AC 2011-1284: IMPLEMENTING THE CAPSTONE EXPERIENCE CONCEPT FOR TEACHER PROFESSIONAL DEVELOPMENT

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Implementing the Capstone Experience Concept for Teacher Professional Development

ABSTRACT

The need for STEM (science, technology, engineering, and math) workforce is well documented in the literature. The lack of interest among school-age students in STEM careers and the reason for such lack of interest are also well documented. Pedagogical research suggests that K-12 students learn best by engaging them in activities that relate to their daily lives and that reinforce principles through hands-on tasks. Research also suggests that the engineering design process (EDP) offers the best platform to implement these activities because it typically involves critical thinking combined with hands-on tasks to motivate the students.

While many variations of using the EDP in student teaching exist, we introduce an innovative methodology of using and implementing the concept of "capstone experience" at the high school level; the EDP encourages open-ended problem solving and multiple solutions. The capstone experience is rooted in the capstone design project course that is typically required in the ABET-accredited college engineering curriculum. Students are motivated by the capstone experience because it shows the elegance of the EDP and relates to how engineering is used in practice to design and manufacture products.

In order to teach the EDP and capstone experience effectively, high school teachers must experience, learn and use the EDP themselves. Our methodology begins by educating the teachers about the capstone experience and how to incorporate it in their classroom instructions when they return to their schools. We continue to work with and monitor the teachers during their teaching activities over one academic year.

We have implemented the capstone experience in the first year of a three-year NSF funded project. We have developed and delivered a professional development (PD) course for teachers in urban school districts such as Boston (Massachusetts) Public Schools. The paper covers the details of the capstone-based PD program and how it is designed and implemented to advance the pedagogical skills of the high school teachers, the results, what we have learned, and the data we collected. We discuss the two types of data we collected (attitude and content knowledge) and what improvements we plan to make for the next PD offering next year. The paper also discusses the evaluation methods developed by the project evaluator and the insight gained from the data analysis. Data is presented on teacher attitude change as well as content knowledge change. The lessons learned and the data analysis should be helpful for other school districts who might be interested in implementing capstone design projects, especially as more states are looking to include engineering standards for high school students.

Introduction

What would you do, as a teacher, if your students came to you for help telling you that they do not get the chemistry or physics lessons, cannot appreciate their value, and/or they are not motivated to learn STEM topics? Well, we have an answer that we share with you in this paper.

The NSF-funded research reported in this paper is motivated by the national and local needs for STEM/IT workforce and professional development for teachers. The Bureau of Labor Statistics identified IT as the U.S. economy's fastest growing industry [1] for the 2000-2010 period. The US Labor Department echoes similar needs [2, 3]. In Massachusetts, similar observations are made by Boston Redevelopment Agency [4]. Regarding professional development of teachers, the National Research Council [5] reports that "… most teachers lack the professional development and support (e.g., training and release time) needed to incorporate information technology into daily instruction, and as a result, significant numbers of such teachers either ignore the pedagogical uses of technology or use technology ineffectively." Gatta [6, 7] and Burns [8] have documented the need for allocating more resources for professional development of teachers rather than for just acquiring more computer software and hardware.

When it comes to the state, Massachusetts Science and Technology/Engineering Curriculum Framework [9] requires school districts to follow and implement statewide guidelines for teaching, learning, and assessment in science and technology/engineering. All Massachusetts school districts face the challenge of meeting these framework requirements.

Reporting on underrepresented groups for STEM career*,* the National Research Council (NRC, 2001) characterized the current IT workforce as "predominantly white, male, young, educated, and U.S. born." Gatta [6, 7] has documented the reasons for such imbalance and traces it back to loss of interest in STEM courses among school girls and underrepresented students. Without a core group of girls in STEM classes, female students are at risk of social isolation in the classroom [10] and not participating in the IT workforce [11, 12].

CAPSULE Learning Model

NSF has funded a three-year strategies project titled "CAPSULE: CAPStone Unique Learning Experience". The goal of CAPSULE is to develop, implement, and evaluate an innovative Capstone project-based learning (also known as capstone experience) model for high school teachers and students. In speaking with teachers in local schools, we learned that students have difficulty staying motivated in STEM courses because they do not see the value of what they learn in chemistry or physics class. To address this issue, CAPSULE learning model uses the top-down project-based learning model [13] to effectively convey to students the value of STEM/IT subjects. In this approach, students learn by doing; as they analyze and solve a real-world problems they discover the connections between STEM concepts and real-world applications. This approach is different from the conventional bottom-up approach, in which students and teachers focus on basic principles, but most often fail to see connections to the big picture, and hence lose interest in learning.

