

**Teachers Teaching Teachers:
Linking K-12 Engineering Curricula with
Teacher Professional Development**

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Abstract

Teachers are accountable for progressively higher expectations of performance in their classrooms. With the addition of standards-based teaching and performance testing, today's teachers feel the pressure of implementing quality lessons and curricular units in the classroom within strict time constraints. Not only is the number of qualified teachers in short supply, often they are expected to teach subjects outside their area of primary preparation. Teachers in science and technology classrooms, especially at the elementary and middle school levels, regularly report a lack of confidence in their ability to teach those subjects and seek content-specific professional development opportunities to enhance their classroom success.

Supported by National Science Foundation and Department of Education grants, the Integrated Teaching and Learning Program at the University of Colorado at Boulder has worked with K-12 teachers for six years to integrate engineering into their science curricula by offering varied professional development models. Most recently, we explored a model that built upon former workshops and incorporated new ideas. The new workshop format combines the talents of university professors, engineering outreach staff and K-12 teachers, and uses already-developed engineering curricula to support two-day teacher workshops in which teachers teach peer teachers hands-on engineering curricula. Working with university faculty content experts, the teachers use their own pedagogical knowledge to aid their content learning and overcome apprehensions associated with the prospect of teaching engineering in their classrooms.

Comprehensive hands-on K-12 engineering curricular units, comprised of multiple stand-alone lessons, form the backbone of the teacher workshop offerings. Teachers benefit by having a tested set of standards-based curricula to take back into their classrooms, coupled with the confidence of having learned how to teach the content. The university K-12 Engineering Program benefits from observing the lesson plan presentations made by the teachers during the workshop and incorporating the teachers' suggestions to improve the curriculum.

This paper examines the model of teachers teaching each other in professional development workshops offered by a university engineering program. The workshops combine engineering subject matter with teachers' understanding of teaching pedagogy to make a significant impact on their content knowledge and confidence to take engineering back into their K-12 classrooms.

Introduction: Why Train Teachers?

Teachers are bombarded with the latest theories of how students will best learn in their classroom. And yet, a disconnect exists for teachers between what is pedagogically the trend and what can actually be accomplished in the classroom [1]. Often, teacher professional development experiences are deemed "too theoretical" and not practically applied to what actually goes on in the classroom. Investigations indicate that learning experiences, for teachers as well as students, need to be modeled within appropriate contexts. A hands-on, experiential approach offers a valuable, real-life instructional method for learning science, especially when it imitates authentic science practice [2]. This also applies to technological literacy. Unfortunately, too few people actually possess enough hands-on technological experience to render them highly knowledgeable from a technological perspective. Greater technological literacy may be directly influenced by one's academic experiences, especially in elementary and secondary school [3]. In an increasingly technologically-driven world, improved technological literacy is beneficial to society so that all citizens can make informed decisions. Therefore, educators must play an



Teachers brainstorm designs for making airplanes out of straws and construction paper.

enlarged role to be able to effectively transfer technological knowledge to students. Unless a teacher specifically has a background in applying technology to address a myriad of challenges, a cyclical learning problem occurs where teachers are hesitant to capitalize on technology to support the teaching of other subjects, often leaving both students and educators frustrated in trying to achieve greater mastery of those subjects. In order to facilitate technological literacy, an integrated approach to teaching math and science that closely resembles how people learn and work in the real world should be explored.

Through grants provided by the National Science Foundation and Department of Education, the Integrated Teaching and Learning (ITL) Program's K-12 Engineering initiative at the University of Colorado at Boulder (CU) has developed practical *and useful* teacher professional development workshops. Through the use of curricula that integrate math and science in an applied real world fashion, we have created a model for teacher summer workshops that engages the teachers to present engineering lessons to their workshop peers before they take them back into their own classroom. Using comprehensive K-12 engineering curricula that convey science, technology, engineering and math (STEM) concepts through an interesting and hands-on approach, the workshops provide K-12 teachers with the background content to teach engineering in their classroom *with confidence*.

Arming teachers with professional development experiences that provide concrete models for integrating engineering curricula into their classroom instruction provides them with both the tools *and confidence* to promote the technological literacy of their students. Providing students such early exposure to engineering and technology potentially opens up new lifelong pursuits, helping students make informed choices rather than relying on high school guidance counselors or teachers to suggest engineering as an educational path because the student demonstrates strong interest or capability in math and science. Too many of today's undergraduate students entered college with no first-hand knowledge of the creative and societally relevant aspects of engineering. For most, the popular icons associated with engineering serve to deter students from pursuing the field; for our profession, this represents significant lost opportunity.

