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A Workshop to Aid High School Science Teachers in Developing Engineering Design Activities (Evaluation)

Dr. Kathleen A. Harper, The Ohio State University

Kathleen A. Harper is a senior lecturer in the Department of Engineering Education at The Ohio State University. She received her M. S. in physics and B. S. in electrical engineering and applied physics from Case Western Reserve University, and her Ph. D. in physics from The Ohio State University. She has been on the staff of Ohio State's University Center for the Advancement of Teaching, in addition to teaching in both the physics department and college of engineering. Her research interests address a broad spectrum of educational topics, including teaching of problem solving skills and incorporating research-based methods in K-20 classrooms.

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Background and Rationale

During roughly the last decade, the nation has seen an increased awareness of the importance of incorporating engineering topics in high schools. This has become especially true with the advent of the Next Generation Science Standards (NGSS), which include engineering concepts and practices as part of the framework at all levels of K-12 education.[1] While some schools have chosen to offer specialized engineering courses, this is not possible at all schools. Even where specific engineering courses are an option, students with already full schedules may not be able to devote an entire term to exploring what it means to be an engineer. While it could not take the place of a dedicated course, a more realistic option for schools in those situations might be to incorporate engineering activities into existing science courses.[2] This can strengthen the connections between science and engineering. Additionally, this approach has the benefit of reaching students who may not initially be interested in engineering, potentially opening them up to new possibilities for their futures. However, for meaningful engineering activities to be included in these courses, professional development for science teachers must be offered. The literature describes a variety of teacher workshops that employ several different approaches and foci. The strategy most similar to the one focused on here is one by Custer *et al.*, a recent effort to assist teachers in infusing engineering activities into physical and life science courses. They point out that this particular approach to integration between science and engineering is “largely a new undertaking” with currently a small research base.[3]

The current paper describes the initial offering of an engineering infusion workshop aimed at a particular population of high school physical science teachers, along with some preliminary assessment efforts at the proof-of-concept level. While it is certainly not a new idea to offer professional development in engineering for high school science teachers, this is the first time that such a workshop has been offered specifically linked to the highly successful and flexible Modeling Instruction pedagogy (which will be described in more detail below).[4] Another element that make this approach rather unique is that its primary focus is the infusion - helping teachers adapt existing science activities to incorporate engineering concepts – rather than on replacing science content with engineering or developing stand-alone engineering units. Also, unlike some other approaches, this one uses the application of science content as the basis for engineering, rather than using engineering projects to motivate the learning of science. Finally, unlike many outreach efforts, this program is not connected with particular content areas of engineering, such as nanotechnology or electrical engineering.

Developed through the collaboration of a university physicist and a high school teacher in the late 80’s, the Modeling framework for science instruction has spread to high schools throughout the U. S. and internationally, largely through grass-roots teacher efforts. It is one of only two high school science reform efforts designated as exemplary by the U. S. Department of Education and has reached an estimated 7,500 teachers. Further, the cohesive Modeling community has created their own professional society, the American Modeling Teachers Association, which now boasts upwards of 2,300 members. Since most high school science reform efforts last five years or less,[5] this persistence and organization speak to the approach's potency. The leadership of the Modeling community has identified several priorities for development of additional resources to support classroom teachers, and one of the top needs is for materials and activities to make clear links between the Modeling approach in science and engineering topics.

The Modeling framework takes scientific content and organizes it around core models that the students are guided to develop and deploy. The cycle associated with a particular model consists of two main phases. In the first part, the model development, students are guided (usually through carefully crafted laboratory experiences) to develop concepts and gain familiarity with the associated representations for those concepts. The students become accustomed to referring to their laboratory data as the authority on scientific relationships. In the deployment phase that follows, students apply the model to a variety of situations and test the limits of the model, often through problem solving and sometimes via lab practica. Incorporating engineering applications in the deployment provides the ideal structure for seeing the relationship between fundamental scientific understanding and well-planned engineering.

The Ohio State University has offered a series of Modeling workshops for area chemistry and physics teachers since 2004, reaching almost 370 teachers during that time. For most of the program's history, three concurrent workshops have been offered each summer: one in mechanics, one in introductory chemistry, and an advanced curriculum writing workshop. The curriculum workshop is open to any teacher who has completed an introductory workshop and implemented the Modeling approach. The majority of participants maintain ties after their workshops to the local and national Modeling community via active listservs and, primarily on the local level, special events. Almost one-third of the teachers have taken at least two workshops through the program. Given that the workshops consist of three intense weeks during the summer and three Saturday follow-ups during the school year, this is a true commitment to the profession and to the teaching approach.

