLM. [A power generator] keeps electricity flowing [like a] HLM keeps blood flowing." "[A] tire pumps air [into a] bicycle [tire like] blood is pumped through a HLM." "[The] Chesapeake Bay flows like blood ... like a reservoir. [The] HLM goes through a reservoir ... [The Chesapeake Bay and blood are] dirty.... they both need to be cleaned.... [The] Chesapeake Bay connects to other rivers ... [the heart-lung machine] connects to other parts of the body." Most teachers encouraged students to generate ideas based on science concepts whereas one teacher insisted his student follow his ideas. "What is the purpose? Here is my idea "Originally you said coil [this out] ... this could be your coil ... Let's try to get the water flowing first ... Would it make sense to not put a hand pump in? ... You have two motors, one to pull and one to push ... I would take out the beaker ... I am wondering if it would be to cold when it goes back into the body."

Theme two: student models. Few students in teachers pre-taping lessons were asked to design or build a model to represent or test their ideas. However, teachers' Lesson 2 enactments frequently asked students to explicitly design a schematic diagram indicating blood flow and the cooling process considering constraints and criteria set forth in the curriculum Teachers asked students to utilize schematic diagrams and physical replicas to help move students from abstract to concrete understanding Several teachers asked, "How are you going to connect this [tube] to your system? I would like everyone to have a sketch of [their] HLM. You were supposed to have volume, direction of blood flow, etc. ... each person should have a full sketch sheet, total system volume, specs of all parts, and cost of [their] system" (Mr. D). "Plans must include the following: [a] diagram [with] labels indicating blood flow, [and] labels

indicating which design components addresses the various constraints. Ensure that all the design constraints and criteria have been addressed" (Mr. J). "You still need to label [blood] flow [and] tubing size. What does the reservoir represent? Where [does] the blood go?" (Mr. J).

Most teachers emphasized the importance of students using diagrams to represent their HLM models. For example, Mr. H asked, "Do you have the drawings? Where is the reservoir? [You will] have to figure out how to seal it because of pressure. Once you have your design, and measurement in terms of volume let me see it so I can sign off on it." Mr. E asserts, "In groups sketch out [your] design, pick [one] design, and begin construction. [Place your] labels on [the] diagrams that indicate blood flow. Everything has to be labeled ... be specific ... I need a drawing from each member on the team." Similarly, Mr. J explains, "Everything must be labeled indicating which design components address the various constraints. Ensure that all design constraints and criteria have been addressed. You will not be able to build until you show me two group drawings that are specifically labeled ... you just need to add the cooling element of the project." Mr. B also explained, "[You are] going out of [the] patient into what?" The student replied, "into [the] reservoir." The teacher replied, "Let me see [this in your] drawing?"

Pre-taped lessons used many teacher-guided or instructed models to mainly demonstrate physical features of phenomena devoid of scientific or mathematical explanations. Lesson 2 provided students opportunities to construct models (e.g. diagrams, physical replica, and computer simulations) based on scientific and mathematical reasoning. Student models were guided by criteria and constraints set forth in the INSPIRES curriculum. Models were mainly based on student ideas and choice of materials with little steering from teachers on how to solve the Heart-Lung System design challenge. Initial student models were re-designed, tested, and modified based on limitations or additional evidence gleaned from students. Most students created schematic diagrams of their Heart-Lung Systems, but others needed access to materials to physically piece together system parts and build concrete understanding. Despite student's unique needs teachers were able to extend students' knowledge and understanding at a deeper scientific, mathematical, and engineering level, compared to previously pre-taped lessons, through student modeling.

Theme three: intra-curriculum connections. Teacher pre-taping lessons asked students to design a product capable of solving a real world problem but many teachers did not connect elements of their lesson to help students make sense of the underpinning classroom objective. Thus students were left with isolated pieces of knowledge and little direction to construct a clear and vivid picture. Nevertheless, teachers' Lesson 2 enactments encouraged

students to utilize scientific ideas from various activities within the curriculum in order to design a HLM. Teachers probed students with questions directly from the curriculum to help make concrete connections and justify their rationale with strong convictions. Mr. D suggested, “Figure out how you want to attach [your] cooling system to it. ...Go back to [your] HLM simulation for calculating change ... according to how long [the] tube [is] inside [your] cooling bath.”

Although talk is mainly centered on scientific ideas, teachers periodically connect steps in the engineering design process to the HLM. Mr. H and E remind students to think about the engineering design loop, “Where do you think we are? Are we in Prototype ... now you need to figure out what type of tubing and what type of containers you need to cool [the] blood?” (Mr. H).