Overview of Teacher Professional Development Initiative

In response to the growing need for relevant professional development experiences for teachers, the ITL K-12 Engineering Program provides educational opportunities for teachers to engage in hands-on, real-life experiences while learning engineering topics to take back to their classrooms. The development of inquiry- and standards-based science, mathematics, and technology *engineering curricula* for teachers is a central focus of the ITL K-12 Engineering Program. Development of workshops that cover useful topics, are of the "right" duration, address age-appropriate curricula and generate teacher interest is challenging. Teachers are careful about where they invest their summer professional development time; attracting teachers and securing their time commitment is not trivial.

The objective of our summer workshops is to provide teachers with a content-rich opportunity to learn *and practice* innovative hands-on engineering activities designed for integration into their existing K-12 science classroom curricula. In our *Engineering in Everyday Life* workshops, teachers become comfortable with the basic theory underlying different engineering topics and learn how to apply that knowledge in their classroom using standards-based curricula rich in hands-on lessons and activities. By interacting first-hand with engineering faculty and adding depth to their science and math knowledge, teachers leave the workshop with an increased awareness and comfort of the world of engineering, consequently providing them with the foundation to incorporate engineering into their own classroom teaching. Over time, this natural pedagogical transition will hopefully expand the pool of youngsters who themselves imagine a future in engineering and technology.

Our K-12 Engineering Program has offered teacher workshops for the past six summers and has evolved a workshop model to fit the needs of today's teacher. Initially, workshops were offered to teachers of multiple grade levels on general engineering topics. A typical four-day workshop engaged teachers in mini-lectures and hands-on demonstrations, and integrated the design/build process. A written curriculum included inquiry-based experiments to help prepare the teachers to engage their students in active learning. CU engineering faculty shared their expertise with the participants and provided a real-world context for the academic content [4]. For example, in one four-day workshop, teachers explored fundamentals to understand how thermodynamics applies to everyday life. The *Too Hot To Handle* workshop included lectures on how energy is measured, transferred and controlled. Through hands-on activities, teachers discovered how to measure heats of reaction, heat transfer and other experiments that could be easily transported to

their classroom. The workshop culminated with the fabrication of a Stirling engine, allowing teachers to demonstrate power cycles to students.

The four-day workshop format was not sustainable due to teachers' busy summer schedules, too little continuing education credit for the time invested, and the high cost — both in terms of administrative and faculty time — to conduct the workshops. Direct teacher feedback guided many improvements to better accommodate teachers' needs and reduce workshop costs. Consequently, a new workshop format was developed and refined.

Workshop Format

Ideally, teachers should be afforded the time to collaboratively exchange ideas as a part of their normal workday; however, the implementation of this is not a reality — even if it would be beneficially practical [5]. Teachers teaching each other lessons during professional development opportunities allows them such an exchange of knowledge in a safe setting.

In the summer of 2003, a newly developed, two-day workshop model was piloted, with each workshop built around a multi-lesson K-12 engineering curricular unit. CU engineering faculty guide teachers in the exploration of fundamental engineering concepts, preparing them to teach science and math in their own classrooms using practical and fun methods. An engineering professor introduces the multi-week curricular unit by presenting concepts and background information, and conducting sample hands-on experiments. Teachers work in teams and are assigned individual lessons from the unit for in-depth exploration. Teachers quickly bone up on their topic with the provided lesson plans, and present their lesson (with its associated hands-on activities) to the other workshop participants, as if they were presenting it to a class of students.

This intensive immersion process makes the teaching and learning of new material engaging and fun. And, the interaction and feedback from their peer teachers deepens both their understanding and confidence. With the background and resources provided, teachers come to understand how inter-relationships among science, math, engineering, technology and human activity affect the world. A multi-week curriculum unit that maps to state educational content standards and includes applications of math and assessment tools is provided to the teachers to take back to their classrooms. All such curricula will become available online in late 2004 through the *TeachEngineering* digital library collection.