We use the engineering design process (EDP) delineated in the Massachusetts Framework [9] as the basis for teachers' professional development (PD) and for formulating students' capstone projects. Working on their capstone projects in accordance with EDP steps, students will deliver the problem solution in the form of prototypes, reports, and presentations rather than memorization and exams.

We utilize the T4E (Teaching Teachers to Teach Engineering) teaching model developed and conducted by the US Military Academy (West Point) during 1996-1998 [14] and its subsequent models [15] to deliver teachers' PD. The key features of these models include active learning, learning objectives, content organization, clear expectations, lesson planning, effective delivery, and teaching styles variation.

CAPSULE learning model is aligned with the state engineering standards. Massachusetts is one of the first states to mandate teaching engineering and technology in its school system. The state has developed the Science and Technology/Engineering Curriculum Framework. The framework has seven areas: (1) Engineering Design; (2) Construction technologies; (3) Energy and Power Technologies – Fluid Systems; (4) Energy and Power technologies – Thermal Systems; (5) Energy and Powers Technologies – Electrical Systems; (6) Communication Technologies – Electrical wire, optical fiber, air, and space; and (7) Manufacturing technologies

In order to ensure its relevance throughout Massachusetts, CAPSULE's curriculum has been carefully aligned with the relevant learning standards in the Massachusetts Science and Technology/Engineering Curriculum Framework areas shown in Table 1.

Table 1 Massachusetts framework engineering areas relevant to CAPSULE

Framework Area	Standard Number and Description
1. Engineering Design	***Standard 1.1:*** Identify and explain the steps of the engineering design process.
	Standard 1.2: Demonstrate knowledge of pictorial and multi-view drawings.
	Standard 1.3: Demonstrate the use of drafting techniques using CAD systems.
	Standard 1.4: Interpret and apply scale to orthographic projections and drawings.
	Standard 1.5: Interpret diagrams and drawings in the construction of a prototype.
7. Manufacturing Technologies	***Standard 7.1:*** Describe the basic manufacturing processes — Casting, turning, etc.
	Standard 7.2: Identify the criteria to select manufacturing processes.
	Standard 7.3: Describe the advantages of manufacturing automation.

Since the Massachusetts standards are aligned with national standards such as NETS (National Educational Technology Standards) issued by ISTE (International Society for Technology in Education), as well as STL (Standards for Technological Literacy) issued by ITEA (International Technology Education Assoc.), the capstone model will be replicable nationally. We anticipate that school districts in other states could adopt the curriculum with only minor modifications.

Teachers' Professional Development

CAPSULE provides an intensive, two-week workshop for high school teachers every summer. At these workshops, teachers learn and practice the capstone experience. Following the summer PD, teachers implement what they learn in their PD into their classroom instructions. As such, we provide two follow-up (callback) sessions through the school year. One session is conducted in the fall semester and the other in the spring semester. The callback sessions are designed to allow the teachers to share their implementation of the capstone experience in their classroom teaching and the challenges they face, and lend them support on how to overcome these challenges.

Table 1 shows the two-week PD schedule. Week 1 is designed to immerse teachers in the capstone experience. We utilize CAD/CAM software as a tool for the teachers to implement and evaluate their designs. Week 1 provides the teachers with the following pedagogical skills: thorough understanding of the EDP, how to use the EDP in product design, and provide the teachers with the tools they need to implement the capstone experience in their classroom teaching.