You are selecting the best solution ... you must use [your] previous design ... (Mr. E)

Some students struggled to connect previous activities to their heart-lung machine design although scientific ideas and concepts were embedded in the lesson. Ms. K realized her students struggled to make such connections and goes back to re-teach students how to calculate blood flow rate. Furthermore, Ms. K encouraged her students to push forward with their designs. Ms. K asserted, “I need your refined drawings.” A Student responded, “We do not have drawings.” Ms. K explained, “My groups that are building go back and draw your redesigns, go back to your original design that worked. One student answered, “I did, but it’s not working.”

As of result of students’ lack of connecting what they learned in previous lessons, Ms. K focused on repairing leaks in students’ systems as opposed to using scientific ideas to help students find solutions to their challenges. Thus Ms. K spent a large portion of class repairing student leaks. Mr. B’s students had similar challenges, but he does not allow students to remain fixated on leaks and encouraged them to continue to sustain blood flow:

Where is the pump? ... Draw as you go along ... keep refining your drawing ... Get water running and get a flow rate ... It will leak but it will flow ... how are you going to fix the problem?” A student replies, “Connector.” Mr. B encourages a team of students, “once you figure out leaks it will work ... Let’s get [your blood] flow ... I will get silicon and you guys fix your leaks. [I also] need a labeled drawing (Mr. B).

In essence, teacher questions and comments remained focused on encouraging students to incorporate and connect scientific and mathematical ideas into their HLM design.

You got flow, what about flow rate? Measure tube length now ... Write down [your] measurements guys ... measure your tube length ... what tubes are you using now? ... Do you have flow rate ... Excellent ... Divide by what? ...

Multiply by six right? [You] have to [use centimeters] ... look at the ruler ... [complete] conversions if necessary ... make sure tube measurements are [complete].

Discussion

Well-designed professional development provides opportunities for teachers to reflect critically on their practice and to construct new understandings about content, pedagogy, and learners (Darling-Hammond & McLaughlin, 1995). However, even with professional development, studies have shown that teachers have difficulty using design- and inquiry-based practices (Schneider et al., 2005). For example, an intricate cognitive system of resolving and rationalizing mechanisms may allow teachers to believe they have incorporated reform practices without actually changing their core beliefs (Yerrick, Parke, & Nugent, 1998). In addition, teachers may have a compartmentalized understanding of science that interferes with innovation (Roehrig & Luft, 2004) and often view inquiry as a de-contextualized collection of isolated process skills as opposed to an array of interconnected processes (Lee, Hart, Cuevas, & Engers, 2004). As a result, design- or inquiry-based instruction is often equated with “hands-on” or “real-world” activities that are unconnected to meaningful scientific ideas (Lotter, Rushton, & Singer, 2013).

Although many of these research findings emanate from studies focused on inquiry, scientific investigation and engineering design are closely related (Katehi, Pearson, & Feder, 2009). The emerging research base in engineering education indicates that the teaching of engineering design is equally challenging for teachers (Householder & Hailey, 2012; Katehi et al., 2009; Ross & Bayles, 2007). Key challenges are associated with the classroom implementation of open-ended engineering design (Householder & Hailey, 2012; Katehi et al., 2009; Ross & Bayles, 2007). and the connection between design and underpinning mathematics and science concepts (Kelley & Wicklein, 2009; Nathan, Tran, Atwood, Prevost, & Phelops, 2010; Nathan, Srisurchan, Walkington, Wolfgram, Williams, & Alibali, 2013). A 2009 survey reported by Kelley and Wicklein (2009) found that the number one challenge associated with engineering integration was “integrating the appropriate levels of mathematics and science instructional content” (p. 45). At the heart of this challenge, respondents perceived that teachers often lack the pedagogical content knowledge needed for appropriate integration of mathematics and science content. For example, teachers need to be able to recognize and implement strategies that translate various activities that implicitly address science and mathematics concepts into meaning-making activities that explicitly intertwine mathematics and science concepts. A study looking at the teaching of pre-college engineering courses suggested that current approaches lack the necessary teacher development to effectively create learning opportunities for academic knowledge (Tran & Nathan, 2010).

Findings from the present study's videotape analysis of the pre-institute lessons were consistent with these previously documented patterns. The pre-institute lessons, in general, demonstrated that the teachers struggled with prompting students to use underpinning STEM concepts, models or peer collaboration processes as mechanisms to inform their design rationale.

