Training Secondary Math and Science Teachers to Bring an Engineering Perspective to the Classroom

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“Training Secondary Math and Science Teachers to Bring an Engineering Perspective to the Classroom”

Bringing engineering education into the classroom is of particular interest to the state of Ohio since the Ohio Department of Education (ODE) has just created State New Learning Standards for K-12 Science that will be fully in use in Ohio science classrooms by 2014-2015. These new standards place greater emphasis on STEM education as an integrated whole. ODE has developed an ideal curricular framework, called the *“Eye of Integration,”* as shown in **Figure 1**. Science content is juxtaposed with Universal Skills (21st Century Learning Skills) and other content areas: mathematics, English and language arts, and social studies. At the center of this framework are **“real world application: connections to engineering.”**

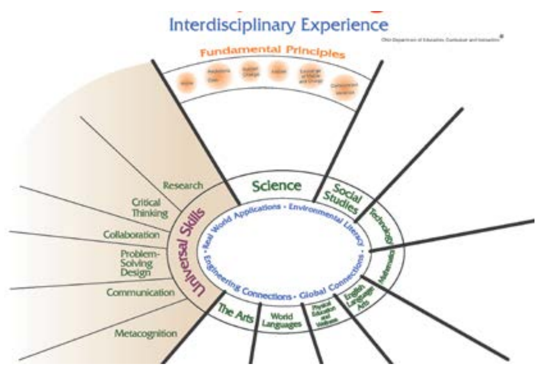

Figure 1: Science Eye of Integration

In addition, on a national level, the Next Generation Science Standards (NGSS) are in the development phase. Engineering design assumes an even greater role in the NGSS, as compared to the Ohio New Learning Standards. In the NGSS, scientific inquiry and engineering design are listed as equally important scientific practices and together form one of the three key dimensions of the new standards. As a Lead State in the NGSS development, Ohio agreed to seriously consider adoption of the new standards.

Despite the emerging focus on engineering design in both state and national standards, most current science teachers are not prepared to bring an engineering perspective to their classrooms.

Meanwhile, Ohio has also adopted the Common Core Standards for Mathematics, which will also be fully implemented in schools by 2014-2015. The new standards are more rigorous than the current state standards as their goal is to better prepare students for post-secondary college and career options. During the development phase, the Common Core Standards were informed by top performing countries around the world to ensure that students could compete in a global economy.

At the high school level, the Common Core Math standards “call on students to *practice applying mathematical ways of thinking to real world issues and challenges.”*[1] Since math is intimately related to both engineering and science, math teachers can use engineering activities as a context to teach rigorous math standards to their students. Like their science counterparts, most math teachers are not prepared to connect math concepts to the real world and even less prepared to connect math content to engineering.

To address the issues described above, the vision of the Cincinnati Engineering Enhanced Math and Science Program (CEEMS), a Targeted Math and Science Partnership (MSP) grant from the National Science Foundation, is to establish a cadre of teachers, some new to the teaching profession and others well-experienced in the classroom, who will implement through teaching and learning, the explicit authentic articulation of engineering in 7th-12th grade math and science classrooms. As a result, CEEMS has developed three pathways to educate in-service and pre-service teachers in engineering content and pedagogy so that they may, in turn, effectively prepare their students to understand engineering design and consider careers in engineering fields:

1. **Masters in Curriculum and Instruction (CI) degree with Engineering Education (MCIEE) specialization:** This pathway provides opportunities for a) pre-service teachers with a degree in math, science, or engineering to obtain an initial Ohio Adolescent to Young Adult (OAYA) teaching license and for b) in-service teachers to obtain a master's degree with an emphasis in engineering education.

2. **Summer Institute for Teachers (SIT):** For two summers, teachers will complete seven weeks of engineering courses, content courses, and professional development to earn a Certificate in Engineering Education. Experienced coaches will follow up and assist the teachers during the academic year to implement engineering design units in their classrooms. This is an opportunity for middle school and high school teachers who are interested in becoming leaders in math and science education by using engineering as a context for guided design- and challenge-based learning.

3. **Education Pathway with Licensure for Engineering (EPLE) majors:** In the College of Engineering and Applied Science, a new ACCEND (Accelerated Engineering Degree) program option will be made available, which offers students the opportunity to complete both a Bachelor's of Science in an engineering major and an OAYA teaching licensure in 5 years.