In response to the NGSS, the expressed needs of the national Modeling community, and requests from local experienced Modeling teachers, a special pilot of a one-week engineering workshop was made available to previous local participants in the summer of 2015. This was the first workshop anywhere to bring the Modeling framework together with engineering content. Held at a local high school, it was advertised to "help teachers incorporate engineering concepts into their existing Modeling chemistry and physics courses." The formal contact time was 30 hours, and participants had the option of registering for one graduate credit paid for through a state grant. Eleven teachers took the workshop, and all of them had taken at least two previous workshops, including the curriculum writing one. The amount of experience teaching with Modeling ranged from two to eleven years with a mean of 7.5 years.

The expertise of the cohort allowed the instructor to incorporate flexibility into the schedule, allowing participant input as to what sorts of activities they would find most beneficial. Tentative topics for the workshop during the planning phase included an overview of NGSS, basic elements of engineering design, a brief discussion of engineering accreditation, and discussion of additional ways to weave engineering concepts into existing deployment activities. The bulk of the time, though, was planned to be spent developing and testing engineering design activities for use in the participants' classrooms. This focus is in line with Custer et al.'s findings that design concepts are the ones science teachers report being the easiest to incorporate into their existing curricula.[3]

Reasons for Taking the Workshop

As the inaugural workshop offering, it was important to check the alignment between the instructor's goals for the week and those of these experienced participants. This was done via class discussion. The two most common goals were engaging more students and helping students know what engineering is. As one teacher put it, "Many of my best students are trying to decide between careers in medicine and engineering. They know what medicine is, but they really don't have a very clear picture of engineering." Another teacher was quick to add, "**I** don't have a very clear picture of engineering!" These reports are consistent with those reported elsewhere.[6,7] Other goals included getting more real-world applications to incorporate in science classes, and learning more about NGSS. Several teachers articulated a desire to incorporate or improve a project aspect in their courses; at least one teacher each said he or she was looking for guidance in how to create, structure, or assess projects. All of the teachers agreed that these were worthwhile topics to explore during the workshop, and these fit well with the instructor's initial concept of the workshop. One teacher added that he wanted to learn how to incorporate more of the Modeling approach into a Project Lead the Way course.

Other topics that teachers wanted to learn about emerged after a brief introduction to design activity (described below). These included brainstorming, planning, creativity, specifications and requirements, optimization, flexibility, accreditation, using notebooks in engineering, and first-year engineering programs.

Setting the Tone

To get participants into an engineering mindset, after the initial collection of goals, they were given the task to build a paper airplane. Each teacher was given one sheet of 8.5" x 11" paper and told that they could use anything in a box of provided materials. The box contained markers, yarn, scissors, a hole punch, and paper clips. The teachers quickly set to work, but did not ask about what qualities were desired in the airplane. The planes began to take shape, and eventually one asked how the leader would choose the winning airplane. The leader had actually been careful to give minimal direction, and had not even mentioned that a winning airplane would be selected. However, the answer was that the host teacher (not a participant in the workshop) would select the one that she wanted to hang above her desk during the school year to show her students that a group of exceptional science teachers had been there. Still, none of the teachers asked her questions about what she was looking for in the airplane. Some used the markers to decorate their creations, a few attached yarn to them and hung them up, and quite a few tested how well theirs flew. The instructor was perplexed as to why any of them would worry about the flight time, but, as it turned out, the host included it among her criteria and chose several winners.

The point of this activity, which was inspired by an account of a chair design project for first-year students described at an earlier ASEE national meeting,[8] was to emphasize the following points: 1) an engineer needs to communicate with clients and/or supervisors when working on a design to make sure the specifications are well understood 2) assumptions often result in not designing the desired product or process. It also served well to get the teachers into more of an engineering mindset, as this is the activity that prompted the second set of goals described above.