The analysis of teacher lessons enacted following their participation in the SI (Lessons 1 and 2) revealed teachers' ability to move classroom discourse from superficial levels of the content to increased integration of core scientific ideas and engineering practices. Particularly noteworthy is that this increased ability was observed in both of the post-SI lessons. The focus of Lesson 1 was to support student understanding of the scientific concept of heat transfer. It therefore would be reasonable to expect increased learning opportunities associated with scientific concepts. This trend was demonstrated based upon analysis of RTOP Propositional Knowledge sub-scale scores. In addition to this trend was also a corresponding increase in the RTOP sub-scale score associated with Procedural Knowledge. A similar trend was demonstrated in the analysis of Lesson 2. Unlike Lesson 1, the second post-SI lesson was designed to aid the students in the planning, construction and testing of their heart lung machines and was not primarily focused on the learning of science specific concepts. In this instance an increased RTOP score associated with Procedural Knowledge would be expected. As with Lesson 1, this trend was found along with higher scores associated with Propositional Knowledge.

Follow-up qualitative analysis of the post-SI lessons showed teachers elicited student responses and engaged them in various aspects of scientific discourse. Students made predictions, asked questions, shared conjectures, and articulated design ideas; unlike teachers' pre-taping lessons. Teachers created an amicable climate that encouraged students to posit their ideas and opinions. Thus student communicative interactions created a gateway for deeper scientific acquisition and comprehension.

Collectively, the RTOP analyses associated with these two lessons are consistent with an overall increased teacher ability to integrate scientific ideas and engineering practices. This finding is very promising considering past research (Katehi et al., 2009) indicated teachers may be particularly uncomfortable with the open-ended nature of engineering design. "A major challenge in PD for K-12 engineering is to undo the mindset that sees answers as right or wrong, and as complete or incomplete" (Katehi et al., 2009, p. 112).

Furthermore, findings from the teachers' SI daily journal entries suggest that the knowledge and skills required to facilitate these connections was related to their SI participation. Teacher summer journal entries included references related to acquisition of content knowledge during the morning content sessions as well as references from their practice teaching

sessions reflecting upon their use (or non-use) of pedagogical strategies that supported the inquiry/engineering design process. As previously mentioned teacher journal entries consistently included linking phrases such as "I should have" or "I need to refine" to phrases such as "made stronger connections," and "include probing questions" to reflect on their overall content and pedagogical knowledge. Findings from teacher journals demonstrated that teachers' acquisition of "content and pedagogical knowledge" was substantial throughout the professional development particularly during the first two weeks.

These findings are consistent with prior findings associated with the use of the employed professional development system (Lotter et al., 2013; Rushton et al., 2011; Singer, Lotter, Feller, & Gates, 2011) Rushton et al. (2011) and Lotter et al. (2013) employed a similar professional development system working with high school chemistry and biology teachers while Singer et al. (2011) worked with middle school science teachers. Rushton et al. (2011) reported that the combination of the morning content and the practice teaching sessions played a significant impact for shifting the instructional practices of the participating high school chemistry teachers. "The program's emphasis on the content instructor's modeling of content-specific inquiry lessons coupled with the practice teaching with high school students and intensive teacher reflection led to the greatest changes in teachers' beliefs about instructions." (Rushton et al., p. 41).

Providing teacher participants, the guided experience of interacting with the educative materials from a student perspective, followed by reflective discussions focused on the pedagogical design of the lessons provides opportunities for teachers to both experience the affordances and limitations of a particular activity from the student's perspective, but also the "space" (Remillard, 2000) to discuss the rationale for how the activity was constructed and how it may be adapted in the future. Under these conditions the curricular materials serve as a scaffold by providing the teachers concrete examples for how to translate the abstract into a tangible useful product. Employing such a strategy has been reported as promoting significant changes in the content knowledge and pedagogical beliefs of high school STEM teachers (Rushton et al. 2011; Lotter et al. 2013).

Furthermore, evidence from self-reported daily journal reflections written by middle school teachers participating in a similarly designed 15-day professional development institute report similar conclusions (Singer et al., 2011). "Responses showed that the morning content instructors facilitated a deeper understanding of scientific concepts while also modeling inquiry-based practices. The controlled practice teaching experience provided the teachers opportunities to 'trial run' and discuss lessons that led to an increased awareness of strengths and limitations" (Singer et al., 2011, p. 31).