Setting

One aspect of our professional development workshops that appeals to teachers is the opportunity to come to the university and spend time learning away from their classrooms. The teachers in our four-day workshops, for example, constructed hands-on engineering projects that required resources not commonly found in a K-12 school, such as a CNC laser cutter. This was a great new experience for most teachers. However, for teachers that were not local, commuting to the university and paying for accommodations was a deterrent from attending. The newer two-day workshop model is portable, allowing us to still present the material in the favored university setting as well as take it on the road to more remote locations.

By taking a workshop to Colorado's western slope during the pilot summer, we accommodated teachers who do not have access to the abundant array of resources found in larger cities. Although teachers may travel far distances for professional development, bringing such opportunities into reasonable proximity made the workshop highly sought after, causing us to significantly increase the enrollment target. The workshop was enrolled to capacity at 24, with more participants on a wait list. Requiring only a modest \$25 registration fee, this distant workshop afforded rural teachers the same opportunity as our local, metro-Denver teachers.

Staffing

Since 1998, a strength of the summer teacher workshops offered by the ITL Program has been the involvement of CU engineering professors and graduate students. The faculty members eagerly share with teachers their passion and knowledge. During this most recent summer, three engineering professors from different disciplines were supported to lead the teacher workshops. As shown in teacher evaluations, all three professors were highly effective and enthusiastic in delivering their content material. A member of the ITL's K-12 Engineering team with previous K-12 teaching experience also assisted with each workshop. Graduate students helped develop the curricular materials specific to each workshop. Having experienced teachers in the workshops teach and critique the lessons provided a useful approach for curriculum revisions. Additionally, graduate students and staff provided workshop support for the recruitment of teachers and organization of materials. In addition to teacher satisfaction, the experience has proven to be rewarding for the faculty, graduate student assistants, and K-12 Engineering staff, as evidenced by their continued desire to contribute.

Workshop Schedule

Day one of the workshop focused on curricular components of lesson plans and engineering content. In later workshops, teambuilding and engineering design (with reflection on each) were added. Engineering faculty experts helped teachers delve into the curricular content by leading content lectures and hands-on activities related to the topic. Workshops also addressed current trends in assessment, both in classroom and in educational research. Late in day one, teachers split into same-grade level pairs to become familiar with the contents of a specific lesson from the curricular unit.



"Up, Up and Away" participant teachers explore drag, thrust and lift as they relate to flight.

On day two, teacher pairs team-taught their lesson to the other teacher participants, focusing on content and motivation, and demonstrating the hands-on activity. They also modeled appropriate lesson closure and assessment. The other teachers in the workshop served as the "students," participating in the lesson. The faculty experts provided guidance on content accuracy. This approach enhances teacher confidence in the entire curricular unit, as other teachers demonstrate the different curricular lessons to the group. Each team lesson taught is concluded with a short

discussion on “what worked” and new ideas for related activities, suggestions that are then added back into the curriculum. Day two ends with a survey to guide workshop improvement.

Connection to Science and Math Standards

To ensure that the professional development workshops have value for teachers, the workshop curricular content is directly aligned with educational content standards for math, science and, in some cases, literacy. Using *engineering as a vehicle for the integration of math and science*, the curriculum incorporates budget-conscious, hands-on activities into a wide range of science subject areas that are currently taught in Colorado classrooms. Curricular units were originally created by graduate engineering students funded through NSF GK-12 and Department of Education FIPSE grants. Elementary school teachers helped with topic selection, age-appropriateness and classroom usefulness. The curricula were reviewed by engineering faculty and education experts and tested, in collaboration with partner teachers, by graduate and undergraduate engineering students in K-12 classrooms. Math, literacy and assessment specialists also contributed to the lesson plans. Each lesson references specific educational standards as well as well-developed background content, expected student outcomes, hands-on activities, and assessment suggestions and tools [6]. Sample lesson plans can be viewed at: <http://itll.colorado.edu/ITLL/index.cfm?fuseaction=SampleK-12LessonPlan>.

