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# Graduate Student Personal Experiences: Improving Collegiate Teaching through K-12 Outreach

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## Abstract

In 1995, the National Science Foundation published recommendations for Systemic Engineering Education Reform.[1] Almost a decade later, the engineering education community still strives to meet the long-term challenges that were set forth by the NSF Engineering Directorate. The goal still remains to educate graduating engineers to:

- Understand the functional core of the engineering process,
- Analyze and synthesize engineering problems,
- Become proficient working in teams,
- Think across disciplines, and
- Communicate ideas effectively to diverse groups.

One of the key actions for sustaining such cultural changes is to train future engineering faculty to realize this new engineering education paradigm.

Supported by National Science Foundation and U.S. Department of Education grants, the Integrated Teaching and Learning (ITL) Program's outreach initiative has engaged engineering graduate and undergraduate Fellows in K-12 classrooms as science and math content experts and engineering role models for the past six years. One program goal is to improve the communication and instructional skills of engineering students, while providing them with classroom experience that serves as a foundation for those who pursue a career in academia. The program also seeks to enhance the graduate Fellow's engineering education experience by improving their ability to teach to diverse populations. In addition, their fellowship affords them an opportunity to understand and appreciate the interdisciplinary nature of their engineering specialty. Engineering Fellows also act as service-learning leaders for the college, and it is hoped that they continue their passion for outreach and teaching into their future careers.

In this paper, we explore the experiences of two graduate students who participated in the ITL Program's K-12 outreach initiative at the University of Colorado at Boulder and subsequently taught university junior- and senior-level engineering courses. The personal and institutional benefits realized will be discussed.

**Preparing Graduate Engineers for Academic Careers**

W.H. Burr[2] expressed a strong opinion about engineering education; he once said:

> *The main purpose [of education in engineering] is to convey instruction, and it should be done in such a way as to induce the student to do his own thinking. No instructor can justify himself in merely puzzling the student with grotesque problems, or in harassing him with abnormal difficulties, but on the other hand the student should be made constantly to feel himself a working part of the system, and that he cannot, without serious loss to himself, take a mere passive part.*

This statement by Professor Burr was recently shared by Lohmann[3] on the Editor's Page of the *Journal of Engineering Education.* The astonishing part about Burr's statement is that it was published in 1894 at the inaugural proceedings of the Society for the Promotion of Engineering Education. These sentiments still ring loudly in engineering education; yet, it is unrealistic to assume that new engineering faculty members entering a collegiate environment possess the talents to foster a meaningful education for today's engineering graduates without prior training.

In 1995, individuals representing academia, industry, professional societies, government and accreditation committees met in Arlington, VA, to publish an action agenda for engineering education reform for the National Science Foundation.[1] The agenda guidelines for achieving the educational goals for graduating engineers (as listed in this paper's abstract), strongly encourage the study of engineering to become an exciting endeavor that truly engages students. It is also recommended that the primary mode of learning in the classroom become active learning.

Changes in engineering education are also being driven by the Accreditation Board for Engineering and Technology (ABET). The 2004-2005 ABET Criteria for Accrediting Engineering programs[4] evaluates the competence of engineering faculty using factors that include "teaching experience, ability to communicate [and] enthusiasm for developing more effective programs."

So, what can be done to prepare graduate students in engineering for a challenging career in engineering academia? What tools can be afforded to a future faculty member to help him/her succeed in this new paradigm of collegiate teaching? As stated by Smith and Waller[5], we are entering a paradigm in which students and instructors are collaborators in the classroom, in which students view school as a place where they can learn and grow, and in which power is shared between faculty and students. If we hope to realize the goals NSF has set forth for graduating engineers of the 21st century, it is essential to encourage institutional change by instilling vision and passion for engineering education at the graduate level — *before* students enter the field of academia. Outreach initiatives such as the National Science Foundation's GK-12 Fellows in the Classroom program can assist with future faculty preparation by providing training in pedagogy and active-learning methodology, while benefiting the K-12 community.

## Overview of ITL K-12 Outreach Program

The ITL engineering outreach program at the University of Colorado at Boulder (CU) is dedicated to the seamless integration of science and math in the K-12 community through hands-on engineering instruction and enriching educational experiences. For the past six years, the ITL outreach initiative has included academic year and summer engineering offerings such as classroom instruction, extracurricular school clubs, summer on-campus workshops and internships. In addition to introducing K-12 students to the benefits of engineering, the ITL outreach program also supports K-12 educators through the development of hands-on engineering curricula and summer teacher professional development workshops.