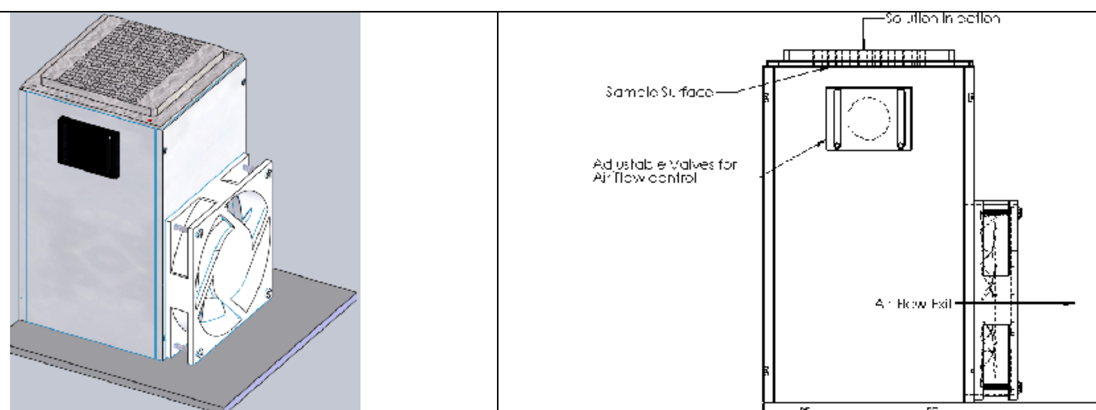
Table 1 Teachers' PD Schedule for Summer 2010

Day	**Date**	**Theme**
		Week 1
1	Monday July 19	Capstone Introduced
2	Tuesday July 20	Capstone skills and tools. Use CAD to conceptualize/design/analyze/prototype
3	Wednesday July 21	Industry Day: Real world design challenge
4	Thursday July 22	STEM capstone projects
5	Friday July 23	STEM capstone projects presentations
		Week 2
6	Monday July 26	Instructional Design
7	Tuesday July 27	Resource Exploration
8	Wednesday July 28	Research and Design
9	Thursday July 29	Instructional Research and Design
10	Friday July 30	STEM/capstone action plan presentations

To help teachers appreciate the EDP and the thinking framework it provides, we use an innovative approach in Day 1 of Week 1 by giving the teachers a design challenge before we discuss the EDP with them. We asked teachers to design a 3-legged chair that is stable and safe and that can carry the maximum amount of weight. We divide the teachers into teams of 3. After they finish and test their designs, we ask them to reflect on their experience and use their reflection to discuss the EDP and its value. Such experience and discussion help them in their design activities of Day 4 and 5. Figure 1 shows some teacher activities during the design challenge.

Figure 1 design of 3-legged chair

We use two pedagogical instruments to relate the capstone projects to real world applications. First, we invite industry experts in Day 3 to share their experience with the teachers. Second, we seek capstone projects from industry and assign to the teachers during Day 4 and 5. We simplify the projects and limit their scope so that the teachers can solve them. The capstone project for this summer was to redesign an industry apparatus shown in Figure 2 to lower its center of mass to reduce its tipping possibility by 25% while maintaining its same mass and overall dimensions (length, width, and height). This project would require them to think of redistributing the mass so that the apparatus is mass heavy near its bottom.


Isometric View

Front View

Figure 2 Sample Surface Elusion Apparatus

The solution would require the teachers to use a CAD system to construct a model of the apparatus and use the mass property calculations to find the model center of mass. The teachers would iterate multiple designs until they achieve the design goal. Figure 3 shows some teachers' redesigns.

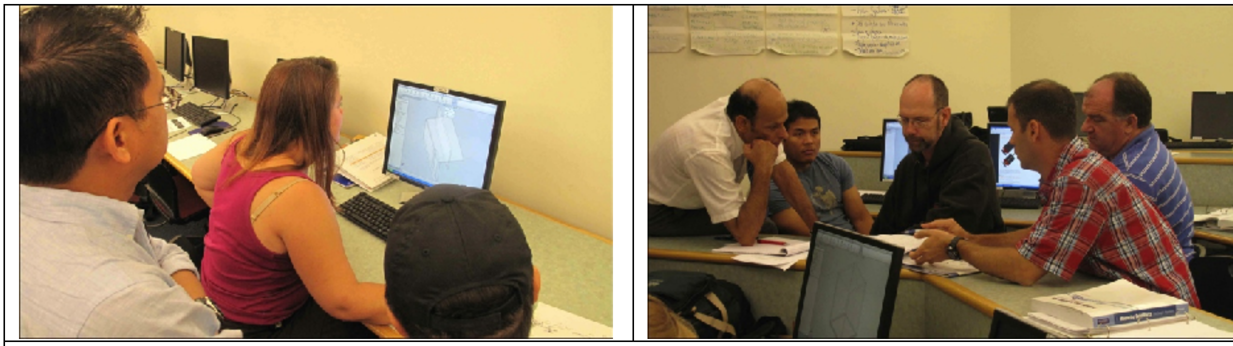


Figure 3 Teachers' redesign of the Elusion Apparatus

The culmination of Week 1 is a poster session shown in Figure 4 displaying each group's unique solution to the Surface Elusion Apparatus problem. Similar to many collegiate capstone courses, the posters display the problem, method and proposed best solution. These posters encapsulate the knowledge of the teachers learned throughout the week and the primary principles of the EDP. The poster session also gives the teachers a unique and renewed perspective of what it is like to be a student again and how one problem can have many solutions.

