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CAPSULE: AN INNOVATIVE CAPSTONE-BASED PEDAGOGICAL APPROACH TO ENGAGE HIGH SCHOOL STUDENTS IN STEM LEARNING

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ABSTRACT

School children in general and high school students, in particular more often than not lose interest in STEM (science, technology, engineering, and math) education. Underrepresented and female students are even more discouraged by STEM courses. Our investigation and interviews with high school teachers cite that the main reason for such disinterest is the disconnect between school and reality. Students cannot relate the abstract concepts they learn in physics, biology, chemistry, or math to their surroundings. This paper discusses a new capstone project-based approach that closes this gap. This work is an outcome of an NSF funded project called CAPSULE (Capstone Unique Learning Experience). We use the top-down pedagogical approach instead of the traditional bottom-up approach. The top-down approach relates the abstract concepts to exciting open-ended capstone projects where students are engaged in designing solutions, like products to solve open-ended problems. This top-down approach is modeled after the college-level capstone design courses. The paper presents the model, its details, and implementation. It also presents the formative and summative evaluation of the model after deploying it in the Boston Public Schools, a system heavily populated by the targeted student groups.

INTRODUCTION

The motivation behind this paper and its related research can be summed up in one question. How can a teacher help and motivate their students to understand the abstract science and math (STEM) concepts? While this question applies to all levels of education (elementary, secondary, or college), this paper focuses on high school teachers and students. High school students, while eager to learn, have difficulty relating abstract concepts in math and science subjects to relevance in their life. High school teachers, alike, while willing to work hard to help their students, always come up short due to lack of innovative ideas to deliver these abstract concepts to their students.

The difficulties in teaching STEM topics are the main reason for the disinterest among high school students to pursue STEM careers, a well-documented problem in the literature [1-4]. The vulnerability of female students in particular in not pursuing STEM career is also well documented [5-7]. Similarly, the lack of teachers' preparation to deliver STEM content to students in an exciting and motivating fashion is also well documented in the literature [8-11].

Realizing the seriousness of this problem, may organizations have committed many resources to solve this important national problem. Government agencies, such as NSF, DOE, NIH, etc., have allocated much needed funding to help solve this problem. Many large corporations and private foundations have been a major driving force also. Moreover, states have joined the effort trying to lead important reforms to re-structure school curricula to emphasize STEM education. The state of Massachusetts is a leader in this effort. Massachusetts Framework always served as a national model [12]. The main idea behind these reforms is to solve the disconnect between STEM abstract concepts and reality by using a variety of engineering based activities such as robotics, design projects, etc.

The engineering design process (EDP) is used in many of these activities. The Massachusetts Framework uses the EDP as part of its requirements as shown later in this paper. The innovative use of the EDP in school learning is a key to student motivation.

Applying the EDP approach to high school teaching will reduce the psychological barriers to women and minorities entering STEM fields. The "vulnerability of female students" comes from their losing interest in STEM careers is due to stereotype threat, biased self-assessments and reduced self-efficacy observed among female and minority students.

The authors have selected the EDP approach (as opposed to other possible approaches) because of its merit over other approaches. The EDP approach offers a collaborative and hands-on learning environment, thus offering a highly attractive and appealing learning atmosphere to both girls and African-American and Hispanic-American minority students. According to the report ”New Formulas for America's Workforce: Girls in Science and Engineering,” girls respond positively to hands-on activities [13]. Girls of all ages like their math and science to be useful and relevant to their everyday lives. Furthermore, girls prefer clubs, communities, and face-to-face interactions to independent study. Research has shown that traditional classroom instruction methods likewise may fail to engage African-American and Hispanic-American students [14]. To a greater degree than their classmates, underrepresented students respond to learning experiences that emphasize oral skills, physical activity, and strong personal relationships [15, 16]. As a result, collaboration, discussion, and active projects in the classroom tend to be more engaging for minority students than work involving independent study and competition [14].

The capstone-based pedagogical approach presented in this paper is a form of the well-known project-based learning (PBL). PBL has been written about extensively in the engineering education literature [17 – 19]. The main benefits of PBL are teamwork, close interaction among team members, and promoting lifelong learning. When students get hooked on to learning, they become lifelong learners, an important trait for maintaining the competitive edge of the United States, and for meeting the ever-changing demands of the workplace and the employers.