One popular component of the ITL's outreach program places engineering undergraduate and graduate students in elementary, middle and high school classrooms to serve as mentors and engineering role models in K-12 science, math and technology classes.[6] Sponsored in part by the National Science Foundation's GK-12 and U.S. Department of Education FIPSE initiatives, this "engineering in everyday life" program concurrently develops standards-based scientific, mathematic and technological curricula focused on engineering for an NSDL-sponsored *TeachEngineering* digital library project.[7, 8]

The preparation and guidance of elementary, middle and high school students — especially those with backgrounds typically under-represented in engineering — towards the university engineering and technology pipeline is important for their success in an increasingly technologically-driven society. During the academic year and through various summer offerings, K-12 students are introduced to the world of engineering and the iterative design/build process by enthusiastic undergraduate and graduate engineering students.

## K-12 Graduate Fellow Experience #1

Daria Kotys-Schwartz is in her third year of participation in the ITL Program's K-12 outreach initiative at CU. During her first year, she assisted in Centaurus High School's (Lafayette, CO) Project Lead the Way classes in its Pre-Engineering Academy inaugural year. During her second year, Daria was immersed in two eighth-grade science classes and three middle school Gateway to Technology classes. In her third year, Daria co-instructs the *Creative Engineering* class for ninth-grade students at the Denver School of Science and Technology (DSST) in Denver, CO.

A middle school student designs an earthquake-proof structure.

For Daria, one of the greatest benefits of participating in the K-12 outreach initiative was the development of her pedagogy skills at the middle school and high school instructional level. Each week, she created detailed 50-minute lesson plans that met a daily learning objective and aligned with state educational content standards. To supplement the daily objective, Daria created and

implemented engaging, in-class science and math activities for 30 students. This required that she purchase activity supplies and materials in advance, and set up before students arrived.

The importance of student engagement in the middle school and high school environment quickly became apparent to Daria. To successfully involve students for an entire engineering lesson, she began integrating technology and active-learning methodology. Creative PowerPoint® presentations embedded with flash animations and movies excited students about the upcoming activity of the day. The hands-on activities provided students with the opportunity *and the motivation* to approach the material as "junior engineers" — exploring, designing and arriving at their own inferences. Incorporating real-world examples into each lesson provided more student connection to the subject area being discussed by increasing their level of involvement, interest and enjoyment.

Daria also learned that success with teenage students required mastering effective classroom management skills. It was clear that if positive classroom management was not achieved, there would not be a productive learning environment for the students. This desire to maintain a healthy classroom atmosphere encouraged Daria to become more versed in educational psychology and development. Understanding students' stages of development and how they learned was essential when employing diverse classroom management techniques with individual students. This knowledge of educational development also proved useful when scaling activities for various age levels.

An additional skill acquired during Daria's tenure with the outreach initiative was creative implementation of activities on a "shoestring budget." Recognizing that teachers could never incorporate many hands-on activities if they were too expensive, she executed an academic year's worth of middle and high school activities on a tight budget. This required strict monetary planning and frugal spending habits to ensure that funds lasted the entire year.

It was not until Daria was teaching as a GK-12 Fellow that she understood the value of pre- and post-assessment methodologies. It typically requires much training and practice to achieve an understanding of the most appropriate assessment practices and evaluation methods to track content learning gains; it doesn't usually come naturally. With this K-12 outreach experience, Daria has since become proficient in the techniques associated with writing and implementing meaningful assessment tools to gauge a class or program's effectiveness.

It also became imperative that Daria master exceptional time management skills to concurrently fulfill her curriculum writing (for the *TeachEngineering* digital library) and K-12 teaching responsibilities, excel in her CU graduate classes and advance her mechanical engineering research.

**K-12 Graduate Fellow Experience #2**

Malinda Schaefer Zarske has always had a passion for education. It was not until one day, while talking to other engineering graduate students, that she started thinking, "Why don't we teach engineering in our K-12 schools? How hard would that be?" Her questions were answered when she joined the NSF-funded GK-12 Fellows program through the ITL Program's outreach

initiative at CU. For the next two years, while she completed her civil engineering master's degree in Boulder, she worked as a GK-12 Fellow, bringing engineering into the hands and minds of local elementary school students.

High school students engaged in engineering design/build activities.