An essential element enabling simultaneous implementation of all three pathways is the development and deployment of a five-course sequence in engineering content, a three-course science content sequence, and pedagogy that will form the core of the three pathways. Leveraging these eight courses in combination with existing Curriculum and Instruction Masters of Education pedagogical courses, CEEMS develops and deploys two pathways for in-service teachers (MICEE degree and SIT with certificate) and two pathways for pre-service teachers (MICEE degree with licensure, dual undergraduate engineering degree with teaching licensure, and teaching licensure for professionals with a STEM undergraduate degree). All courses are offered during seven weeks in the summer and the program is structured for a participant to complete the MICEE degree or SIT with certificate in two years. The sequence of eight courses (four core and four electives) are:

Core Courses (required):

- *Engineering Foundations*: Students are introduced to the scope of engineering disciplines, basic foundations of engineering science, and engineering design.
- *Applications of Technology:* Students will implement the design process from the need to prototype in an open-ended environment working in teams. Problems are presented that allow students to define, build, and test the solutions.

- *Engineering Applications in Math*: Students are introduced to salient math topics presented within the context of their engineering application reinforced through hands-on laboratory or computer simulation assignments.
- *Models and Applications in Physical Sciences:* Physical science and lab modules are used to understand the importance of modeling and math in discovering principles of physics and chemistry.

Elective Courses (participants choose two):

- *Engineering Models*: Students will connect algebra, trigonometry, and calculus to engineering applications using math fundamental theory.
- *Engineering Energy Systems:* Students learn about thermodynamics, mass, and energy balances to evaluate energy supply systems and their efficiencies, including renewable energy and nanotechnology.
- *Models and Applications in Biological Sciences:* Students will learn biology applications by studying statistics in experimental design, pattern seeking in bioinformatics, and modeling in evolution, ecology, and epidemiology through algebra.
- *Models and Applications in Earth Systems:* Students will learn about the complexity and interaction among natural systems that shape our world.

The remainder of this paper will focus only on the second pathway, the Summer Institute for Teachers (SIT). Soon after the MSP grant was awarded, the University of Cincinnati began planning and recruiting teachers for the first SIT, which was offered in summer 2012. Participation was limited to partner school districts: Cincinnati Public Schools, Norwood City Schools, Oak Hills Local Schools, Princeton City Schools, Winton Woods City Schools, and the nine districts in the Clermont County Consortium.

The entire Summer Institute for Teachers was built around a unified pedagogical approach—engineering design and challenge-based learning. The ability to design, using principles of science and mathematics, is the central element of engineering education. Not only is design-based instruction central to engineering, it can also complement learning in the sciences. For example, in a design-based science curriculum, Fortus and colleagues collected pre- and post-tests to capture changes in science knowledge and evaluated student designs for approximately 100 ninth graders.[2] In this curriculum, students learn science as they design artifacts. Students scored significantly higher on the post-tests. The authors observe that design based science can lead to personal ownership of science and math content as compared to a consensus driven ownership in other forms of inquiry. In a further study, students made gains in science learning that were significant and associated with large effect sizes.[3]

Challenge-based learning is also a key element of SIT's pedagogy. Within a challenge-based learning environment, students learn specific content as they solve engineering problems related to real world problems. Within this context, students are motivated to learn science and math content as they tackle issues of global relevance or societal impact. Not all challenge-based learning involves engineering, but it does serve as an ideal conduit for design challenges. In a three-year study of challenge-based instruction, the success of this approach for learning engineering was demonstrated.[4] Students in the experimental group had statistically higher gains on measures of relevant science tests for most topics, as compared to a control group.

The flowchart in **Figure 2** demonstrates how SIT teachers create curricular units that incorporate both challenge-based learning and engineering design. Within each unit, at least one activity needs to incorporate the engineering design process, as demonstrated in **Figure 3**. An example from one of the units developed by a SIT teacher is presented to illustrate how the pedagogy is interwoven with science and math standards. All units must start with academic content standards. Using the concepts of motion, velocity, and acceleration, a science teacher created a unit around the global problem of transportation, specifically the big idea of designing or re-designing unsafe or inefficient roadways. Essential questions included:

1. Why is the smooth flow of traffic important with minimum waiting time at intersections?
2. What causes accidents in intersections?
3. What are the economic effects of sitting in traffic?
4. What are the economic impacts of accidents?
5. How much time is wasted during rush hour?
6. How much time in your life is wasted waiting in lines?
7. How do poorly designed roadways affect the U.S. economy?

The unit challenge was to choose an inefficient intersection and re-design its geometry and signal light timings to reduce waiting time and enhance safety. The students considered guiding questions such as:

1. How does one graph motion in order to understand velocity and acceleration of vehicles and the relationship between the two?