The remainder of the paper discusses how the (EDP) framework is applied in high school teaching, and its needs to train teachers to use the EDP process in their classroom. The paper also discusses the required pedagogical tools, how to evaluate the new method of teaching, and how to measure its effectiveness.

TRADITIONAL BOTTOM-UP TEACHING MODEL

Bottom-up teaching approach is the classical model of teaching. Let us call it the “textbook approach”. A physics teacher, for example, uses a physics textbook to teach a topic and assigns end-of-chapter problems to students as homework. Students, in turn, use the textbook as a reference material to study and solve the homework problems. The teacher and students move from one chapter to another. The same model is used to teach all STEM courses including biology, chemistry, and math. Some textbooks do a better job than others in trying to inject real-life applications to the subject matter. However, this material comes across as artificial material lacking the real context that is needed to excite students about the topic they are studying. For example, consider teaching Newton's second law of motion given by this equation:

$$F = ma \qquad (1)$$

The textbook may use the example of a car that is accelerating or decelerating with a certain value a, and asks the students to calculate the inertia force F. While the students are able to use Eq. (1), substitute the given values and calculate F, they never connect with the concept of the inertial force F or its physical meaning.

Had the teacher or the textbook started from a real-life perspective, the students would relate to the abstract concept conveyed by Eq. (1) and truly understand it. All the teacher needs to do is start by asking the students this question: “What happens to you when the car you ride starts or stops?” The teacher then guides the students to the answer that their bodies move backward when the car starts and leans forward (around the waist line in both cases) when the car stops. The teacher then solves the mystery by telling the students what they experience is the inertia force. The teacher may also discuss with the students the effect and value of wearing seat belts.

This example would even be more interesting to the students if the teacher engages the students by questioning the design of a car that is more fuel efficient by applying Eq. (1) using the mass of the car. Now the students are challenged to solve this problem – most likely thinking of their own cars.

INNOVATIVE TOP-DOWN TEACHING MODEL

The above section concludes with the top-down teaching model. The main goal of the model is to connect the abstract STEM concepts to the reality surrounding the students. This serves two purposes. First, the model helps students understand the concepts in a better way that allows them to see the concepts in action, thus minimizing the amount of memorization they have to do. Second, the model should excite the students about STEM careers, thus thinking about applying to colleges to pursue college education and a degree in science, engineering, and technology. The top-down teaching model changes the way students think and the way they look at the world. By connecting STEM concepts to their environment repeatedly, students begin to think how something was designed or how they could modify it to improve upon its functionality.

The EDP is an ideal mechanism to deliver the top-down teaching to school students. It promotes innovation and creativity to solve open-ended problems. When used in conjunction with real-life projects, it provides a motivating learning environment where students thrive to learn and become more engaged. Open-ended problems and the EDP allow students to follow a path that promotes deviation. With the EDP and open-ended problems, two plus two does not always equal four.

While the top-down teaching seems appealing, its implementation in high schools poses many challenges. First, do the teachers have the proper knowledge of the EDP to be able to teach it to their students? Second, if we prepare and train the teachers, how would they implement the EDP into their curriculum? We are all well aware of the crowded curriculum and the specific curriculum the teachers must teach to meet state requirements.

We have thought answers to these questions as part of an NSF-sponsored project. Investigating the second (delivery) question, there exist two approaches: in school or after school. One drawback of an after-school program is that we do not reach all students; it curtains the impact and effectiveness of the model. Thus, we reject this approach, leaving us with the in-school program. The challenging question for this approach is how to use the EDP in the classroom while teaching new STEM concepts to students across all STEM areas?

Investigating this question and after extensive discussions with science departments, including Boston Public Schools (BPS), we identify three possible alternatives: mini projects, capstone projects, or science fair competitions. Each alternative has its pros and cons. Using mini projects allows teachers to weave the EDP into their classroom teaching by developing lesson plans that apply a given STEM concept, during its introduction, to an exciting real-life problem. This alternative would require the teachers to develop an action plan and a lesson plan prior to covering the STEM concept in class. Thus, teachers must plan well in advance if they use this alternative.