Figure 4 Teachers' Poster Session

Week 2 builds on Week 1 outcomes. Teachers have immersed themselves in the capstone experience and know firsthand how it works. It is time now to challenge them to think critically of how to use the capstone experience in their classrooms to improve their teaching and how they delivery material. At the beginning of the week, we ask the teachers to identify a STEM topic in their STEM course, where their students have difficulty grasping, understanding, or relating to. We then ask the teachers to develop action plans of how they would use the capstone experience to facilitate and incorporate STEM topics in their teaching and to their students. As Week 2 shows in Table 1, the teachers would spend four days to conceive and develop their actions plans. They would implement these plans during the fall and spring semesters of the school year following their summer PD. Thus, Week 1 and 2 complement each other. Week 1 focuses on EDP and Week 2 focuses on instructional design.

Teachers' PD requires much expertise to design and deliver a successful program. Therefore, CAPSULE team involves multiple organizations. Northeastern University leads the project and is responsible for the EDP and engineering content (Week 1). Boston Museum of Science (MoS) is responsible for the instructional design and action plan content (Week 2). Boston Public Schools provide consulting and guidance throughout both weeks allowing the entire CAPSULE team to receive daily feedback from the teachers resulting in immediate adjustments.

SolidWorks Corporation assists in teaching CAD tools and providing SolidWorks CAD software to participating schools free of charge. Local Industry helps with providing teachers with real-world insight. Finally, an external evaluator is responsible for evaluating the program.

Teachers Demographics

The program had 23 participants, 61% male and 39% female. Sixty-one percent were Caucasian/White, 17% were African-American/Black, 13% were Asian, 4% were Hispanic, and 4% reported being from an ethnic/racial background that wasn't listed.

Courses that participants reported teaching included engineering (42%), technology (33%), physics (29%), math (25%), environmental science (13%), chemistry (8%), and CAD robotics architecture (4%). One teacher each also reported teaching adult learners and senior projects.

Grade levels taught by participants included 9th (63%), 10th (58%), 11th (71%), and 12th (67%). One teaches 7th and 8th grades, and one teaches special education intensive students. In addition, the number of full-time equivalent years as a certified teacher ranged from one to thirty-five years. Fifty-five percent (N=12) have been certified between three and ten years and the median was six years.

PD Evaluation

The PD evaluation consists of two types: formative and summative. The formative evaluation was conducted with the help of a PD expert from Boston Public Schools. The expert designs a daily evaluation form for the teachers to complete at the end of each day. The CAPSULE team reviews them and makes any necessary adjustments for the following day.

The summative evaluation was conducted by the project external evaluator. The evaluator is an expert specialized in evaluating funded STEM projects such as CAPSULE. The evaluation instruments includes pre- and post-surveys and focus groups. All these instruments are anonymous and do not identify the teachers. They use a code consisting of letters and numbers. A pre-survey was conducted on Monday of Week 1. The post-survey was conducted on Friday of Week 1. The survey questions were designed to measure the knowledge gained by teachers pertaining to EDP, CAD, capstone experience, and manufacturing processes.

The focus group evaluation was a two-hour meeting between the evaluator and a randomly selected group of 10 teachers out of 23 on the last day of Week 2. The focus group was compiled to gain a broader perspective of the benefits of the PD.

In addition, the evaluator conducted a mid-term evaluation to gauge how much implementation the teachers have done since returning to their schools.

