ENGINEERING WORKSHOPS FOR K-12 SCHOOLTEACHERS

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Abstract — K-12 teachers’ professional development workshops providing educational content standards-based engineering curriculum are offered every summer at the College of Engineering and Applied Science’s Integrated Teaching and Learning Laboratory on the CU-Boulder campus. A typical four-day workshop format engages teachers in mini-lectures and hands-on demonstrations, and integrates the design/build process. A written curriculum includes inquiry-based experiments to help the teachers be fully prepared to engage their students in active learning. Written feedback evaluations gauge the effectiveness and developmental appropriateness of all workshop materials. Practicing engineers and CU engineering faculty share their expertise with the participants and provide a real-world context for the academic content presented.

Index Terms — engineering outreach, K-12 outreach, K-12 teachers, outreach, K-12 educational content standards and professional development.

INTRODUCTION

The offering of engineering workshops for Colorado K-12 teachers is central to the outreach mission of the Integrated Teaching and Learning (ITL) Laboratory and Program at CU-Boulder. When the university’s ITL Laboratory was designed, K-12 teachers were considered an integral part of the learning community to be accommodated. The development of interactive, standards-based science, mathematics, and technology engineering curriculum and activities for these teachers is key to the outreach program. Teaching materials are piloted and refined in weeklong summer classes for K-12 students, and the most effective of these curriculum modules form the basis for four-day professional development workshops for K-12 teachers.

To jumpstart an outreach initiative, the ITL Program convened an “Outreach Summit” seeking input from educators on the formation of its outreach program goals. The summit included educators from the Colorado Department of Education and several area school districts (including a curriculum director, and a science and math coordinator), several practicing K-12 teachers, the director of a statewide minority science and technology program, and representatives from regional technology corporations. In response, topics for teachers’ pre-engineering workshops were determined and classes were conceived, developed and have been conducted every summer since 1997.

The emphasis of the undergraduate ITL Program in the College of Engineering and Applied Science is on integrating engineering theory with practice in a hands-on, team-based learning environment [1]. In the teachers’ workshops, this fundamental approach is also applied as various engineering subjects are presented in an easy-to-learn style. Workshop topics include kinetics, fluid mechanics, environmental engineering, thermodynamics and heat transfer, and electrical engineering.

Each workshop follows a well-honed model developed during several summers. Teachers engage in mini-lectures and hands-on demonstrations during the morning sessions, learning theory interspersed with hands-on activities (see Figure 1). Teamwork is emphasized in the afternoons when teachers build tabletop devices. This design and build workshop component not only models the engineering process, but also results in each teacher having a self-made device for their classroom use.

ENGINEERING FOR K-12 SCHOOLTEACHERS

We learned from the outreach summit that a strong selling point for any teachers’ workshop would be providing an educational content standards-based curriculum. CU-Boulder’s unique approach is using engineering as a vehicle for K-12 teachers to address many of the math, science and technology state educational standards to which they are required to teach. Teacher participants attend a workshop, observe demonstrations, participate in hands-on activities, and integrate their new understanding and knowledge into their own classroom curriculum. Each workshop activity is
matched to a Colorado state standard. Both math and science standards, from elementary to high school level, are pertinent to the pre-engineering curriculum content [2].

All the teacher workshop activities, demonstrations, and design and build components are analyzed for educational standards content, and then mapped to the appropriate standard. For example, in the Too Hot to Handle workshop, one thermodynamics activity is to design and build a calorimeter to measure energy. The design and construction of the calorimeter fits the Colorado Science Standard #5 relating to technology and resources, while identifying, measuring, calculating, and analyzing energy meets the Colorado Science Standard #2 that relates to matter and energy. Furthermore, the data analysis and calculations fulfill the Math Standard #2 that addresses problem solving and reasoning.

Workshop names are critical for successful marketing. A workshop titled “Engineering Thermodynamics” would interest few K-12 schoolteachers. However, naming it Too Hot to Handle and emphasizing the principles of conservation of energy rather than the 1st law of thermodynamics makes it considerably more palatable to this audience. Other non-intimidating workshop titles include Green by Design for environmental engineering, Shock Your Socks Off for electrical engineering, and Go With the Flow for fluid mechanics.

**TEACHER RECRUITMENT**

We have identified 16 as the ideal enrollment number for a teacher’s workshop. This class size allows for adequate personal attention and divides well into sub-teams of four teachers each. We learned after a summer 1998 workshop, in which 18 teachers participated, that this number is too high. Yet, in summer 1999, three workshops enrolled an average of 12 teachers each — too few participants. In summer 2000, five workshops on four different topics were taught to an average of 15 teachers each — a manageable number.