Using capstone projects, teachers mimic the well-known college level capstone course. The main drawback of this approach is that it demands a dedicated course to capstone. That also requires creating a new course in the school curriculum, which is a non-trivial task. The science fair competition is a better mechanism to implement capstone projects where students work on the project all year long and compete in the fair with other students from different schools.

After various discussions, we concluded that teachers are free to implement the delivery method that best fits their needs. The common concept among the three methods is the capstone experience that motivates the students' learning and increases their interest in pursuing STEM careers.

COLLEGE CAPSTONE DESIGN COURSE

The familiar college capstone design course is an important requirement of engineering programs. The course provides the graduating seniors with a culminating engineering experience in which they have a chance to apply what they have learned in their college engineering education to solve an open-ended problem. Students work as design teams (typically 4 students per team), select a project, work on it all semester long, and present their projects to a panel of judges. Each team creates a prototype and a poster for presentation. Some teams are able to apply for patents based on their projects. Some projects have industry sponsors, allowing students to work on solving real-life problems. Teams compete for prizes that come with a certificate and monetary reward.

The core of the capstone course is the EDP that guides students' activities during the semester. Figure 1 shows the familiar EDP steps. Students follow this process throughout the semester. Students use their engineering skills. They also use the engineering modeling, analysis, and computational tools at their disposition. The major modeling tool they use is a CAD/CAM system. For analysis, they use MatLab. For computations, they use FEM/FEA software. For prototyping, they use STL files to build prototypes using prototyping machines.

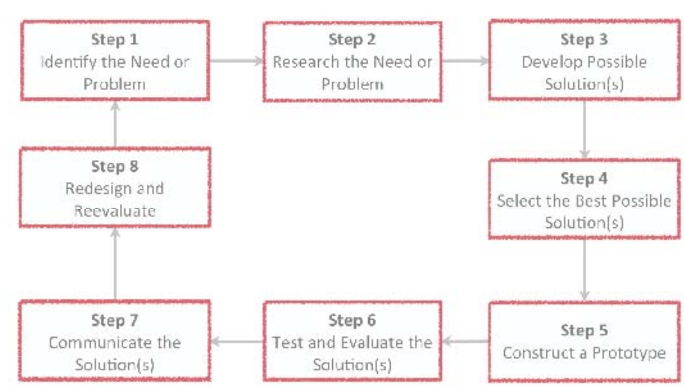


Figure 1 Steps of Engineering Design Process

CAPSTONE EXPERIENCE TEACHING MODEL

The impetus for this model has stemmed from the fact that college students enjoy very much their capstone design course and the experience that comes with it. We have asked the question: "What if we bring this experience and its enjoyment to high school students?" We further investigated the idea by meeting and talking to high school teachers who confirmed that their students need to connect concepts to reality.

However, there are subtle differences between college and the high school models:

A. Capstone project versus capstone experience: a college course uses capstone project while capstone experience may use other forms besides a project. The key similarity between the two is an open-ended challenge that needs to be solved. Thus, high school teachers may engage their students via the three alternatives (mini project, capstone project, or science fair competition).

B. Capstone scope and difficulty: High school capstone experience is more limited in scope and difficulty than college capstone projects.

C. Teachers' preparation: not all high school teachers are qualified or trained to teach the capstone experience. Thus, we have a capacity problem. We need to train teachers to become "semi" engineers. Such training may be done for existing teachers (in-service training) or before they graduate and become certified teachers (pre-service training). In-service training is also known as "train the trainer" model and is done in the form of teacher PD (professional development). Pre-service training is harder to do because it requires changing college curriculum.

D. Available resources: at the college level, engineering departments allocate funds to provide materials and supplies to capstone projects. This is not the case in science departments of cash-strapped high schools, especially in urban school districts where our target students (diversified and underrepresented students) are clustered.

E. Student motivation: college students tend to be more mature and responsible than high school students because of the age difference. The problem is compounded in urban schools where teachers have to deal with high absentee percentage and non-uniform student background. Urban schoolteachers report that a student may change high schools three to four times before graduating. Further, in these underrepresented environments, students are not just students – some support their families, work after school as well as take care of younger siblings.

In the context of the foregoing, a capstone experience teaching model for high schools is not a trivial task of mapping a college experience to high school experience. It requires careful planning and execution as we discuss in the remainder of the paper.