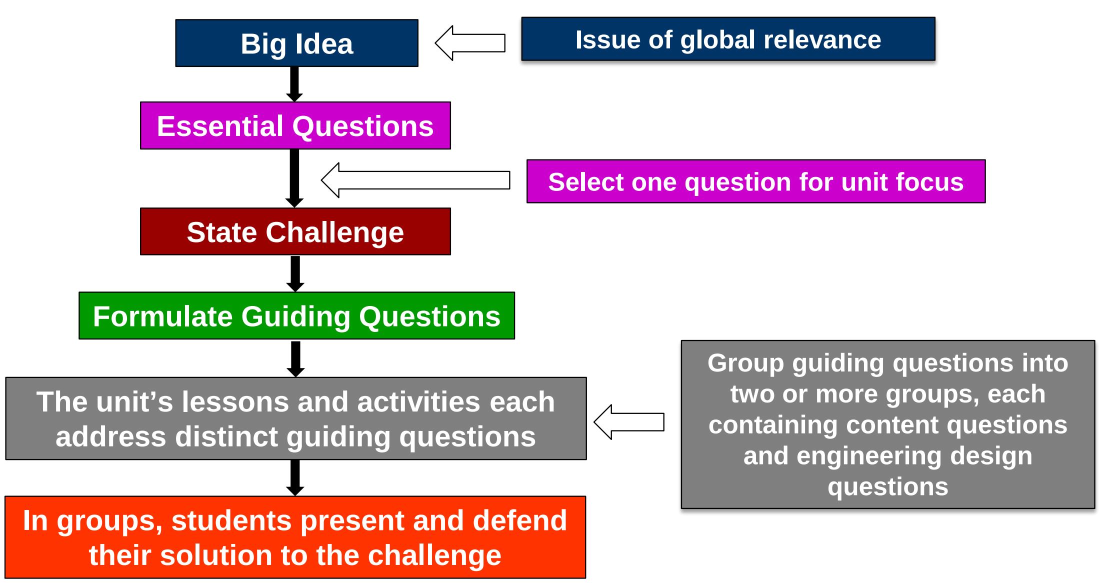

Figure 2: Challenge- and Design-Based Learning SIT Unit

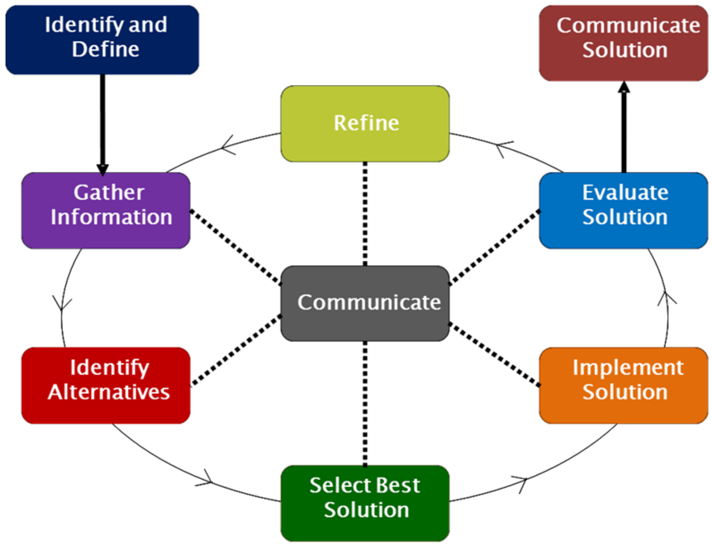

Figure 3: Engineering Design Process

2. How does one calculate reaction time using linear motion formulas, which will help determine drivers' reaction time?
3. How does one calculate stopping distances depending on different vehicle speeds?
4. What is the optimal timing for yellow lights based on reaction time and braking distances?
5. What sites will help one research intersections to determine current problems, such as traffic flow issues, number of lanes, turn lane geometry, and causes for accidents?

A number of hands-on activities helped students answer their guiding questions. Using the engineering design process shown in **Figure 3**, students then worked in groups to re-design a current intersection near their school and present their proposed solution via a class presentation. The design process included collecting on-site traffic data.

In order to aid the teachers in creating innovative units, such as the one described above, the SIT course contents had to be carefully designed to model and teach the engineering design process, science and math content, and the challenge-based learning pedagogy. Thus, it was be imperative for the university faculty designing and teaching the SIT courses to model the same approach. Thus, prior to developing their courses, the university faculty attended four professional development seminars designed to introduce them to the pedagogical approach that serves as the centerpiece for grant, challenge-based learning and engineering design. The seminar series' purpose was to assure that all of the faculty and staff involved with the project were working in concert toward common goals and using a common perspective. The topics for these seminars were: 1) CEEMS Vision, Goals, and Structure; 2) Deconstructing Challenge-Based Learning; 3) Instructional Approaches and Connecting Academic Content to Design Projects; and 4) Sharing Course Plans. The seminars were spread out over three months, February to April, during which the instructors were also developing their course materials. Each of the seminars included activities, discussion, and assignments that helped the instructors to develop their SIT courses. More details of these professional development seminars are presented next in this paper.