It has been surprisingly difficult to recruit teachers for the workshops. We have faced a number of obstacles in our recruitment effort:

- The existence of many other local teachers’ programs provides competition.
- Most teachers local to CU-Boulder have plenty of district and school resources, and are highly educated. While many are interested in attending, our impact on their teaching is minimal.
- Local teachers tend not to be as consistent about attendance and commitment to the work asked of them, compared to non-local teachers who seem to value the learning opportunity more.
- Many teachers who might benefit the most from the workshops encounter difficulties commuting to the university workshop and drop out before completion.

Erroneously, we initially assumed that if we presented a high quality workshop, teachers would come. Our first workshop attracted 18 participants, but attendance was sporadic and many teachers did not finish their design/build project. We have since tried a number of enticements to improve recruitment and attendance. The second year, we held a competition for mini-grants for teachers who completed the workshops and offered one continuing education credit. Less than half of the participants applied for the grants, and the paperwork involved in paying the grants was so cumbersome that the process was ineffective and resulted in bad feelings from the participants. The following year, we offered teachers’ stipends. Based on the National Science Foundation’s standard rates, we paid each teacher $250 after successful workshop completion. We defined “successful completion” as attendance on all four days, and completion of the design/build project and all homework assignments. This approach attracted more participants, and most completed the entire workshop. We concluded that stipends are necessary to attract and retain participants. While we initially resisted the idea of stipends because we (egotistically) felt that the opportunity to participate in our workshops was enough of an attraction, we have since realized that our workshops are a form of professional development, and teachers — as professionals — should be compensated for their time.

We are interested in enrolling teachers who would most benefit from and be impacted by the curricula and tools that the workshops provide. Our “target” teachers are those in schools with fewer resources and located at a distance from universities that might provide content resources. While stipends helped with the overall low attendance problem, we still faced difficulties in recruiting our target teachers. To address this, we raised additional funds specifically to pay expenses for teachers attending from outlying areas in Colorado. Now, in addition to a $250 stipend, each K-12 teacher who attends our workshop from a location more than two hours away is provided university dormitory lodging and meals, and reimbursed for mileage. This has changed the mix of teachers who will attend the upcoming summer workshops; now, two thirds of the attendees are from outside the Boulder-Denver region. We have, however, set aside one workshop exclusively for local teachers so that we can continue to offer professional development opportunities to our local K-12 community.

For both strategic and financial reasons, plans for summer 2001 include a reduction in the number of teachers’ workshops offered — to three total, with only one for local teachers. Giving higher priority to reaching teachers in outlying areas has resulted in considerably more costs. Consequently, we decided to offer fewer workshops overall. In addition, the ITL Program is concurrently expanding the participation of other outreach initiatives, such as the Engineering Success Institute for high school students of color, and the facility is at its maximum summer capacity [3].
WORKSHOP FORMAT

Each teacher workshop format is identical: it lasts four days and covers four main concepts within a subject area. A workshop facilitator, usually a graduate student or the ITL Director of Outreach, coordinates the entire workshop including activity set up. Each morning begins with the facilitator’s mini-lecture to introduce the basic theory for the day. This is followed by a pertinent hands-on experiment conducted by an engineering faculty member. After a lunch break, an hour-long seminar covers miscellaneous subjects varying daily (discussed in more detail below). The day concludes with two to three hours devoted to the design/build project, led and coached by a mechanical engineering professor. Table 1 summarizes examples of the various workshop components.

Teaching Non-Boring Theory

Although the workshops emphasize hands-on active learning, some portion of the day is always dedicated to learning the basic theory of the subject area. If this part is neglected, the teachers will learn how to do the activities and experiments, but will not understand why. The mini-lecture is interspersed with brief activities — included in the primer that all teachers take home — that reinforce the theoretical concepts. For example, the first day’s lecture in the *Green by Design* workshop introduces mass balance equations and shows how to use them to measure air quality. The talk incorporates activities such as the “rubber-band air test” and the well-known “cloud in the bottle.” During the next day’s lecture on water quality, teachers learn to take pH measurements. While learning about the greenhouse effect during the third day, activities illustrate solar effects. During the fourth day, reverse engineering is discussed, and the age-old *Paper or plastic?* question is analyzed. Presenting these activities, along with simple hands-on homework assignments, in the lecture portion of the day serves the dual purpose of reinforcing the theory and breaking the monotony of the typical “chalk-and-talk” format.