IMPLEMENTING CAPSTONE EXPERIENCE

We have implemented the top-down capstone experience teaching model as a 3-year NSF funded project titled "CAPSULE: CAPStone Unique Learning Experience". The implementation is centered around the EDP as delineated in the Massachusetts Framework [12] and shown in Figure 1. We use the EDP as the basis for teachers' PD and for creating student capstone experiences. Students are guided by the steps of EDP to deliver solutions to their capstone challenges. These solutions are typically documented via reports, prototypes, and presentations (posters, video clips, etc.).

I. Teachers Demographics

Twenty seven teachers were selected from a pool of 46 applicants. Preference was given to BPS teachers (12 out of the final 23 teachers were BPS teachers). In addition, the selected teachers were well diversified (balanced demographics), and provided a good mix of females/males, and a good mix of race/age. Twenty three attended while four could not attend for personal reasons. Thus, 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 (12 teachers) have been certified between three and ten years and the median was six years.

II. Teachers PD

We align our CAPSULE PD for teachers with the Massachusetts engineering/technology curriculum/standards documented in the Massachusetts Framework [12] whose seven areas are: (1) Engineering design; (2) Construction technologies; (3) Energy and power technologies – fluid systems; (4) Energy and power technologies – thermal systems; (5) Energy and power technologies – electrical systems; (6) Communication technologies – electrical wire, optical fiber, air, and space; and (7) Manufacturing technologies. CAPSULE focuses on areas 1 and 7. Table 1 shows the standards within each area. 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 Association), the capstone model is replicable nationally.

The PD for teachers is an intensive two-week workshop that takes place during the last two weeks of July. Teachers attend each day form 8:00 AM to 3:00 PM. Table 2 shows the two-week schedule at a glance. The focus of Week 1 is to enable teachers to experience the EDP and its tools including CAD and open-ended projects.

Table 1. CAPSULE focus areas

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.

In Week 2 teachers focus on designing their own action plans. This enables teachers to blend EDP into their classroom teaching.

The CAPSULE team is well prepared to lead the teachers during the two weeks. The team consists of Northeastern University and The Center for STEM Education, the Boston Museum of Science (MoS), SolidWorks Corporation, and local industry sponsors. Northeastern faculty and students lead Week 1 while MoS leads Week 2. SolidWorks Corporation provides SolidWorks free to participating schools. Local industry provides capstone projects and guest speakers.

Week 1 begins with an ad-hoc design experience for teachers. We give them a design challenge (open-ended problem) and ask them to solve it within the given design constraints. One successful challenge we have used is to design a 3-legged chair that is stable and carry a maximum weight. The idea is to let teachers use their design instincts. Later, we discuss with them what they did and introduce the EDP. Teachers are then given a more challenging capstone project and we ask them to follow the EDP to solve it. Week 1 ends with documenting the design via a presentation and a poster.

Week 2 picks up where teachers left off in Week 1. Their main task is to think of innovative ways to augment their classroom teaching with the EDP and its related concepts. The outcome of their activities during Week 2 is to come up with "action plans". The teachers work in groups but individually at the same time. We group teachers by subject and interest, e.g. chemistry, biology, physics, math, technology. Group members brain storm together, but each teacher develops his/her own action plan. An action plan is different from a lesson plan. The former is a high-level thinking, and the latter is the implementation of the former. Teachers would not have enough time to develop a lesson plan in a week. Lesson plans require a lot longer because of the required level of details. Week 2 ends with presentations of the action plans. Figure 2 shows some of the teachers' activities during the two weeks of PD.

Table 2 Two week PD curriculum

Day	Topic
Week 1: Engineering Design	
1	Capstone Introduced
2	Capstone skills and tools. Use CAD to conceptualize, design, analyze, and prototype
3	Industry Day: Real world design challenge
4	STEM capstone projects
5	STEM capstone projects presentations
Week 2: Curriculum Design	
6	Instructional Design
7	Resource Exploration
8	Research and Design
9	Instructional Research and Design
10	STEM/capstone action plan presentations

III. Classroom Deployment

Teachers are required to implement their action plans in the following academic year. As part of the NSF grant, we provide teachers with funds to help defray the implementation costs. Teachers use the funds to buy materials and supplies, ranging from basic materials to design kits. Teachers have found out that the best implementation mechanism is to use mini projects in their existing courses that they teach. Teachers have reported that they implemented projects in geometry, physics, and technology classes, to name a few. Project ideas include design of a 3-legged chair, mousetrap, catapult, etc.