Teaching engineering to elementary students is a complex task. Every week, Malinda arrived at eight different grades K-5 classrooms for an hour each to lead the students in engineering explorations. Basic classroom management and organization was not enough to capture the interest of the young students and keep them engaged for an entire hour. Neither were well-prepared, snazzy technical presentations. She quickly learned that elementary students need to be drawn in by stimulating, hands-on learning experiences. Malinda was repeatedly impressed by the students' incessant inquiries and ability to see engineering topics from viewpoints different than she had ever experienced. Teaching elementary engineering meant bringing in active, age-appropriate activities that excited the students and kept them involved. Malinda discovered how important real-world connections were for students in the classroom if she wanted to open their minds to an alternative future career option. By their very nature, elementary students are observant and curious about the world around them and want to know how everything works and fits together — a perfect match for engineering.

Malinda refined her prior experiences with teaching and writing to create curricular units on motion (mechanical engineering), energy and environmental engineering. Each unit adhered to state and national science and math standards, and included hands-on student activities. Meeting the educational content standards, and providing clear curricular documentation was important if teachers were going to find her engineering lessons useful enough to implement in future classes. Students were immersed in intriguing design / build projects, including rocket balloons, water filters and roller coasters. Each project mapped to the engineering design process through a planning stage, a design blue-print stage, and a prototype creation and reiteration stage. To reinforce the culture of cooperative teamwork, students were encouraged to work together in engineering groups.

Malinda instantly noticed many advantages to participating in the ITL K-12 outreach program, including learning the patience and pedagogy skills necessary to teach at the elementary school level. Notably, the respect and partnership with the elementary school teachers compelled the need to be prepared ahead of time. 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. To bring engineering into the classroom, Malinda needed to align the activities directly to the topics the teachers were already teaching. To be most effective, it was necessary for her to plan in advance with the teachers and test all activities *before* she brought them to the students.

Malinda wanted to develop engineering lessons that used budget-conscious, hands-on activities and supported the wide range of science subject areas that were being taught in Colorado classrooms. The goal was to develop a repertoire of activities for a particular teacher that would excite their students and encourage the teacher to continue to use the activity long after the Fellow was gone. This would provide the teachers with the tools and confidence to teach technological literacy via engineering to their future students. Such planning required a tremendous amount of time and energy to develop the activities, purchase the supplies, and practice and refine the lesson in advance.


An elementary student tests her drinking water filter design.

Malinda wanted to understand what was going on in the minds of the youngsters. She learned the developmental stages and instructional techniques for working with younger, diverse learners; ethnically and academically. Bringing complex engineering theory down to the third-grade level is not easy. She cultivated her skills for in-classroom flexibility to be able to immediately change focus in response to the observed student learning. By employing a variety of assessment techniques, Malinda was able to gauge how well the students understood the concepts that she was teaching. In this way, she expanded her repertoire of pre- and post-assessment techniques and discovered just how well engineering could tie together the science and math concepts for the students, allowing them to critically apply what they had learned to the context of their own lives. Malinda also gained an appreciation for effective lesson motivation and closure. For example, without closure for reflection, students often did not remember the original objectives of the lesson and were often confused during the next week's lesson.

The experience teaching engineering to elementary students was one that Malinda had not experienced before. Besides learning how to communicate engineering concepts to a specific audience, her acquired skills included adaptive strategies for diverse learners, collaborative teamwork with educators and an appreciation for educational pedagogy.

**Subsequent Impacts on a Collegiate Teaching Experience #1**

In 1999, Daria began her teaching career at The Ohio State University in Columbus, Ohio. At that time, she instructed a Parametric Design course for senior and graduate students in mechanical and industrial systems engineering. Walking into class the first day, Daria realized that she had no formal training in college teaching. Concerned with her inexperience, Daria wondered what possible credentials qualified her to develop students' talents and aptitudes. She was not familiar with education research or the word "pedagogy." The only background that Daria drew upon was the positive learning experiences in her own secondary and post-secondary education. During the next 10 weeks, Daria used a syllabus that included a basic course outline, grading policy, exam dates and academic honesty policy. Her attempts to transfer information to her students typically involved lectures with black and white overhead slides. During the quarter,

she tested a few in-class activities in an effort to covey the logic that is used in parametric design. Though Daria strived to deliver the content with enthusiasm, her lectures were typically dry and lacked engaging elements. Despite good reviews from the students, she knew that her instructional abilities could be improved.