The first seminar (February 21, 2012), titled **CEEMS Vision, Goals, and Structure**, facilitated by two of the Principal Investigators of the CEEMS project, began by providing a detailed explanation of challenge-based learning. As shown in **Figure 2**, the challenge based learning process begins with a big idea and cascades to the following: an essential question, a challenge, guiding questions, activities, team projects, determining and articulating the solution, taking action by implementing the solution, reflection, assessment, and presentation. When using this pedagogy, the teacher's primary role shifts from dispensing information to guiding the construction of knowledge by his or her students around initially defined guiding questions. Students refine the problem, develop research questions, investigate the topic, and work out a variety of solutions before finding the most reasonable one. The process demonstrated how the engineering design process, as shown in **Figure 3**, could be incorporated into the solution component of the challenge-based learning model. Seminar participants engaged in a brief design cycle practice exercise in order to better understand the process. They were asked to pair up and given the challenge of designing a free standing prototype of a structure that will prevent a golf ball size object (for example, an egg) dropped from 6 feet from impacting the floor. They were given 10 minutes to complete the task, 2 sheets of 8.5x11 inch paper, 6 inches of tape and a rubber band. The seminar ended by outlining the goals of CEEMS, as indicated in the grant proposal so that the participants would be aware of their role and the project's wider scope which intends to establish a cadre of teachers, both new and experienced, who will implement engineering as a context for teaching and learning math and science in the middle school and high school classrooms.

Two high school teachers led the second seminar (March 6, 2012), **Deconstructing Challenge-Based Learning**. Both teachers teach Foundations of Engineering in their respective high schools and thus they provided an example from their classes of a specific design challenge—building a cardboard chair capable of holding a 200 pound person without using any glue or tape. The teachers outlined for the participants the unit learning goals and the phases of the design project, including the products due at the conclusion of each phase. In the middle of the seminar, one of the teachers led the participants through another smaller design challenge.

The third seminar (March 27, 2012), **Instructional Approaches**, was also led by the same two high school teachers who conducted the second seminar. This seminar covered three topics: 1) organizing students into teams, including how to manage and assess teamwork; 2) assessments in challenge-based units; and 3) connecting academic content to design projects. The teachers shared their guidelines for teamwork, strategies for keeping student teams on-task, and accountability measures for teammates who did not contribute significantly to the group project. Formative and summative assessment strategies for design projects were introduced. In particular, the presenters shared examples of rubrics used to assess different dimensions of the projects. The last topic, connecting academic content to design projects, was included in the third seminar in response to the design team's feedback after the second seminar. While they could clearly see evidence of engineering design in the cardboard chair project, the design team wondered how math and science content was incorporated into that unit in order to enhance student success. As a result, the two high school teachers provided additional examples of other design projects and the science and math standards connected to them.

At the fourth and final seminar (April 10, 2012), **faculty instructors shared plans for their courses**, including what content they planned to cover and their proposed design challenges. The design challenges proposed to be modeled to deliver the course content were discussed and the project team members and other course instructors provided feedback. This seminar also provided an opportunity for the course instructors to fully understand the content planned to be covered in other SIT courses other than their own and to investigate common and connected content topics between courses. The instructors for the courses which shared common and connected content topics met individually to revise their course plans to avoid duplications. In addition, they discussed which pre-requisite knowledge topics participating students would need and determined which courses would introduce those specific pre-requisite topics.

The Evaluator for the CEEMS project collected anonymous evaluation surveys after each seminar to assess the faculty's perceptions of the course development seminars and track the changes in how they viewed and understood challenge-based learning and the engineering design process. Overall, the evaluation results indicate that these workshops met the goal of supporting faculty in their development of the SIT courses, as can be seen from the evaluations results presented in **Tables 1 to 4** for the four seminars respectively. A five-point scale is used in presenting the results in these tables, with 5 being most positive, 3 being a neutral response, and 1 being the most negative.

In addition, the faculty's answers to the open-ended questions in the surveys suggested that their understanding of challenge and design-based learning developed over the course of the seminar series. Examples of faculty definitions of challenged-based learning, by workshop, are presented below.