Teachers have the choice for how long a project lasts. Teachers report periods as short as a week and as long as one semester or a full academic year. Teachers have also mastered the EDP so they use it effectively with their students. One teacher reported that he set his students up to fail early in their designs so that they become familiar with the iterative process of problem solving and master the EDP.

IV. Teachers Callbacks

We hold two callback sessions, one in January and one in April. Each callback session is half a day. The main goal of the callback sessions is both social and technical. The social aspect includes networking among teachers to share experiences and resources. The technical aspect includes teachers' presentations about the implementation of their action plans and their experiences with their students. The timing of the two callbacks allows teachers who implement in the fall or spring (or both) semester to share their experiences.

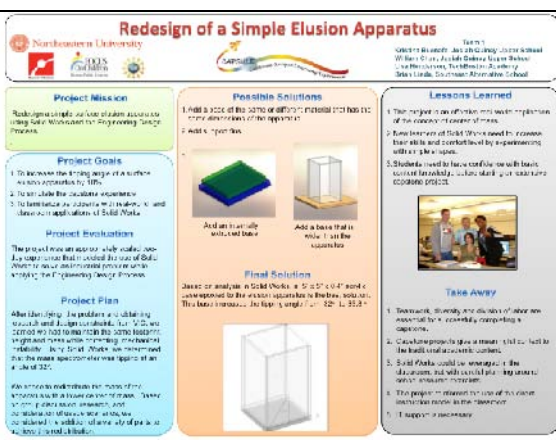
One key concept we emphasize with teachers prior to inviting them to the callbacks is that we are not evaluating them on their student performances, but rather we want to hear their needs and if we can help in any way. Needless to say that we remain in contact with the teachers on individual basis after the summer PD ends. But the callbacks bring all teachers back together as one group.

V. Support System

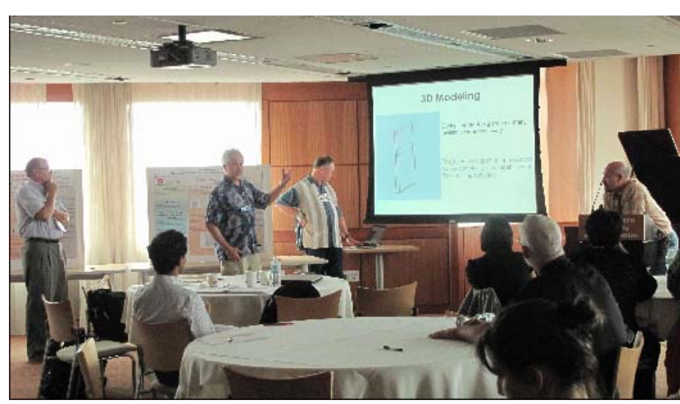
One key concept of working with teachers is to provide them with support after they go back to their classrooms. The support comes from our team, but more importantly from the school administrators. One requirement for teachers to participate in the CAPSULE program is a support letter from their administrators before admitting them to the program. This administrative support as documented by the Guskey model [20] is important to teachers' success after returning to school.

(A) Design of 3-legged chair

(B) Design of a Helping Hand Device



(C) Design Posters



(D) Teachers Presenting Capstone Projects

Figure 2 Sample teachers' activities during the 2-week PD

Our support to teachers includes the callbacks, visits to schools upon a teacher's request, and field trips to Northeastern University's engineering and science labs for school students. As for school visits, our engineering doctoral graduate students visit classrooms in the Boston schools and talk to students face to face about engineering and STEM. As for field trips, Northeastern's Center for STEM offers these trips on regular basis. A trip is half a day activity where students come to our campus in Boston. We give a tour of the campus, some engineering labs, and a free lunch. Students and their teachers enjoy these trips immensely and begin to see what the collegiate experience is like. But more importantly, the day trips present problems and their respective solutions to expose students to college-level STEM experiences.