In 2002, Daria embarked on a new journey: teaching with the NSF GK-12 program and pursuing her doctorate in mechanical engineering at CU. Now in her third year of participating in ITL's K-12 outreach initiative and pursuing her doctorate, Daria returned to the university classroom. In autumn 2004, Daria began instructing Manufacturing Processes and Systems, a required course for undergraduate mechanical engineering seniors. She still uses a syllabus, but this one clearly outlines the course, classroom expectations, grading policies, mandatory dates and the academic honor code. Her lesson plans comprehensively address the 10 learning objectives established by the departmental undergraduate curriculum committee.

Currently, Daria focuses on what motivates and engages students. For this university manufacturing course, she integrates cooperative / active learning into the traditional lecture. At every class meeting, students work cooperatively in groups, discussing and exploring the assigned problem of the day. Since supplemental class funding was not available and there was no lab component to the class, Daria developed affordable in-class activities that were applicable to the content. For example, when facilities were not available to demonstrate the metal casting process, she cast chocolate in plastic molds to illustrate the defects associated with the metal casting process. She also found success scaling up activities that she had used during her years as a K-12 outreach Fellow. For example, the formation of flubber (a glue, water and Borax mixture) used as a basic mixtures and solutions exercise in middle school, was adapted in the university course as a polymerization cooperative learning exercise. She also incorporated a variety of technological components into her class: PowerPoint® presentations with photographs that illustrated manufacturing processes, a class e-mail list, a class webpage providing all of the information presented in class, flash animations relating to content, interactive clicker technology to gauge student understanding in real time and virtual case studies. The inclusion of in-class demonstrations and product part examples is commonplace in Daria's lectures. Realizing how real-world exposures assist in student buy-in of the presented subject matter, she schedules industrial plant tours throughout the semester.

Some events illustrating her teaching success during the past semester include Daria being nominated for the CU *Graduate Part-Time Instructor Teaching Award* and being honored with the *Residence Hall Teaching Award*, the *Leads Faculty Appreciation Award* and the *Sullivan-Carlson Innovation in Teaching Award*. The following comments by CU students express their positive experience in Daria's Manufacturing Processes and Systems class:

> *To me the best quality a professor can have is enthusiasm. If the professor is not excited to teach the material, then why should a student be excited to learn the material? And for this I thank you, every single day you came prepared, excited and always willing to help with a subject you truly enjoy.*

*I just want to thank you…..for having energy and enthusiasm! I think this is honestly the first time in my career at CU and especially in the ME department that I am psyched to come to class and really excited about the material!*

Daria's classroom successes are directly related to her participation in the ITL Program's engineering outreach program. Her instructional format in her autumn 2004 Manufacturing Processes and Systems course closely emulated the approach she honed in her middle and high school GK-12 outreach classes. Meticulous course planning, daily preparation coupled with engaging mini-lectures and collaborative activities proved equally effective in the K-12 and collegiate environments. Daria's acquired ability to communicate advanced technical knowledge to any level was especially beneficial when developing varied explanations or analogies to teach complex subject matter. Once the collected quantitative assessment results for the course have been reviewed, they will be discussed in future papers.

**Subsequent Impacts on Collegiate Teaching Experience #2**

In spring 2004, Malinda co-piloted a new course at CU's College of Engineering and Applied Science for junior and senior undergraduate students. This course, K-12 Engineering Outreach Corps[9], was based on her experiences as an NSF GK-12 Fellow. In the course, upper-division engineering students entered K-12 classrooms to use their understanding of real-world engineering applications to improve science and math learning, and promote the engineering profession. With her teaching experience limited to the K-12 arena, the college-level course was intimidating.

Malinda and her co-teacher approached the project by setting course goals. To provide the college students with a meaningful experience, they focused the course objectives on the students acquiring effective communication to a variety of audiences and learning to write lesson plans. Real-world K-12 topics, such as classroom management, educational standards and budget limitations, provided the students with an understanding of the issues with which teachers are concerned.

Malinda structured the undergraduate seminars similarly to how she would lead a K-12 class, by motivating the students, allowing time for individual and cooperative group explorations and providing closure for the students at the end of each lesson. She established course objectives and expectations in advance. She scheduled time for each university student to plan and test activities in front of an audience of their peers before they brought them to the classroom. Diverging from the traditional lecture format, the course was structured into two studio classes and one topic-based pedagogy discussion seminar each week. During one studio session, Outreach Corps students shared their creative explorations into K-12 science and math — in the form of hands-on activities. During the other studio, pairs of undergraduate students presented their applied science and math (engineering) lessons in local public school classrooms. The engineering students received much constructive feedback from the co-instructors during the studio lessons and in-classroom observations. This role placed Malinda on the other side of K-12 teaching, assuming the role of an in-service mentor instead of a classroom teacher.