Summer 2003 Pilot Courses

The following three workshops were successfully piloted in summer 2003:

- *Up, Up and Away* — Taught by an aerospace engineering professor, 20 upper elementary teacher participants (80% women) explored the underlying concepts of aerodynamics. Through hands-on activities, they acquired a real-world understanding of weight, drag, lift, thrust and air pressure, as well as Bernoulli’s principle. Discussions explored the effects of airplanes on society and the future of flight. K-12 content covered includes the predictable ways in which matter is affected by external forces and the laws that define the interactions of matter and energy.
- *Mechanics Mania* — Conducted in Grand Junction, Colorado, this workshop engaged 24 grade 3-5 teachers (71% women) from Colorado’s western slope schools. Guided by a mechanical engineering professor, teachers came to appreciate the importance of understanding mechanics in solving everyday problems. Teachers explored Newton’s laws of motion and applied them to real world situations. Hands-on activities made the concepts of friction, rotational motion, simple machines and structures come to life. Content included the forces of gravity and friction and the factors that cause change on matter, such as kinetic and potential energy.



Teachers work together to solve an engineering challenge.

- *Air Pollution Solution* — An environmental engineering professor introduced environmental engineering concepts to 14 grade 3-5 teachers (86% women). They explored the air cycle, greenhouse effect, air pressure and weather to better understand air pollution and its clean-up. Content included the measurement of weather and its effects on humans and the effects of air pollution on the environment.

Program Logistics

We have learned — through previous summer classes/workshops — that a modest registration fee discourages participants from last minute cancellations. Although our teacher workshops are tuition-free, teachers pay a non-refundable \$25 registration fee to secure their space in the workshop. This modest monetary investment generally suffices to ensure teachers' time commitment.

In return for completing the two-day, 15-hour workshop, teachers are provided with a \$125 stipend and also receive a take-home notebook with the fully documented curriculum used during the workshop. Teachers who wish to receive the one-hour CU continuing education credit — often necessary for their professional advancement — pay a \$45 fee.

Teacher Recruitment

Over the past six years, we have learned that the recruitment of teachers for summer professional development requires persistence and a firm registration policy. Although we list our workshop offerings on both our program website (<http://itll.colorado.edu>) and the university's community affair's website (<http://www.colorado.edu/cu4k12>), as well as mail brochures to all past participants, we strive to reach a broader audience of teachers who are interesting in using engineering as the vehicle for math and science learning.

In order to effectively recruit teachers from schools other than those in our own backyard, it is necessary to obtain access to the most apposite teachers; i.e., those who wish to supplement their science teaching with standards-mapped curriculum that has an engineering focus. We found that the endorsement of the Colorado Department of Education was invaluable. Upon their approval, our workshops were listed on their website, which helped us recruit participants from other districts. As a result of these recruiting techniques, our summer 2003 workshops were enrolled with engaged teachers from 31 schools in 11 different school districts.

Assessment and Evaluation

For each of the three summer 2003 workshops, an assessment survey solicited participant ratings of the course components and instruction, open-ended opinionnaire questions, and pre-/post-content quizzes covering the course material. Participants rated course components highly with a 4.48 (out of 5) average rating across all workshops (see Table 1). The highest ratings went to workshop instructors, who received an effectiveness rating that averaged 4.71 (out of 5) across workshops. Average overall ratings increased over the three workshops as changes were made in the delivery of content. Participant content scores indicated significant increases (+27%, +26%,