CBL requires a big idea to act as a framework and also inspiration for studying the context. As you get to the level of guiding questions, activities, and resources, these are taught in context with the challenge. This provides real-world context for the learning. (Workshop 1)

DBL [design based learning within challenged based learning framework] is like a highway map for students. They know where they will start and where they will end. (Workshop 2)

CBL - having students understand a problem, and design something that fits certain criteria to solve the problem, within certain guidelines, learning content in the process. (Workshop 3)

Challenge based learning in my course will have the characteristics of combining scientific knowledge with engineering skills. (Workshop 4)

Table 1: Evaluation Ratings for Seminar 1- CEEMS Vision, Goals, Structure

Item	N	Mean	Standard Deviation
S1-1. Please provide an OVERALL RATING for this seminar.	9	3.56	0.527
S1-2. OVERALL, how would you rate this seminar in helping you understand the CEEMS project?	9	3.89	0.601
S1-3. OVERALL, the information presented will be USEFUL in my development of my CEEMS Summer Institute course.	9	3.78	0.833
S1-4. The seminar's activities helped me understand the materials presented.	9	3.89	0.601
S1-5a. The seminar provided you opportunities to learn about how to integrate challenge based learning into your course.	9	3.44	0.726
S1-5b. The seminar provided you opportunities to learn about visions and goals of CEEMS project.	9	4.11	0.601
S1-5c. The seminar provided you opportunities to learn about secondary teacher grant-related responsibilities.	9	3.44	0.882
S1-5d. The seminar provided you opportunities to learn about CEEMS faculty grant-related responsibilities.	9	3.56	1.014

Table 2: Evaluation Ratings for Seminar 2 - Frameworks for Instruction

Item	N	Mean	Standard Deviation
S2-1. Please provide an OVERALL RATING for this seminar.	6	4.00	1.095
S2-2. OVERALL, how would you rate this seminar in helping you understand the CEEMS project?	6	4.00	0.894
S2-3. OVERALL, the information presented will be USEFUL in my development of my CEEMS Summer Institute course.	6	3.83	0.753
S2-4. The seminar's activities helped me understand the materials presented.	6	4.00	0.632
S2-5a. The seminar provided you opportunities to learn about instructional practices that help students develop challenged based skills and practice.	6	4.17	0.983
S2-5b. The seminar provided you opportunities to learn about the student assessment implications of using challenged based skills and practices.	5	3.40	1.342

Table 3: Evaluation Ratings for Seminar 3 - Instructional Approaches

Item	N	Mean	Standard Deviation
S3-1. Please provide an OVERALL RATING for this seminar.	6	3.83	0.983
S3-2. OVERALL, how would you rate this seminar in helping you understand the CEEMS project?	6	3.83	0.983
S3-3. OVERALL, the information presented will be USEFUL in my development of my CEEMS Summer Institute course.	6	3.67	0.816
S3-4. The seminar's activities helped me understand the materials presented.	5	3.60	1.140
S3-5a. The seminar provided you opportunities to learn about teacher behaviors that help students develop challenged based skills and practices.	6	4.50	.837
S3-5b. The seminar provided you opportunities to learn about the role teamwork has when implementing challenged based learning in the classroom.	6	4.33	1.211
S3-5c. The seminar provided you opportunities to learn about how to incorporate explicit math and science concepts within challenged based learning.	6	3.50	1.378

Based on evaluation data gathered from the teacher participants after taking the SIT courses, some of the faculty were more successful in modeling challenge-based learning and engineering design process in their courses than others, as indicated in the **Table 4**. The scale used to report the mean is: 5 = Very Useful; 4 = Useful; 3 = Neutral; 2 = Useless; and 1 = Very Useless.

Table 4: Usefulness Ratings for Courses within the 2012 SIT

Please indicate **how useful or useless** the following aspects of the CEEMS Project 2012 SIT experience were in helping you create Challenge-Based Learning (CBL) units	N	Mean	Standard Deviation
Overall - Foundations of Engineering Course	16	4.88	0.342
Overall - Engineering Applications in Mathematics Course	16	3.88	0.885
Overall - Models and Applications in Physical Science Course	8	3.25	1.390
Overall - Models and Applications in Earth Systems Course	7	4.86	0.378
Overall - Models and Applications in Biological Sciences Course	2	4.50	0.707
Overall - Engineering Models Course	2	4.50	0.707

The Foundations of Engineering course and the Models and Applications in Earth Systems course were the most highly rated. In both courses, engineering design challenges were the primary focus. In Foundations of Engineering, students were introduced to the different engineering disciplines and learned about the engineering design processes. Design challenges comprised the agenda every day, many of which could easily be replicated in a middle school or high school classroom. In the Earth Systems course, course content focused on discovering the challenging problems earthquakes present for earth scientists and structural engineers. Students built structures and tested them in shake table experiments.