Reporting and Analysis of Evaluation data

While we cannot include all the data we have collected for the 10 days, we provide a meaningful subset in this section. We begin with the formative data. Over the two week CAPSULE PD course, the participants were given a daily reflection (form) to provide feedback to CAPSULE team. Feedback was extremely important due to multiple reasons - some of which included being the first year of the program, what major and minor participant issues and overall what was liked and disliked. The quantitative analysis was founded based on a modified Likert Scale [16]. A Likert Scale is based on a 0 to 4 scale for both rating a response as well as yes and no responses. We use the following scale to evaluate teachers' responses:

SCALE				**MODIFIERS**	
Yes	3	**No Comment**	0	**Positive Comment**	1
No	1	**No Answer**	NA	**Negative Comment**	-1
Neutral	2				
YES / NO OR 50/50 RESPONSES					
Understand	4				
Not Understand	0				

For example, on July 19, 2010, the first question was "Including all the course start-up activities, I have a sense of what the next two week's work will be." The average Likert value was 3.33 indicating that most participants understood the question and answered positively that they understood the expectations.

Unlike the third question, "What is your current understanding of 'Capstone'?" – the average Likert Value was 1.4 indicating that most participant response was incorrect about the definition of Capstone or they didn't understand the question. In this case, the majority stated an incorrect definition of what Capstone is.

Similarly, for the question pertaining to "I still have questions about…" when the scoring was either a 0 or 4. If the average is closer to a zero, the majority of participants had concerning questions or negative feedback. In some cases, all the feedback/questions were negative and the average would be zero.

Figure 4 shows the teachers' responses to Day 1 five questions. All teachers agreed unanimously that the 3-legged chair activity was valuable. The mid-term teacher survey (see next section) further confirms this conclusion. The response to the third question reveals that the teachers were still not clear on what constitutes a capstone experience.

Figure 5 shows the teachers' responses to Day 3 six questions. Teachers struggled with using SolidWorks and have mixed feeling about the value of the industry project. Our further analysis indicates that we need to do a better job teaching teachers about how to use SolidWorks and its importance in the EDP. Similarly, we need to find better and more engaging industry project, something simple but challenging like the 3-legged chair.