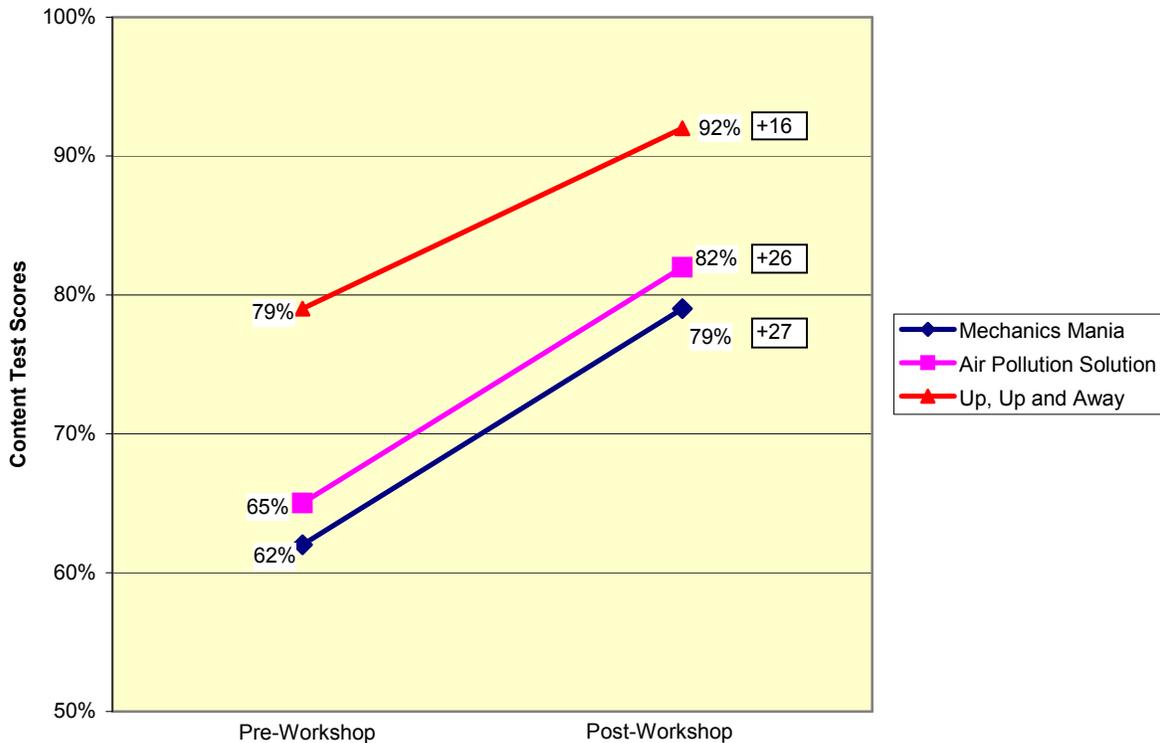
+16%, respectively) in teachers' understanding of course concepts after the two-day workshop (see Figure 1).

Table 1. Course Component Ratings

Component	Workshop Name		
	<i>Up, Up and Away</i>	<i>Mechanics Mania</i>	<i>Air Pollution Solution</i>
Instructor	4.48	4.83	4.81
Instruction	4.44	4.73	4.73
Content	4.16	4.50	4.52
Applications	4.19	4.35	4.41
Outcomes	4.16	4.33	4.56
Average Scores	4.29	4.55	4.61

Rating 1-5 (5 = High Rating)

Figure 1. Workshop Content Scores



In response to the open-ended question regarding what participants liked best about the workshop, the most frequently cited items were the hands-on activities, curricular content and instruction. One teacher wrote, “I appreciate the interactive / hands-on nature of the workshop, rather than being lectured at.” Other comments included, “Wonderful background knowledge...” and “The instructors were always pleasant, knowledgeable and helpful at all times.”

Longitudinal Assessment

It is difficult to obtain long-term data due to a poor response rate; however, we are interested in assessing if what teachers learn in summer workshops remains applicable to their teaching after a year has passed. Assessment data were collected from teacher participants before the workshop and *one-year after* the workshop was taken. Unfortunately, surveys mailed to teachers one year after the workshop were seldom returned.

In previous years, assessment data measured the teachers' perceptions of the importance, preparation and frequency of application of 16 teaching strategies for the use of engineering content in the classroom. Assessment results indicated the strongest findings in the area of preparation, with 12 of 16 strategies showing a significant increase on the post-workshop survey. The largest gains were for participants' preparation to develop students' conceptual understanding of engineering (62% gain) and use of mathematics as a tool in problem solving (39% gain). In addition, there were significant increases in the area of frequency in applying teaching strategies in the classroom with 6 of 16 categories demonstrating a significant increase.

To measure the effectiveness of the 2003 teacher workshops, surveys — with the added incentive of a completion award to encourage their prompt return — were mailed to all participants requesting their feedback on the in-class use and applicability of the knowledge and skills they gained from their involvement with the engineering curriculum-based professional development. Although data are not yet available from that assessment, we know that initial response to the workshop was positive, as many teachers have contacted us asking for additional units to use in their classroom (other than what they received through the workshop). The teacher participants have also informed us via email that they've been "...bragging so much to other teachers what a good class you all put on" and "...I just wanted to let you know that I am currently using the Up, Up and Away curriculum with my sixth graders...It has been great! The kids are loving it, and so am I!"

Sustainability

Teacher professional development is key to a sustainable K-12 engineering education program, and teacher buy-in is essential for integrating engineering into K-12 education. The curricula used for the two-day summer teacher workshops are concurrently being developed for inclusion in the National Science Digital Library (NSDL) web-based *TeachEngineering* collection, scheduled to go online in late 2004 to increase accessibility for all teachers.