CAPSULE MODEL EVALUATION

The evaluation of CAPSULE model utilizes many instruments to gauge its success and effectiveness. The evaluation includes both teachers and students. For the teachers, we evaluate and measure the effectiveness of the PD program. For the students, we measure the effectiveness of capstone experience based instruction. We report only on the teachers' evaluations of the PD program in this paper. We do not have students' evaluations yet because we are in the first year of the NSF project. For teachers, we use formative, summative, midterm, and focus group evaluation instruments.

I. Formative Evaluation

We perform this evaluation at the end of each day of the PD. A PD expert from Boston Public Schools designs the evaluation form each day based on observations during the day. Each participating teacher fills the evaluation at the end of the day. The CAPSULE team reviews the forms daily and makes necessary adjustments for the next day. The following are the evaluation questions for the first day of the first week of the PD as an example:

1. Including all the course start-up activities, I have a sense of what the next two week's work will be? Yes/No. Why/Why not?
2. The "Make the Three-Legged Chair" activity was valuable? Yes/No
3. What is your current understanding of "capstone"?
4. The "Elements of Manufacturing" presentation was valuable? Yes/No. Why/Why not?
5. I still have question(s)! I have a question about………..

Figure 3 shows the teachers' answers to the above questions. The Y-axis shows the teacher's answers to the above questions. We have quantified these answers using the Likert scale [21]. All teachers agree that the three-legged chair is a useful activity. Also, many teachers did not have a good grasp of what a capstone experience is and its purpose. The CAPSULE team made adjustments in the next day program to address this gap of understanding. We presented the EDP as shown in Figure 1 and applied to the three-legged chair and emphasized its iterative nature.

As shown in Table 2, we introduced and used CAD/CAM software (SolidWorks) during Days 2 and 3. Teachers' evaluations of their CAD experience was somewhat mixed. After further investigations, we realized that we did not start with basic training and we did not provide the teachers with enough time to do the SolidWorks tutorials under our guidance. We plan to make these adjustments in round 2 of PD. We also plan to limit the number of CAD topics we cover with the teachers to avoid overwhelming them.

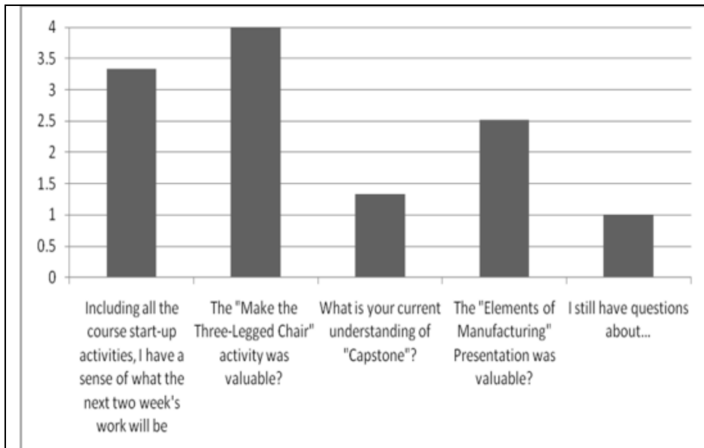


Figure 3 Teachers' evaluation of Day 1 Activities of PD

II. Summative Evaluation

The CAPSULE project has an external evaluator who designs and conducts the remaining evaluation instruments. All these instruments are anonymous, protecting the teacher identity. The evaluator conducts pre- and post-surveys, focus group meetings, and mid-term evaluation. The evaluator uses a code to correlate the two surveys without revealing the teachers' identities. A code may include letters from the teacher's name and numbers from his/her social security number.

The pre- and post-surveys are designed to measure the knowledge gained by teachers as a result of the PD workshop during the two weeks of summer. The surveys focused on four areas: EDP, CAD, capstone experience, and manufacturing processes.

Gains in content knowledge from pre-test to post-test are shown in Tables 3 and 4. The tables also show the statistical analysis of the results of the surveys. Table 3 shows the absolute gains from pre-test to post-test. Table 4 disaggregates the data to the number of teachers who improved, declined or stayed the same. When analyzed using the Wilcoxon signed ranks test, the Capstone Projects score and the Total score show statistically significant increases ($p<.01$), meaning that these gains were unlikely to have occurred by chance, and therefore may be attributable to the course. Gains on the EDP, CAD, and manufacturing process components were not statistically significant.