The other courses included a few design challenges, but were still dominated by traditional teaching. As a result, the faculty seminars for 2013 will focus on the following goals:

- Each course will contain a design challenge to help participants understand challenge-based learning.
- The courses' activities and projects will help the participants apply challenge-based learning to their teaching.
- The courses will help participants understand the engineering design process.

In addition to the courses, the SIT participants' summer schedule included time each day to receive support and guidance from the CEEMS Resource Team. The concept for the resource team was borrowed from the Clinical Model in teaching hospitals, where practitioners, clinical professors, and researchers work together to improve services to patients.[5] The Resource Team's role is to monitor and provide assistance for the teachers as they create, implement, and revise their challenge-based, engineering design units. The selection of the Resource Team was completed in April 2012 and currently consists of nine educators and engineers. The four seminars given to the SIT faculty members were videotaped and made available to the Resource Team members along with the handouts.

In May 2012, the CEEMS resource team began meeting weekly to plan the presentations and coaching opportunities they would provide to SIT participants over the summer. In addition to the three courses SIT participants completed in summer 2012, they also enrolled in a one credit hour seminar course. During this seminar course, the Resource Team provided monitoring and assistance as participants developed their challenge-based learning units.

As a result of their extensive planning, the Resource Team developed the following professional development workshops for the SIT participants, all geared to help them prepare their deliverables at the end of the SIT, which included: one complete unit and its associated lessons and activities, a display poster, a short video showcasing the unit, and ideas for the other two units:

1. **Resource Team/SIT Introductions**: This ice breaker activity helped resource team members and SIT participants get to know each other and start to build trust since they will be working closely with one another throughout two summers and academic years.
2. **Challenge-Based Learning in Action:** Participants were introduced to the components of challenge-based learning (CBL) with examples.
3. **Unit Template:** Resource Team members introduced the unit template they developed for participants to use as they create their challenge-based learning units. Units need to be presented uniformly as they will be posted on the CEEMS website for dissemination to non-participating teachers to download and use in their own classrooms.
4. **Academic Standards:** Math teachers received an overview of the common core math standards and science teachers received an overview of the new Ohio New Learning Standards for Science and the Next Generation Science Standards.
5. **Wiki:** During the summer and the academic year implementation phase, participants will post drafts of their challenge-based learning units on Wiki sites for Resource Team

members to review and provide suggestions. A technology survey revealed that many participants have never used Wiki and, as a result, a workshop was developed to teach them to create their own Wikis.

6. **Making Posters Using PowerPoint:** Resource Team members taught the participants how to create a poster using PowerPoint. For each unit they create, the teachers will develop posters about the units to display in their classrooms to serve as a "hook" for the students. In a technology survey, none of the teachers had ever created a poster using PowerPoint.
7. **Video Creation:** The participants will develop short, one to three minute videos previewing each of their CBL units. Just as a trailer to a movie helps one decide whether to view the entire movie, these short videos will be on project dissemination website and serve as summaries of the units for other teachers who may be interested in a particular unit and want to decide if it is worth their time to read the entire unit template. The videos can also be shown to the participating teachers' students prior to the start of the unit. This workshop provided the teachers with tools to create video using free, web-based resources.
8. **Assessments/Rubrics:** Challenge-based learning units require formative and summative assessment strategies that involve more than a multiple choice test. This workshop explored formative assessment strategies and best practices for performance-based assessments.
9. **Misconceptions:** In science classrooms, students often hold misconceptions or preconceived notions that are not scientifically correct. These misconceptions can be hard to change if students have held particular views for a long time. In addition, since people build knowledge on their current understanding, misconceptions can have serious impacts on student learning. This workshop addressed some common science and math misconceptions and strategies for counteracting them.

In addition to the above-mentioned professional development workshops, the teachers also attended a seminar given by a Research Experience for Teachers (RET) high school science teacher on integrating engineering application, career awareness and societal impact in a lesson on Bio-Inspired Flight; a panel discussion session with practicing engineers and scientists; and a seminar on Next Generation Science Standards. The latter two were part of an Administrator's Academy, described later in this paper. The SIT participants also interacted with pre-service student teachers, who were part of the Woodrow Wilson Project, and took some of the SIT courses as part of their degree program. Additionally, the Resource Team offered approximately fifteen 90-minute coaching sessions throughout SIT for participants to report on unit development progress and receive help on all aspects of the unit, including academic content, the design process, and the technology components.