A More Structured Introduction to Design

As a vehicle for introducing a structured engineering design process, the teachers next worked in small groups to perform a variation on the popular spaghetti and marshmallow tower. During this challenge, a graphic representing a general engineering design process was displayed, and the instructor referred to it as she moved the participants through the various phases of design. See Figure 1.

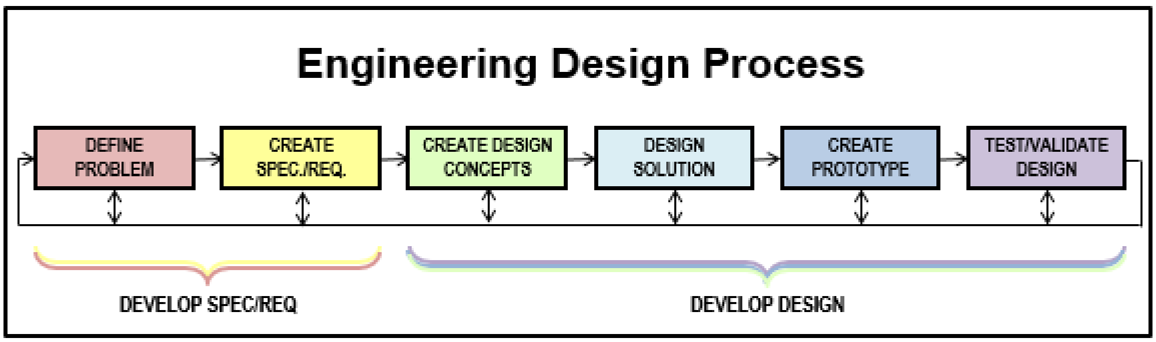

Figure 1. Representation of engineering design used in the course

Participants were provided with a write-up of the challenge and a worksheet packet to fill out as they progressed through the challenge. The packet, based on one used in the University's first-year engineering program, clearly labeled each section of the process and the amount of time teachers were expected to spend on each section. The instructor did her best to prevent people from working ahead. Since the write-up defined the problem, the teachers began with creating specifications. The write-up had been written vaguely on purpose. For instance, it did not specify the criteria for determining the best tower, and the maximum amount of spaghetti and marshmallows permitted were given in grams. Teachers were instructed to generate at least three clarification questions about the challenge. Perhaps due to the priming of the airplane activity, none of the groups had any difficulty generating questions.

After a question-and-answer period, teachers moved to creating design concepts. They were given fifteen minutes for this phase. They were to list at least three criteria for determining the best design and rank them. Then they generated as many ideas as possible for tower construction and selected the best solution. The worksheet instructed them that they must "use the criteria developed earlier to justify your design choice."

Then it was time for the teams to take ten minutes to sketch their design and discuss key features. At this point, they still had received no building materials. Parts five and six of the process were somewhat combined. The materials were finally given to the teams, and they were encouraged to prototype portions of their towers before committing completely to their design and identify modifications to the final tower that they would make based on the prototype. After fifteen minutes, they were encouraged to move on to building the final tower for another fifteen minutes. At the conclusion of judging, participants were asked to describe how their design performed and to describe any modifications that they would make on their next tower.

This activity served several goals: 1) to introduce a structured process for engineering design, 2) to emphasize the importance of planning in design, and 3) to demonstrate the value of a worksheet to strongly encourage students to engage in all phases of the design process.

After some discussion, teachers were given the task to develop an alternative activity (or modify an existing one) to serve as a one- or maybe two-class-period introduction to design that would work with a similar worksheet to guide student thought. The idea was that the task would be independent of detailed scientific content, so that it might be used near the beginning of a course to start conversations about engineering that would weave throughout the term. They created a variety of challenges, including a linguini cantilever, two styles of rafts, a marshmallow launch, an index card structure, and a parachute ping-pong ball drop. Each project contained several variations, giving teachers the flexibility to use different versions in different years, or even multiple versions over the course of a day to prevent "contamination" from morning classes to afternoon ones.

Content-Related Design Projects

While there were readings and brief presentations followed by discussions about some of the less process-based topics of interest (e.g., accreditation, NGSS, first-year programs), the bulk of the time was spent developing and testing design activities to incorporate within the deployment phases of specific curricular units. In particular, participants were encouraged to think about lab practica that might need only slight adjustments to make them involve some key aspects of engineering, such as defining constraints, meeting criteria, optimization, cost-benefit analysis, communication of ideas, and/or iteration.