Faculty Experiments

The hands-on experiments that follow the lectures are important to workshop participants for numerous reasons. After an hour and a half listening to a theoretical lecture that incorporates a number of ugly, intimidating equations (think Navier-Stokes!), it is a relief to witness these equations put into practice. Since a faculty member from one of the various engineering departments conducts this workshop segment, teachers are given the opportunity to interact directly with professors — a chance for K-12 teacher and university professor communication exchange. Feedback indicates that this is a highlight for many teachers: “(a strength of this workshop) was the respect that professors had for my ideas and experience.” Hands-on experiments are also important because they are a lot of fun. For example, as part of the *Green by Design* environmental engineering workshop, teachers sampled water from a nearby river at sites before and beyond a water treatment plant, and used engineering techniques and methods to analyze the data.

Real-World Lunch Speakers

The lunch hour is spent interacting with professionals from the realm of the workshop subject area. Speakers hail from academia, industry and government laboratories. University professors present their research and professional engineers talk about real-life applications. Some of the favorites include: a scientist from the National Center for Atmospheric Research who discusses weather models and how a background in fluids is pertinent to his work; a civil engineering professor whose entertaining talk about his earthquake research “brought the house down”; and a physical scientist from a specialty gas company who related thermodynamics to his job.

<table>
<thead>
<tr>
<th>Workshop Title and Subject</th>
<th>Topics Covered</th>
<th>Sample Activities</th>
<th>Experimental Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetics for Kids Newton’s Laws</td>
<td>Vectors, velocity, acceleration Vertical, horizontal and projectile motion Angular momentum Potential/kinetic energy</td>
<td>Nickel karate; inertia activity Marble launcher Ring and disk; bucket with water Ball machine; track</td>
<td>Bowling Projectile motion from sink Laundry wheel; loop the loop Build a roller coaster</td>
</tr>
<tr>
<td>To Hot to Handle Energy</td>
<td>1st law of thermodynamics Gas laws Phase behavior Heat transfer</td>
<td>Fire syringe Crushed can Ice bomb Conduction activity</td>
<td>Calorimeter Heat engines Refrigerator Radiation module</td>
</tr>
<tr>
<td>Go With the Flow Fluids</td>
<td>Fluid properties Flow rates Immersed bodies Lift and drag</td>
<td>Density rainbow Bernoulli box Card and spool Making airplanes</td>
<td>Viscosity module Hydraulic flume Pressure coefficient Angle of attack</td>
</tr>
<tr>
<td>Green by Design Environment</td>
<td>Air quality Water quality Greenhouse effect Reverse engineering</td>
<td>Cloud in a bottle Cabbage juice Thermometer demo Paper or plastic?</td>
<td>Indoor air quality River water sampling Solar oven Life cycle analysis (LCA)</td>
</tr>
</tbody>
</table>

TABLE 1.

SUMMARY OF TEACHERS’ WORKSHOP TOPICS, ACTIVITIES, EXPERIMENTS AND THE DESIGN/BUILD TAKE-HOME PROJECT.
Early-Afternoon Seminars

The after-lunch, early-afternoon seminar topics vary daily. Monday is spent learning computer basics, including Excel®, PowerPoint®, and the Internet — tools that are used throughout the workshop to analyze data, present results and research topics. On Tuesday, teachers learn about different learning and social styles and how to most effectively teach to the various styles they encounter in their students. On Wednesday, teachers are presented with tools and advice on how to attract girls and foster their interest in math, science and technology. Finally, Thursday’s seminar focuses on grant writing and how to raise classroom funding.

One of the most appreciated seminars explores the challenges encountered regarding gender differences. Teachers break into discussion groups and address the following topics:

- **Communication Differences** — *What observations have you made about the differences between male and female communication patterns? What about the different ways of learning? How do these issues impact students? What can teachers do?*

- **Classroom Participation Differences** — *How do males and females typically differ in their science/math classroom participation styles? In their group or lab work? What suggestions do you have for making participation more equitable?*

- **Language Bias** — *Describe examples of language bias. How does this impact students? What can teachers do to reduce the use of biased language?*

- **Curriculum** — *What forms of gender bias are found in the traditional curriculum? What changes could be made to reduce this bias?*

In the seminar, guidance is offered on how to minimize these differences and biases. Suggested strategies to reduce class participation differences include: rotating roles and responsibilities so all students have opportunities to operate equipment, record notes and present results; monitoring group and class activity, and intervening when males are directing or doing the hands-on work; encouraging students to trade notes to build collaboration and fill knowledge gaps; and watching for non-verbal clues that indicate a readiness to participate.