At the end of the Summer Institute for Teachers, participants rated the professional development workshops offered by the Resource Team in terms of usefulness, as well as their overall interactions with the Resource Team. The results of these surveys are presented in **Table 5**. The scale used to report the mean is: 5 = Very Useful; 4 = Useful; 3 = Neutral; 2 = Useless; and 1 = Very Useless.

Table 5: Usefulness Ratings for Different Aspects of the 2012 SIT

Please indicate **how useful or useless** the following aspects of the CEEMS Project 2012 SIT experience were in helping you create Challenge-Based Learning (CBL) units	N	Mean*	Standard Deviation
Overall - Interactions with Resource Team	16	4.44	0.512
Overall - Interactions with Pre-service Teachers	15	3.13	1.30
CBL in Action presentation (July 5)	15	4.27	0.594
Unit Template presentation (July 6)	16	4.44	0.629
Academic Standards presentation (July 9)	16	4.13	0.500
Wiki presentation (July 11)	16	4.44	0.814
RET Teacher presentation (Amy Jameson-Dater, July 11)	16	3.81	0.911
Life of an Engineer poster presentation (July 16)	14	4.29	0.994
Video Creation presentation (July 18)	16	4.63	0.806
Assessments and Rubrics presentation (July 18)	15	3.67	0.900
Misconceptions in Science and Math presentation (July 25)	16	4.13	0.885
Panel discussion with practicing engineers (July 26)	16	4.69	0.479
Exploring Design in the Next Generation Science Standards lunch presentation (July 27)	14	4.29	0.914
Coaching Sessions with Resource Team Members (ongoing)	16	4.56	0.512

In the SIT evaluation, the Resource Team was rated as one of the most useful aspects in terms of helping the teachers create challenge-based learning units (average rating of 4.44 out of 5). In the open-ended section of the evaluation, when asked to describe at least three strengths of the CEEMS project, nine out of sixteen in-service teachers cited the Resource Team. A few sample comments are presented below:

Resource team members/coaching sessions were very helpful.
Resource team members were extremely qualified and knowledgeable.
The coaches! It was awesome to have such a wealth of insight and experience and the ongoing support.
The support was amazing. I am not sure how we would have done this without the resource team.
Resource team members were very helpful in details of projects.

Resource Team support continues throughout the school year. Each teacher has been assigned to two or three resource team coaches. At minimum, an experienced science or math teacher and an engineer are assigned to each teacher. Resource Team coaches observe portions of unit implementation and provide constructive feedback to the teachers. For each teacher some portions of each unit are videotaped, which are streamed and made available to the Resource Team to provide critique to the teachers. Since the engineers never served as educators, they were trained in Reformed Teaching Observation Protocol (RTOP). It should be mentioned that the coaches are not formal evaluators. The feedback is purely for the purpose of improving the implementation of CEEMS units; observation notes are <u>not</u> shared with the teachers' school administrators. In summary for the units implemented by the teachers, the Resource Team members attended selected classroom implementations, observed select videotaped lessons, and met participants during the academic year to implement the process shown in **Figure 4**.

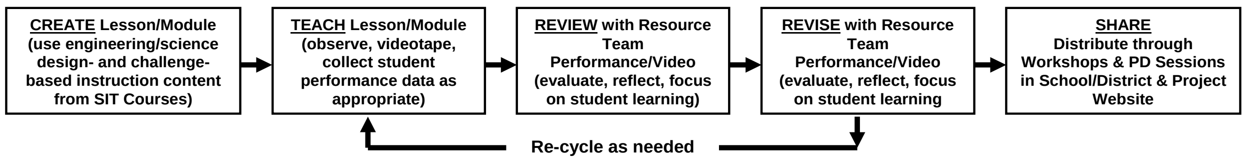

Figure 4: Academic Year Unit One Implementation Process

The coaches are also monitoring the development of subsequent units via the teachers' Wikis and face-to-face meetings. CEEMS' pedagogical methods are new to most of the participants, so they require assistance throughout the process, including brainstorming ideas for new units, incorporating engineering design and introducing career connections, engaging students in the big idea, drafting lesson procedures, creating unit assessment rubrics, and managing group work.

Furthermore, without support from their school administration, the knowledge and skills teachers acquired in the summer will not result in effective implementation. In order for a teacher to participate in the SIT, an administrator, such as the building principal, assistant principal, or department chair from each teacher's building was required to attend a three-day Administrators' Academy to learn about CEEMS and become exposed themselves to the challenge- and engineering design-based learning.