Malinda assessed the college class using methods she learned while working in elementary schools, adjusting according to the observed student learning. Pre- and post-semester subject matter content and attitude surveys help her determine what was working and not working in the course. Overall, Outreach Corps students reported a 22% gain in confidence in working with K-12 students. The strongest gains in confidence were for the following course aspects: integration of engineering curricula into the K-12 classroom (+73%), K-12 engineering curriculum development (+67%), and working with English as a second language children (+60%).

Most students reported that the course exceeded their expectations. One student said, "I learned a lot about the different aspects of teaching (in and out of the classroom)." All students thought integrating engineering into K-12 education is a valuable practice and enjoyed the lessons on current issues in the educational system. One reported, "The value is priceless. Influencing kids at such a young age is the right step towards education. All universities need to begin recruiting in grade school." The university students documented their experiences in journals. Through their writing, it was apparent that having the seminar sessions modeled after a K-12 classroom was an invaluable teaching tool for them. The flexibility of focus that Malinda had mastered in the elementary classroom benefited the collegiate studio session, as the Outreach Corps students learned to change focus as well. The students said that topic flexibility was a major strength of the course. They wanted to be able to discuss their experiences and issues in their own classroom instruction. Finally, all Outreach Corps students envisioned themselves engaged in the teaching profession in the future (two are considering full-time teaching work), indicating the impact of the course and instruction on their personal career focus.

The pilot course was highly successful and so was Malinda's new understanding of how elementary classroom instruction can apply to learning at the collegiate level. Providing engaging topics; opportunities for collaborative work; time for planning, hands-on exploration, documentation and reflection; as well as good assessment and flexibility cultivates the best possible learning experience in a collegiate classroom as well as a K-12 classroom. Malinda's experience as a GK-12 Fellow improved her ability to be an effective instructor at the collegiate level. As one student said, "The support and encouragement from the faculty (Malinda) was above and beyond the call of duty." She succeeded as a new college instructor and was rated highly on her end-of-semester student reviews. In the end, the course was well received. It was approved by the college-wide curriculum review committee as a 4000-level, general engineering technical elective after its pilot offering. The spring 2005 semester is currently enrolled at twice the number of students as the pilot.

**Institutional Benefits**

The University of Colorado at Boulder has begun to realize benefits from having graduate students who participated in the National Science Foundation's GK-12 initiative. The two instructors profiled in this paper bring their passion for and expertise in engineering education to the formulation of exciting and engaging engineering curriculum at the collegiate level. As required by ABET Criteria for Accrediting Engineering programs, Daria and Malinda possess previous teaching experience, good communication skills and enthusiasm about effective teaching methodology. Additionally, both met the challenge of balancing the demands of

instructional, research and institutional responsibilities. Most importantly, they have successfully provided meaningful educational experiences for collegiate engineering students.

From an institutional perspective, graduate students with experience similar to the K-12 graduate fellowships described in this paper require minimal training in education methodology from their college and have already begun to refine pedagogy skills before attaining permanent faculty positions. Such junior faculty members bring experience in teaching to diverse populations, and are already familiar with effective assessment methodologies and pedagogy to ensure high-quality instruction in the engineering classroom.

## Conclusion / Recommendations for Others

Graduate student GK-12 Fellows in the Classroom outreach programs, such as the ITL Program's engineering outreach initiative at the University of Colorado at Boulder, are successful avenues for the preparation of future engineering faculty for the new paradigm in engineering education. In addition to their positive impact on the student participant, these programs bring profound benefits to the academic institutions at which these graduate Fellows subsequently accept faculty positions.

Graduate students who participate in National Science Foundation's GK-12 initiatives, similar to the ITL's engineering outreach program at CU, are a valuable commodity for any college of engineering. These individuals possess prized instructional experience, good communication skills and a passion for engineering education. They have the ability to clearly impart technical knowledge to diverse student populations, while incorporating particulars from a multitude of engineering disciplines. GK-12 graduate Fellows are also trained and experienced in active/cooperative learning techniques, which NSF has recommended as the primary mode of learning in collegiate classroom. These up and coming faculty members bring the essential experience and motivation to instill permanent cultural changes in engineering education.

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