**Take-Home Design / Build Project**

The bulk of each afternoon is spent learning via a hands-on design/build project. Participant teachers are organized into teams, using pre-workshop information (described in more detail below) to compose groups with a blend of abilities and personalities. A mechanical engineering professor experienced in teaching the design process to untrained undergraduate students leads this workshop component, providing instruction in software such as AutoCAD® and SolidWorks® and offering guidance throughout the week. For most teachers, this is the best part of the workshop: they produce something that they never imagined they could. The design/build phase instills a great amount of confidence in abilities that many doubted they possessed. And, they acquire a new “toy” for classroom use (see Figure 2).

![Teachers show off their Stirling engines, made in the Too Hot to Handle workshop, and ready to take back to their classrooms.](image)

**Take-Home Primer**

In addition to the design/build project, another workshop deliverable is a take-home primer for each teacher. The primer chapters contain:

- Theoretical material (math and science basics),
- In-class student assessment tools for each activity,
- Materials list and instructions for classroom activities,
- Handouts on topics such as grant writing, addressing gender differences, etc., and
- References (articles, Web sites, etc.).

**ASSESSMENT AND PROGRAM EVALUATION**

The ITL Outreach Program believes that continual program evaluation is essential for its ongoing success. This is pervasively true in our evolutionary development of the teachers’ workshops. Our workshop approach is to see that teachers enhance their own math and content knowledge so that they, in turn, increase their students’ knowledge. We use our engineering-based curricula to accomplish this goal. As a byproduct, we hope to educate the teachers and their students about the opportunity and value of engineering as a career. Keeping this in mind, we evaluate our workshops to verify that we meet our goals.

**Pre- and Post-Workshop Surveys**

Program evaluation begins as soon as a teacher signs up for a workshop. Along with a confirmation letter, each teacher is mailed a pre-workshop survey that requests basic demographic data, where and how s/he teaches, information...
on his/her math and science background, and attitudes towards both engineering and the subjects s/he teaches. The survey questions ask teachers to evaluate how well:

- The culture of their school would support new ideas in teaching pre-engineering.
- They have adequate access to computers for teaching science, math, and pre-engineering.
- They enjoy teaching science and/or math.
- Their principal enhances the science and math programs by providing needed materials and equipment.
- They understand the difference between science and engineering.

To assess their attitudes and experiences, teachers are asked to rate a list of statements in terms of each item’s importance for effective science, math and pre-engineering instruction in the grades they teach; indicating how prepared they feel to do each item; and indicating the frequency with which they implement the listed form of instruction. Sample statements include:

- Make connections between science and engineering.
- Have students participate in hands-on learning.
- Engage students in inquiry-oriented activities.
- Write reflections in a notebook or journal.
- Design objects within constraints.
- Work on solving a real-world problem.
- Engage students in open-ended problem solving.

The pre-workshop survey information is used initially to tailor the workshop to teachers’ backgrounds and comfort levels, and form teams for the design/build projects. The surveys also become the baseline to which a post-workshop survey is compared.

Towards understanding the longer-term impact on teachers, a post-workshop survey is mailed to all teacher participants approximately a year later to ascertain the effect of the workshop on teachers’ curriculum, as well as attitudes and practices vis-à-vis science and math. Posing nearly identical questions to those asked in the pre-workshop survey allows for direct comparison. We are currently collecting data to complete a long-term survey.

### End-of-Workshop Feedback Survey

At the end of each workshop, a written evaluation is administered to solicit feedback on the format and content of the workshop itself. This survey asks the teachers to rate whether or not:

- The design of the workshop provided opportunities for them to consider classroom applications of resources, strategies, and their own techniques.
- Pre-engineering, math and science content and classroom instructional materials were appropriate for their professional development and background.
- Appropriate connections were made from engineering to math and science, as well as real-world contexts.

- A climate of respect for their experiences, ideas and contributions was pervasive in the workshop.
- The workshop had a positive impact on their ability to identify and understand important engineering concepts.

### Embedded Assessment

Beyond program evaluation, additional assessment tools are provided for the teachers to use in their classroom in conjunction with activities and experiments to verify learning. The embedded assessment tools [4] provided are valuable for teachers, in theory, but in practice, still require refinements. We suspect that the present form of the tools is too intimidating and unwieldy for easy in-class application. We are working to better present and incorporate the embedded assessment into the workshop materials.

### Lessons Learned

The ITL Program thrives under a continuous improvement model, and what we have learned has shaped the teachers’ workshops. Although at one point we reported that our workshops did not pay stipends [5], we have since become convinced that it is necessary, and reasonable, to offer teachers stipends for this form of professional development. Frankly, we cannot attract enough quality, committed teachers without paying stipends. We have also learned that the supply of our limited local audience has been exhausted, and our impact on instructional practices was minimal in our highly educated and resource-rich locale. This realization has led to our emphasis on engaging and supporting more distant, out-of-town teachers.