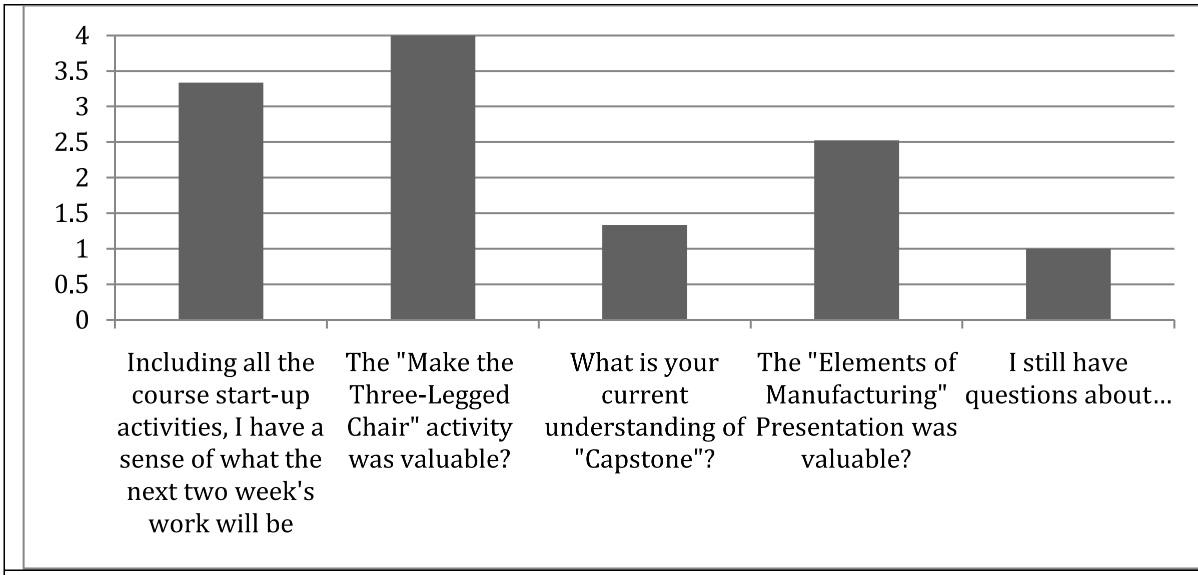


Figure 4 Teachers' reflections on Day 1 of Week 1 Activities

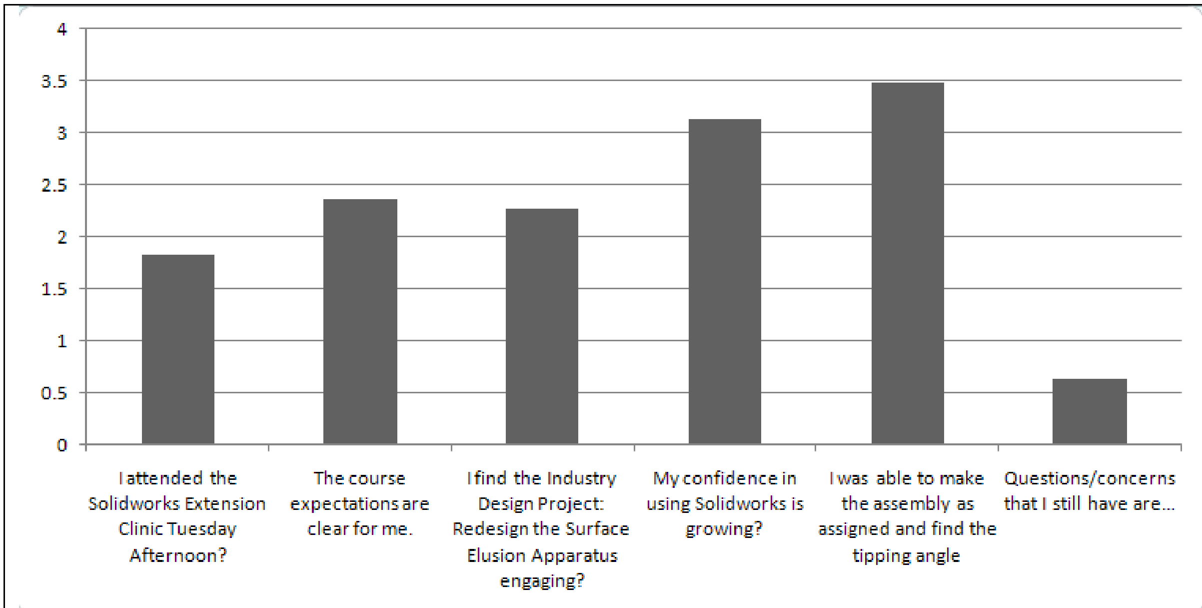


Figure 5 Teachers' reflections on Day 3 of Week 1 Activities

We now turn our attention to the summative evaluation conducted by the project evaluator:

Evaluation Issue	**Results**
Self-Reported Level of Pre-Workshop Experience	▪ 70% reported moderate (%48) to extensive (22%) knowledge of the EDP ▪ 69% reported none (43%) to minimal (%26) experience with CAD ▪ 83% reported none (48%) to minimal (35%) experience with capstone projects 78% reported none (48%) to minimal (30%) experience with manufacturing processes

Benefits of Summer PD	▪ 95% (52% agree and 43% strongly agree) reported that CAPSULE summer course increased their ability to carry out engineering capstone projects that students will find engaging and meaningful ▪ 100% (39% agree and 61% strongly agree) reported that CAPSULE course significantly increased their intention to carry out capstone projects with their students ▪ 43% “Agree” that CAPSULE course increased their ability and intention to utilize CAD in capstone projects with their students ▪ 78% (43% agree and 35% strongly agree) reported that The CAPSULE summer course significantly increased their intention to advocate for changes/improvements to engineering education in my school ▪ 87% (55% agree and 32% strongly agree) reported that The CAPSULE summer course significantly increased their knowledge of excellent engineering course practices that they can use in my classroom 87% (61% agree and 26% strongly agree) reported that The CAPSULE summer course significantly increased their knowledge of Massachusetts technology and engineering education frameworks
Usefulness of Program Components	▪ 100% found it useful to be engaged in capstone-like learning experience ▪ 98% found it useful to develop an action plan ▪ 22% found it not useful to learn SolidWorks software while 30% found it very useful
Pre- and Post-survey	The survey results indicate that there were minimal content knowledge gain in the survey areas: EDP, CAD, capstone projects, and manufacturing processes. These results are contradictory to the results reported above in the Self-Reported Level of Pre-Workshop Experience bullet. This indicates that our pre- and post-survey questions were not designed properly.
Focus group survey	The focus group was conducted in a round-the-table fashion meeting between the evaluator and the selected participants. Here are the two main questions and sample responses ▪ Aspects of course found most valuable: Collaborating with colleagues, Learning SolidWorks, The professional qualities of the participants, The design challenges, EDP, practice of EDP, learning the capstone process, exchanging ideas, Manufacturing modules after class, Mini projects: three legged chair, mechanical grip hand which I can bring back to my class and incorporate, Engineering in a capstone-like experience / presentation, The SolidWorks sessions were valuable but insufficient ▪ Aspects of course that need change: Rethink the SW portion, The SolidWorks part of the course. Need more time and more