Dissemination of K-12 engineering curricula via the Internet provides a resource for educators world wide — both K-12 and university level — seeking tools for integrating engineering into their science and math classroom. The *TeachEngineering* collection, a web-enabled and standards-based collection of K-12 engineering lessons and hands-on activities, is under development through a collaboration between the University of Colorado at Boulder, Worcester Polytechnic Institute, Colorado School of Mines, Duke University, Oregon State University and the American Society of Engineering Education. The *TeachEngineering* team has developed a template for curricular contributions, specifying that curricula be aligned with national and state educational standards and include quality-control criteria to ensure cost-effective and teacher-

friendly lessons and activities that assimilate science, math and technology concepts through hands-on engineering exploration. The *TeachEngineering* collection will allow educators access to a growing curricular collection, evolving and maintained under the stewardship of the American Society for Engineering Education [7]. For additional information, visit: <http://www.itll.colorado.edu/TeachEngineering>.

K-12 Engineering Workshops for Teachers — Lessons learned

Historically, the length of our teacher workshops was four days for one hour of CU continuing education credit. Through a teacher focus group, we learned that the preferred workshop length was a two-day, 15-hour workshop. Overall, the current workshop model appeared to be favored by teachers and ran more smoothly than our previous designs. The off-campus location was fully enrolled, with teachers requesting more offerings in locations distant from the university in future summers. And, the two-day length was well received by the teachers.

This year's revamping of the format and duration of our teacher professional development workshops using a "*teachers teaching teachers*" model was successful. Built upon the standards-based engineering curriculum created for the *TeachEngineering* digital library, the format of teachers presenting portions of a curricular unit to an audience of their peers was initially received with some trepidation, but wound up being highly motivating and beneficial for teachers. They liked the hands-on nature of the activities, the in-depth background content, and the accessibility and expertise of the instructors, but admitted that they still were a little intimidated by the engineering concepts and requested more workshop time to solidify their confidence in the content. Comments from teacher feedback included, "Pick a few lessons to do, maybe five, all (ten) is too much, and have more time on solidifying concepts" and "Put it more on a level of understanding for those with little or no engineering background." Responding to such teacher feedback, we adapted succeeding workshops by more thoroughly summarizing content and increasing the real-world application of the theory. Also, we added a discussion on the engineering design process to help teachers distinguish between science and engineering. An added lunchtime discussion on "cool new topics" in the content area, led by the engineering professor, was met with appreciation.

Overall, the workshops garnered positive feedback. Teachers valued the informal, yet professional, learning atmosphere created at both sites. Also, knowing that they are an integral part of a curriculum development initiative that will be nationally unveiled within the year was exciting and motivating for teachers. In fact, at the end of the workshop, teachers were asked to sign up for curriculum review user groups and to assist with literacy additions, and we had an overwhelming response by teachers eager to stay involved in the K-12 engineering curriculum project. Furthermore, many teachers emailed the outreach staff throughout the months following the workshops asking for other curriculum being developed by the ITL K-12 Engineering initiative — another indication that the workshops were helpful. Teachers also suggested topics they wish to see offered in the same workshop format for summer 2004. Suggestions for future workshops also includes incorporation of teambuilding activities, and splitting the content lecture and lesson plan delivery, focusing on the first half of the lessons on the first day and the latter half on day two.

An effective marketing strategy is imperative for any type of workshop, especially those that occur during the summer when teachers typically unwind from their demanding academic year. By offering teacher workshops in high-demand areas (which, in our case, are not conveniently located near the university), advertising standards-based workshop content and availability through the state Department of Education website (coupled with mailings and organizational website listings), charging a reasonable registration fee to enhance commitment, and offering a modest participation stipend, K-12 engineering workshops can be quite successfully marketed and well enrolled.

Conclusion

By providing teachers with the tools and understanding to deepen their science and math content knowledge and to anchor that knowledge with relevant real world applications, teachers are better positioned to help improve the technological literacy of our nation's students. Teachers and students who are comfortable with *engineering as a vehicle for the integration of science and math* will ultimately contribute more to a world that is becoming increasingly driven by technological innovations. The teaching of K-12 engineering promotes both basic and technological literacy of our general populace, and opens students' eyes to the possibilities provided by engineering and technology careers. Toward that end, the ITL K-12 Engineering initiative continues to hone the teacher workshop model to prepare teachers to eagerly take engineering back to their classrooms.

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