A standardized workshop format has evolved through many lessons learned. We found it was better to have four- (rather than five-) day workshops; not only does a four-day workshop better fit into tight summer schedules, but sufficient content is covered in four days and teachers appreciate having the Friday off, especially if traveling a distance. Teachers told us that they valued the discussion group format and networking opportunities, especially when teachers came from different school districts. So, we have altered the format in a number of the early-afternoon seminars to allow for discussion groups. In addition, we found that it was counterproductive when teachers from too great a variance in grade levels participated in the same workshop. Typically, the elementary teachers felt intimidated, and the high school teachers were bored. In response to this, for summer 2001, one workshop will be for elementary teachers only, another one for middle school teachers only, and a third workshop limited to upper middle / high school teachers.

As mentioned earlier, we are still not satisfied with the functionality of the embedded assessment tools. Further refinement is necessary before successful classroom implementation. One thought is to include a workshop session in which we guide each teacher in the creation of
his/her own set of tools for a particular activity, which s/he will, in turn, share with the rest of the workshop participants.

**FUNDING SOURCES**

Our funding model for teachers’ workshops is complex. The workshops are funded by a creative mix of numerous grants, each providing specific support.

A Program of Excellence award from the Colorado Commission on Higher Education (CCHE) provides five years of funding that contributes greatly to meeting the ITL Program’s ambitious outreach goals. This support is the backbone of all components of our K-12 engineering outreach program.

Our university partially supports the workshops through the UCB Outreach Committee, which provides funding to myriad outreach initiatives across campus. The workshops are also partially funded by the Colorado Institute of Technology (CIT), an industry-sponsored organization that supports opportunities for Colorado teachers and students to develop workforce skills in math, science, and technology. CIT seeks to generate interest in technology education and careers, and enhance the technology skill level of students and teachers. CIT funds support teacher stipends and out-of-town teacher expenses.

A September 1999 National Science Foundation (NSF) grant funds fellowships for 10 engineering graduate students to serve as engineering outreach fellows in local K-12 classrooms for three years [6]. These fellows have been essential to the creation of our hands-on activity library; they have developed, tested, taught and documented more than 100 engineering lessons that combine the excitement and challenge of hands-on activities with the state’s educational standard requirements. The fellows also serve as workshop facilitators, seminar instructors, organizers and resources.

**WHAT’S NEXT?**

In addition to the continuing refinement of our current workshops, future plans include the development of new workshops, perhaps one per year. When polled, teachers from the last three years overwhelmingly expressed interest in an electricity and magnetism workshop. Consequently, during summer 2001, Shock Your Socks Off will be presented. Other possible workshops include The Sounds of Music, to address the engineering, physics and math that explains sound, music and instruments; and How Do Things Work?, in which teachers would build motors, and take apart and put together equipment. Other workshop topic candidates include computer science, biomechanics and biotechnology, and civil and architectural engineering.

Over the years, the ITL Program has developed an extensive library of hands-on, portable engineering activities for use by K-16 teachers. Hence, one of our future goals is dissemination. We are currently directing resources to complete the documentation of our engineering activities and disseminate it throughout Colorado via publications, Websites and CD-ROMs. Beyond this, we intend to make the curricula available nationwide as we incorporate other states’ educational standards.

Our long range plan is to use engineering as the vehicle to increase the math and science content knowledge of a broad population of teachers, subsequently increasing the content knowledge and interest of K-12 students by:

- Disseminating our library of standards-based, hands-on activities and design projects to teachers.
- Providing a hands-on, standards-based curriculum for use by science and math teachers nationally.
- Offering varied methods of distribution (i.e., hard copy and CD-ROMs) so that teachers are not dependent upon the Internet for materials.
- Suppling activities that can be scaled up or down, accordingly, for all levels of K-12 students.
- Providing a venue for topical discussion through a question/answer component on our Web site.
- Evaluating consistently and often to incorporate curriculum revisions.

**CONCLUSION**

The primary goal of the teachers’ workshops is to make content resource and knowledge available to the teachers. According to a September 2000 report by the National Commission on Mathematics and Science Teaching for the 21st century, “our students’ performance in mathematics and science is unacceptable.” The ITL Program’s overlying solution matches that proposed by the Commission — to better prepare teachers in the content areas of science and mathematics, so that they may better educate their students.

**REFERENCES**