Conclusion

The purpose of this study was to implement and describe an educative-material-aligned professional development system for high school technology education teachers. Our findings demonstrate a positive shift in teachers' content and pedagogical knowledge in classroom lessons associated with design-based curriculum. The employed professional development system has demonstrated a great deal of promise among multiple contexts, however additional development and investigation of the affordances and limitations are still needed. Teachers' RTOP scores and qualitative findings revealed most teachers followed the INSPIRES curriculum as a script and added very little or no content knowledge to their lessons to extrapolate or expound upon scientific meaning and concepts. Although shifts in elements of extraction, coherent conceptual understanding, and connections within the content were visible, some students lacked the ability to articulate deep understanding and extend its meaning within or amongst other content areas. This concern is neither novel nor unique to the INSPIRES curriculum. Studies looking at the teaching of pre-college engineering courses such as PLTW demonstrated deficiencies of learning opportunities for academic knowledge (Tran & Nathan, 2010). While students may have exposure to (and even understanding of) the underpinning STEM concepts and processes within the specific problem context, teachers struggle with providing learning opportunities for students to fully develop a robust, generalizable "academic" understanding of the concepts/processes (Tran & Nathan, 2010). Additional research is required to determine other support networks or strategies STEM teachers can utilize to strengthen students' ability to conceptualize core mathematical and scientific ideas as well as self-regulate their learning to apply core content knowledge to solving real world problems. Furthermore, research is needed to determine the robustness of the instructional practices enhanced via this professional development system.

Finally, the reported results open the door to future professional development programs searching for ideas to support high school STEM teachers' employing curriculum aligned to STEM educational reforms. Although exposure to the INSPIRES curriculum heightened teachers' ability to integrate STEM concepts, practices, and discourse among students, future development programs should consider helping teachers make stronger intra-disciplinary and inter-disciplinary connections. Currently our findings associated with changes in teacher pedagogical practices have been contributed to curricular materials used during the professional development program. It is currently unclear if the acquired instructional strategies are employed in lessons that are external to the INSPIRES module. The authors have recently been awarded additional NSF research support (DRL-1418183) to initiate research in this direction.

Appendix: INSPIRES example Module: Heart-Lung System

Figure 1. Design principles within INSPIRES: A heart-lung system case study.

An introductory video focuses on a 16-year-old girl who undergoes open-heart surgery, thereby requiring the use of a heart-lung machine (**Context**). Student teams are given the challenge to design, build, test and refine a system that mimics attributes and functions of a real heart-lung machine including a flow rate between 3–5 L/min, a total system volume less than 1.5 L, a "blood" temperature decrease between 5–8°C, and a construction cost under \$50 (**STEM Practices**). After watching the video and receiving the challenge, students use a "Think, Pair, Share" strategy to reach consensus (**Collaboration**) on key ideas as well as the criteria and constraints required to construct a design solution.

As students attempt to solve the design challenge, they are introduced to the engineering design process as a rational and methodical cycle of steps (**STEM Practices**). The various steps are explicitly addressed during the lessons to ensure that students are cognizant of the process they are utilizing (**Metacognition**). A large classroom poster is utilized to facilitate these explicit connections (**Public Artifacts**). In order to understand the various design constraints and criteria as well as make informed design decisions, the students learn relevant scientific principles as well as mathematical equations to quantitatively assess and refine their design (**Standards Based**).

In this module, students learn concepts associated with (1) heat transfer, (2) fluid flow/pumps, (3) anatomy and physiology of the heart and lungs and (4) system volume. These science concepts are introduced in the curriculum through a variety of "just in time" phenomena-first activities (**Context**) and inquiry-based investigations (**STEM Practices**). During "The Let it Flow" challenge (Lesson 4 of 13), individual group members submit potential design solutions, followed by small discussion to build consensus (**Collaboration**) on a prototypical design prior to receiving teacher approval to start construction. This mini challenge is then utilized to reintroduce the engineering design process as well as to introduce the idea of volumetric flow rate (**Context/Standards**).

Following these activities, online models and animations are used to illustrate the "non-visible" mechanism(s) driving many of the observed macroscopic events. Computer-based mathematical simulations are utilized prior to the final design and build phase allowing students to alter a variety of design parameters and quantify their impact on the system performance (**STEM Practices**). Students then plan, build, test and refine a "heart-lung system" (**Integrates all principles**). Student teams present their final designs along with an analysis of design decisions in an open forum (**Collaboration/Public Artifacts**). Concepts and key ideas are reinforced and

continuity among lessons is maintained by having students present daily artifacts representing their understanding (**Metacognition**) that are publically displayed on a classroom artifact board (**Public Artifacts**).

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