While some areas did not show statistically significant gains, it is possible that this assessment does not adequately represent the actual learning that took place during the summer course. It is possible that particular topics were covered in the coursework and learned by participants but not measured on the assessment. After reviewing the pre- and post-survey questions, many of the questions could be answered easily by guessing. We plan to review and revise the questions and the assessment to better reflect participant learning.

Table 3 Content gains

Mean Gains on Content Items from Pre-Test to Post-Test			
Test Component	Pre-Score	Post-Score	Gain
Engineering Design Process	1.8	1.8	0.0
Computer-Aided Design	1.4	1.9	0.5
Capstone Projects	2.8	3.4	0.6
Manufacturing Process	1.5	1.8	0.3
Total Score	7.5	8.9	1.4

Table 4 Wilcoxon Signed Ranks

Pre- and Post-Assessment Scores with Wilcoxon Signed Ranks Test Results				
	Improved from Pre to Post	**Same from Pre to Post**	**Declined from Pre to Post**	**Level of Significance (p)**
Engineering Design Process	7 (30%)	8 (35%)	8 (35%)	1.00
Computer-Aided Design	13 (57%)	6 (26%)	4 (17%)	.081
Capstone Projects	12 (52%)	9 (39%)	2 (9%)	*.007***
Manufacturing Process	9 (39%)	9 (39%)	5 (22%)	.176
Total Score	16 (70%)	3 (13%)	4 (17%)	*.004***
*** p<.01*				

III Focus Group Findings

During the focus group session, the participants were asked to discuss their experiences and offer their opinions about the program. The summary of this session is broken down into four parts:

(A) PD components that are most beneficial to classroom teaching: Teachers reported that spending time during Week 2 to develop their actions plans was very valuable. They also felt that the EDP is a great way to implement capstone experiences. Moreover, they appreciated meeting other fellow teachers.

(B) Most challenging or frustrating PD component(s): The main issue here is the SolidWorks CAD software. Teachers reported that not enough time was spent to learn the software, and also the structure and delivery method need to change.

(C) Implementing capstone experiences in classroom teaching: Some teachers expressed concern about their ability to implement capstone in their classroom teaching due to the intensive demand of classroom teaching. But they all vowed to do it.

(D) Amount and type of support that teachers need to implement capstone experiences in their classrooms: Teachers expressed interest in field trips, guest speakers, and video to help them implement quality projects.

IV. Mid-term Evaluation

The evaluator conducted a mid-term evaluation to probe teachers on their progress of implementing CAPSULE in their classroom. The evaluator divided the evaluation into four sections:

(A) Start date: half of the teachers reported that they already started implementing the capstone experience in their classrooms.

(B) Project length: it varies from one week long, to one month, to a full semester, to a full academic year.

(C) Sample projects: use of 3-legged chair in geometry classes with 125 students, discussion of open issues in AP biology class with 25 students, use of SolidWorks™ modeling in "Principles of Engineering" class with 45 students, and construction of electric motors in a technology/engineering class with 64 students.

(D) Other comments: some teachers are implementing fine while other encountered school changes (such as moving from one school to another or teaching new courses) beyond their control that slowed them down.

LESSONS LEARNED

The delivery and evaluation of our first PD workshop have proven very valuable to our team to plan for Year 2 and Year 3 of the NSF 3-year program. In general, what worked is providing the teachers with basic but effective capstone pedagogical material and projects. What did not work are general overviews of topics. We now realize that teachers see little value to non-concrete and specific materials because they cannot use them in the classrooms with their students. Moreover, we have learned the following:

(A) The most effective tools we provide to the teachers are the simple but effective ones. For example, all the teachers have loved the 3-legged chair and have used it in their own classrooms,

(B) We need to change the way we teach and use SolidWorks™ (we plan to cover the basic 3D modeling, and get teachers to complete the SolidWorks tutorials), and

(C) Teachers are highly motivated and willing to use new concepts to help their students in the STEM classes. Over half of the teachers reported that they already implemented a capstone experience in their classroom by the mid-term evaluation.

CONCLUSION

Based on the various evaluation instruments, the use of the capstone experience in high schools in STEM courses is valuable. Teachers have been implementing the capstone experience in their classroom. Some have taken advantage of our field trips. We plan to incorporate the lessons learned from Year 1 into Year 2, and then re-evaluate the Year 2 activities.

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