The first Administrators' Academy was held from July 25-27, 2012, which was in the sixth week of the SIT. The overall goal of this academy was to build administrative support both at the school and district level to ensure the successful implementation of CEEMS. The academy introduced administrators to the engineering design process, how it fits in the Ohio New Learning Standards for Science as well as the Next Generation Science Standards, what challenge-based learning and engineering design process looks like in the classroom, and how this will help students become more college and career ready. By asking administrators to participate in some smaller design challenges and reflect on those experiences via large group discussion, they began to understand that the open ended nature of engineering design requires a flexibility (of approach, of timing, of what is demanded of the students) on the part of teachers. Through hands-on experiences and guest speakers, they learned importance of iteration in design, what engineering looks like when done well in the secondary classroom, what materials are involved, and what support CEEMS teachers will need from their administrators.

Most importantly, administrators were exposed to data demonstrating that design-based learning results in greater student academic achievement than traditional teaching methods, especially with underserved minority populations. Dr. Christian Schunn of the University of Pittsburgh addressed the administrators on the first day of the Academy. Dr. Schunn leads a project that is developing and implementing design-based learning (DBL) units for middle school and high school math, science, and technology classrooms. Dr. Schunn shared data from his project that pointed to academic gains resulting from DBL, when compared to control groups of students who learned the same content using traditional teaching methods.

On the second day of the Academy, a panel of practicing engineers and scientists conducted a question and answer session with the teachers and administrators regarding the importance of preparation for and engagement in STEM careers. On the third and final day, Dr. Ramon Lopez, Professor, Department of Physics, University of Texas at Arlington and one of the authors of the Next Generation Science Standards, prepared an interactive workshop for the teachers and administrators about embedding engineering design in middle school and high school science curriculum. He outlined the features of engineering design as: 1) Clearly define the problem and why we want to solve it; 2) Articulate and describe thinking process; 3) Turn ideas into questions; 4) Brainstorm ideas and define constraints; 5) Use science and math content; 6) Go back and refine the design; 6) Prototyping; and 7) Use representations to articulate design.

The Administrators' Academy was well-received by attendees, as noted by the high ratings in the evaluation results presented in **Table 6**. The scale used to report the mean is: 5 = Very Useful; 4 = Useful; 3 = Neutral; 2 = Useless; and 1 = Very Useless.

Table 6: Average Agreement Levels for the Close-ended Evaluation Questions in the Administrators' Academy 2012 Evaluation

Item	N	Mean	Standard Deviation
1. Overall, I understand the purposes and objectives of the CEEMS project.	9	4.78	0.441
2. Overall, the CEEMS Administrator Academy will help me better support the participating teachers in my school or district.	9	4.78	0.441
3. The information was organized so that a logical progression of ideas was presented to participants.	9	4.78	0.441
4. The presentations included in this academy were helpful to my understanding of how CEEMS project fits into science and math education.	9	4.89	0.333
5. The exercises and activities helped me understand the concepts being presented.	9	4.89	0.333
6. I left this academy with a plan of action for CEEMS implementation in my school or district.	7	4.43	0.535

On the final day of the Summer Institute for Teachers, the participants showcased the work. At a morning poster session, participating teachers described their newly created engineering units to pre-service teachers, project staff, resource team members, UC faculty, and community members. In the afternoon, the short video trailers describing the units were shown to the entire audience. A group of industry volunteers provided teachers with feedback regarding their posters, videos, and unit concepts. Overall, based on evaluation results in the **Table 7**, the SIT participants were satisfied with the seven-week summer experience. The scale used to report the mean is: 5 = Very Useful; 4 = Useful; 3 = Neutral; 2 = Useless; and 1 = Very Useless. The average overall satisfaction rating was 4.75 out of 5.

Table 7: Satisfaction Results from 2012 SIT Participants

Please indicate your **level of satisfaction or dissatisfaction** with the following aspects of the CEEMS Project 2012 SIT experience	N	Mean	Standard Deviation
Access to UC Computing Services	16	4.06	1.24
Support to make your CBL unit	16	4.63	0.619
Support to make your poster	16	4.44	0.727
Support to make your movie	16	4.69	0.602
Overall - Experience as a participant in the CEEMS project SIT during this summer	16	4.75	0.447

In the open-ended section of the evaluation, the teachers identified the resource team, learning about challenge-based learning, the integration of engineering concepts, and teacher collaboration as strengths of the SIT. When asked to suggest areas of improvement, the teachers requested better communication of expectations, including CBL into the courses more effectively, and revisiting the participant's total workload and timing of the workload.

Despite the success of the first year, the CEEMS Executive Committee plans to execute changes in 2013 to further improve the Summer Institute for Teachers. SIT meets a growing need for teacher training in engineering and the design process, given the evolving academic standards. SIT graduates will be poised to serve as leaders among their peers in this field.

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