	tutorials, I would integrate SolidWorks into both weeks in order to gain more practice, I would shift the focus on SW to more of classroom applications rather than learning complex skills that would be more suited for a semester-long CAD course, The first week should be a more focused mini-capstone experience that still introduced and utilizes CAD as a tool.

Midterm Teacher Survey

As a follow-up, the project evaluator conducted a survey during the middle of the school Fall term to gauge the teachers' progress on implementing their action plans that they conceived during the summer PD. Here are sample responses from the teachers to sample survey questions:

Evaluation Issue	**Results**
Project already started	Half of the teachers already started implementing the capstone experience (capstone project) in their classrooms
Project duration	Some projects last for one week, one month, an entire school term (September to January), or an entire school year (September to June)
Sample capstone projects teachers are doing	▪ 3-legged chair in 4 Geometry classes with total of 80 students ▪ 3-legged chair in 3 Geometry classes with total of 45 students ▪ AP Environmental Science: 35 students; Working in groups of two or three, students will address a specific environmental problem ▪ AP Biology: 25 students; Working in groups of two or three, students will address a current issue in biology ▪ Implementing the capstone in my Game Development class ▪ Solar cookers with special needs students. General Science class ▪ Students will use the Engineering Design process to design a robot ▪ Course is the Principles of Engineering with 45 students. We use SolidWorks in the course ▪ Course: Technology/Engineering: Number of Students: 64 The project begins with studying Ohm's Law, proceed to series and parallel circuit analysis, the students will build an electric motor from a kit, and finally they will generate power by turning the motor into a generator. All activities will be documented in a PowerPoint presentation
Teachers comments	▪ It is good to let students know what you use as the weight to test on the chair. Some students make surface of the chair too small to put on the weight. Also, set a time limit. I took picture while they were working and posted them around the room, students really like to see their picture in the classroom. I know other teacher did the same project, except she use drinking straw instead of stick and it work just fine. Be creative about the materials and just let students have fun with the project. ▪ We are still working on getting Solidworks. That would be a

	problem if I wanted to be done by now. ▪ This year, I am developing a new program in Technology and Engineering. One of the challenges that I am having is converting one off hacker style projects into classroom lessons with repeatable results across the population of students. ▪ Need to reinforce prior learnings with intro of each new lesson and always relate the engineering design process steps when applicable. Students need training in teamwork and project planning ▪ There is another CAPSULE teacher at my school and he has already done the three-legged chair with my math students in his tech class ▪ Went AWESOME. :) It was interesting to see that that the students preferred to not follow the EDP process, their one idea was perfect and does not need adapting at first. Also, though they were able to determine which bridge type was the strongest, they did not apply that information to their design. It is clear that they have very little experience building a strong working team that shares and decides plans together.

Lessons learned

We have gained valuable experience from the first year activities of CAPSULE. We have identified the challenges that we will address next year. These challenges also should help other school districts who might be interested in implementing capstone design projects in their school districts.

- Clarify and explain the meaning of capstone experience on Day 1 or 2 of Week 1
- Redesign the instructions on how to teach teachers SolidWorks CAD software
- Rethink and redesign the industry capstone project to make it more engaging to teachers
- It is challenging for teachers to learn and use CAD software. We need to make sure that their schools support them
- Redesign the pre- and post-survey questions to correctly gauge the true knowledge of teachers and the knowledge gain at the end of the two weeks of PD

Conclusion

As the teachers have indicated in our multiple evaluation instruments, the use of the capstone experience (capstone design projects) in high schools in STEM courses is very valuable. As of the midterm evaluation, half of them are already using capstone projects in their courses ranging from eng/tech, to Geometry, to AP Physics, to AP Biology, etc. Also, a good number of them are using the PD 3-legged chair project. The evaluation of the first year activities have provided us with valuable feedback that we plan to incorporate in our second year PD of the new cohort of teachers.

Acknowledgment

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