Participants worked in groups of up to three on these activities, with frequent interaction between groups. Most attempted to tweak an existing activity from one of their courses, while a few developed projects from scratch. All of them modified the handout from the spaghetti tower to encourage students to follow the design process. The activities came from several different content areas in physics, chemistry, and physical science, including conservation of energy, Hooke's law, density, specific heat, optics, and electric circuits. Two of these put a new twist on common egg drop activities. The teachers themselves engaged in aspects of iteration by testing their activities themselves, making modifications, then presenting them to the rest of the participants for additional feedback and improvements. For those who modified activities they had previously used, a common theme was that they changed the presentation of the problem so that the constraints and criteria for success were more explicit features. Two of the groups added cost-benefit analysis to the activity. All included a prompt at the end of the worksheet to start students thinking about future iterations of the design.

At the end of one week, the teachers had developed or adapted a total of seven new introduction to design activities (each with multiple variations possible) and seven new design projects for inclusion in specific science units. All of them were shared with each other through a common electronic storage area.

End-of-Course Evaluation

The responses on the end-of-workshop assessment were very positive. Every participant chose "agree" or "strongly agree" for the statements, "This workshop will help me improve student performance in my classes." And "I have a better understanding of how to use modeling in my classes." The second result is especially impressive, given the expertise this group already had with the methodology.

Additionally, the survey asked about specific areas of science instruction that the workshop aimed to address. The number of participants who chose "agree" or "strongly agree" for each area are shown in the table below.

Table 1. Participants' Reports of Increased Understanding (N=11)

Area of Science Instruction Addressed	#
Effective applications of inquiry-based instruction in classrooms	11
Strategies that can be used to improve students' science performance	11
Effective uses of alternative assessment	11
Strategies for facilitating change in science instruction in my building	10

In the open-ended comments section of the evaluation, teachers identified the following components of the workshop that they found most helpful: example engineering lessons (the airplane and the marshmallow tower), applying engineering design concepts to teaching physics, introducing the design concept on the first day, and having enough time to develop and try out activities. One wrote, "Developing our own activities, and learning from our failures, is a critical aspect….Our peers and instructors are ready to help us figure out better ways to proceed before heading back to our schools." They were pleased to leave the workshop with concrete "plans for….engineering-specific activities [to use] during the course of the year."

They also appreciated the insight through discussions with the instructor of what engineering is like at the college level and learning more about the "type of work engineers do and the practices they use." They felt that this information would help them be a better resource for their students. As one said,

> *The level of detail about college engineering is something I can really take back to my students to help them with career decisions and college choices. I really appreciated the discussion of the design aspect of engineering and the comparison and contrast between science and engineering, and that engineering is about a lot more than math and science. It's important to let students know this early to attract a more diverse population of students.*

And another,

> *Information about the design cycle and characteristics of a good engineer gave me a better understanding of what engineers do. This will help me target a variety of skills when I plan new engineering activities…. I am much better able to discuss educational pathways with my prospective engineering students.*

These positive responses indicate that many of the workshop's goals, both those initially set by the instructor and those articulated by the teachers at the beginning, were met. Teachers learned more about what engineering was and how to incorporate engineering elements into their existing courses. They felt that they could help their students understand more about what engineering was. Most practically, they learned about creating, structuring, and assessing engineering activities in their courses, and they left with specific plans for the next school year.

One area where modifications were suggested was in the area of structure and guidance. The instructor made the decision based on the experience of the cohort to let them take the lead on many of the scheduling and some of the content decisions. Nearly two-thirds of the participants reported, however, that they would have liked more structure from the instructor. This is something that can be modified easily for the next workshop. Another area that could use improvement is in developing activities tied to chemistry content. This feedback was not entirely unexpected, since both the instructor and the majority of the participants had substantially more experience with physics than chemistry. The instructor has already been in touch with chemistry colleagues to try to improve this aspect.

The majority of the participants also indicated that they believed their prior experience with the curriculum writing workshop provided an excellent support for their work in the engineering workshop, to the point where most said they thought the curriculum workshop should be a pre-requisite for the engineering. The current plan for the 2016 workshop is to give priority to applicants who have that experience, but not to require it.

A shortcoming of this evaluation is that it did not specifically assess the teachers' engineering content knowledge, either before or after the workshop. Efforts are already underway to devise a survey for use as a pre- and post-assessment for the second workshop.

School-year Feedback

In early 2016, the instructor e-mailed eight of the participants to seek informal feedback on whether the summer experience had impacted their classes. (One participant was on leave-of-absence, one was teaching social studies instead of science, and another had an assignment out of the classroom.) They were encouraged to share both successes and failures. Of the eight, six responded that they had used design activities and resources from the workshop in their classes during the first half of the year, and the reports were positive. Each of them mentioned a specific activity. Two were of the introduction to design variety, while the other four were incorporated in science units. While not specifically prompted to comment on it, four of the teachers included that they used handouts and/or diagrams from the workshop to good effect. One teacher described the effect of incorporating the design process worksheet into a project she modified from another source:

> *The students did not see the value in drawing the design before creating it. They just wanted to be able to play with the actual materials until they had the design they wanted [but they couldn't]. The students that did follow the steps and draw out their designs had better end results. I gave them a sample of the materials… to test their design before the actual build day. This step went VERY well and most students had to redesign, or improve their design from what they thought they were going to do.*

Many of the teachers went into some detail regarding the engineering elements that were highlighted for their students through the use of these activities. These included planning, considering alternatives, looking at cost benefits, iteration, technical writing, solving true problems (as opposed to exercises), processing failure, and prototyping. One teacher, who had been trying to incorporate engineering into his courses prior to the workshop, said,

> *I felt [during the workshop] I learned how to not only challenge my students with a quick, think-on-your-feet "build it" challenge as I'd done in the past, but make it a true engineering experience. Meaning students had to design a solution, consider alternatives/cost-benefits, redesign with prototypes, and then finally build a working product. This was [a] much more iterative and realistic approach to design challenges.*

One teacher found the experience valuable for her students in giving them a "difficult and frustrating" challenge, stating that it "just shows me that I need to spend more time doing it to increase their ability to problem solve." Another found the design challenges to be the vehicle he had been looking for to incorporate more writing into his curriculum through the "increased writing and justification" he was requiring.

Two of the teachers commented on how the design projects served to highlight specific concepts they were teaching, including comments like, "Many tried to brace their structures but did not have a good upward component of force … to counter the downward force due to gravity. If there were some prototypes built or some post-build discussion maybe more would realize the need for the upward force and be more successful in their final build." and "It was an effective conceptual introduction to collisions and the relation between momentum and impulse, it also did a great job illustrating the relation between time and force during impacts." One teacher reported that all of the other chemistry teachers in her school also used the density column design challenge she had helped create during the summer.

None of the responses described any negative aspects of using ideas from the workshop. However, in true engineering style, five of the responses included ideas for improvements, either of the specific activity, or the next engineering activity planned for the year. Several also included that they were looking forward to sharing their activities with other Modeling teachers at a local conference later in the year.

The shortcoming of this aspect of the initial evaluation is that it was completely self-reported from the teachers. To get a more accurate measure of what is going on in these classrooms, the instructor is going to conduct classroom observations in the period following Advanced Placement examinations; this is when many of the teachers have indicated they are going to engage the students in some extended design projects. Most of the teachers are planning on having the students engage in writing as part of the evaluation process, and this student work will serve as the basis of a qualitative analysis to determine the extent to which the teachers incorporated engineering design elements into these science projects. This data will inform the second offering of the workshop.

Conclusions

The pilot offering of a one-week engineering workshop for experienced Modeling teachers was well received and led to the incorporation of engineering concepts in the participants' courses. The goals of the workshop instructor aligned well with those of the participants, and the end-of-course evaluations indicated that these goals were met. In addition to learning how to structure and assess elements of engineering design, teachers felt that they would now be a better resource to students who might be considering engineering as a career option. Approximately halfway through the school year, at least 75% of the participants who were in the classroom had used resources, activities, and methods from the workshop with their students and reported success. As a proof-of-concept offering, it worked. Feedback from the participants highlighted two major areas for improvement: incorporation of more chemistry content and additional structure/ guidance during the workshop time. Plans are already in place to make these modifications, and the workshop will be offered again in 2016. Tools to assess gains in teacher and student content understanding are in development for use in this second offering. Additional data will be taken in classrooms in the spring, including observations and analysis of student work.

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