Applying K-8 Engineering Education to Graduate Student Studies

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Introduction

The typical graduate student experience includes a research or teaching assistant position at some point throughout the course of study. Traditional positions such as these are focused on graduate level class work and research. Alternative experiences, such as elementary and middle school level engineering outreach, are rare but offer a surprising number of benefits to the graduate student. Teaching engineering to K-8 students presents challenges usually unfamiliar to a graduate student who has spent the last four or more years in a rigorous technical engineering program. Simple concept communication and non-technical explanations become necessary for any level of success. Rising to these challenges produces situations uncharacteristic of the typical graduate student experience. These situations strengthen communication skills and require development of new problem solving methods.

In 1998, the Tufts University Center for Engineering Educational Outreach received a National Science Foundation GK-12 grant. This grant allowed for the placement of graduate student fellows in K-12 classrooms with the intent of infusing engineering into the existing science and technology curriculum. Their primary role is to not only develop content knowledge for the teacher but various non-traditional skills for the graduate student as well. The fellowship is a twelve month position open to both Masters and PhD level graduate students. There are eight fellows in the program, two from computer science and six from various engineering disciplines. Each fellow is assigned to a classroom/school, working closely with a single teacher or small group of teachers. Fellow participation ranges from working with in a single grade level to working with a range of grade levels.

Role of a GK-12 Fellow

The work completed by the GK-12 fellow involves teaching activities in addition to writing and assessment aspects. A major role and motivation for having the fellow in the classroom is to be a technical resource for the teacher. This allows for content development as well as instruction to the students from a technical background. The fellow becomes a "real-time" resource to answer questions and clarify any concepts that a teacher not specifically trained in science or engineering may have. Through this resource position, vital communication skills are developed that will be further discussed at length. Another key role for the fellow is to develop activities that are integrated into existing science and technology curriculum. In order to best fill this role, the fellow must learn to write to a variety of audiences. The last major role of the fellow is actually a co-teacher in the science classroom. The classroom structure often takes on a team teaching approach depending on the comfort level of the teacher with any given subject material. This provides the fellow with significant teaching experience to an alternative population, which further develops the fellow's aforementioned communication skills.

Challenges of K-8 Engineering Education

Traditional methods of presenting engineering concepts and principles through mathematical proofs and derivations can be confounding for individuals without a strong math and science background. These proofs and derivations rely heavily on upper level math: algebra, trigonometry, geometry, calculus, and differential equations. This method of explanation is widely accepted at the collegiate level because the students are required to have an extensive math and science background. In these classrooms, an individual must trust that the math behind the explanation is telling the truth. At times there are experiments that can be run to illustrate these concepts. For example, one can calculate the heat transfer through an insulated metal rod with known properties and boundary conditions, and then run an experiment to measure these same values. However, for more complicated problems, one cannot easily run an experiment to demonstrate the theory. For mathematical explanations to work, students must also have a strong understanding of the associated scientific principles in order to visualize the concept.
These burdensome proofs and derivations are not useful methods of explaining engineering concepts to those individuals with limited math and science knowledge. At the third and fourth grade level, students are just learning to use multiplication and division. This eliminates the possible use of any kind of upper math to present an engineering topic. In middle school, students are exposed to basic algebraic concepts, but using these concepts as the primary method of explanation results in confusion, boredom, and even frustration.

Unlike professionally trained engineers, K-8 students and their teachers do not need to know the exact mathematical theory behind engineering principles. Engineers need to know the quantitative answer in order to effectively design products, and accurately solve problems. Teachers and their students need to know the qualitative ideas behind the theory. They need to be able to recognize what makes sense as a reasonable solution and what the end result is. As an example, consider the velocity gradient of a river. Engineers want to know what the actual velocity is at the edge of the river to calculate the erosion rate of the bank. Students need to know that the river velocity is faster in the middle of the river and slower at the sides because of a "friction" from the banks that has the most effect on the sides. K-8 teachers often do not have technical backgrounds, and some do not even like the idea of teaching technical topics. However, they do not need to teach the in-depth mathematical theory behind engineering concepts. They can teach the qualitative side of engineering topics, which is what the children need to learn.

Alternative Methods of Concept Communication

A GK-12 fellow must be able to recognize the level of understanding students have for a particular topic and explain the topic at this level. To do this, the fellow utilizes various methods that do not involve derivations and proofs, which are traditionally used to teach engineering concepts. Alternative methods, such as physical representation, real world analogies, simplification of a topic, and cross-referencing can aid the fellow in explaining complex engineering concepts to students at any level. When using these methods to develop a lesson plan, the fellow must take into consideration the students' levels of understanding, attention spans, and levels of interest in the topic.

Physical representation is a great way to help children learn engineering principles. Students often react well to a demonstration illustrating how something works, rather than being told the reasons. Physical representation can be achieved through a variety of methods. Students can model the concepts with art supplies (paper, scissors, glue, staples, paper clips, etc.). A teacher can perform an experiment to demonstrate a concept to the class. The students can actively take part in a demonstration in the classroom. Physical representation can involve any method that does not focus around simply writing down information on the board that can be copied down into a notebook. For example, an experiment was conducted where a fourth grade class went to a river and measured the time an object took to float down the river 100 feet (at 25-foot intervals). Multiple trials were run, and the velocity was calculated for each trial. There was a wide range of velocities resulting from the various locations between the bank and the middle of the river for which the velocity was calculated. As a follow-up to this activity, a lesson was presented to explain the general theory behind varying velocities in a flowing body of water. The general theory is that the water will flow slower at the bank of the river as a result of frictional forces and faster in the middle of the river (where the frictional forces are greatly reduced). For the demonstration of this principle, the students were asked to play the part of the water. Each student represented a "drop" of water. The students were not familiar with a water molecule and did not need to be in order to understand the velocity theory. The students were instructed that as water they were to walk straight ahead unless they ran into an obstruction (a desk or another student). As water, they were to move around the obstruction and continue moving straight along the river. Starting on one side of the room, the students were then instructed to flow (walk) through a channel (two parallel rows of desks) until they got to the other side of the room. The channel was set up such that there was not enough space for the students to fit through. The students at the edge of the channel bumped into desks and subsequently, other students. The students were then asked to explain what they experienced during the demonstration. The students at the sides of the channel stated that they had bumped into the desks, and that slowed them down. The students in the center of the channel did not notice many disturbances. The students were then told that the same things happen in the real river. The water at the side of the river "bumps" into the bank and is slowed down, while the water in the middle of the river does not bump into anything and moves relatively quickly. This demonstration allowed the students to get up and move around, actively participate in the demonstration, and use their personal experience as a means to remember the lesson.

In addition to physical representation, there are a number of other methods that can be effective in conveying engineering concepts to students. An analogy made between a new engineering concept and something the students are familiar with can help students to grasp a difficult or complex concept. When explaining the concept of electrical current to middle school students, students will inevitably have difficulty in grasping the abstract concept. To help students understand current, one could use an analogy to compare electrical current to a pizza. Students know as the number of people sharing a pizza increases, each person will receive less pizza. Similarly, as the number of lights, or other devices, sharing an electrical current increases, each light will receive less current. Relating an engineering concept to something that is obvious to students will help them learn and remember the concept. Another helpful technique to present a complex topic to students for the first time is to break down the new topic into very simple ideas and then built back up again to the original idea. Students can be overwhelmed when tackling a complex topic and this technique can prevent intimidation. In our program we frequently use Legos as a tool in the classroom. Legos can be particularly useful when explaining gear systems. Understanding a complex gear system is difficult, but if each student is given a simple gear system and is able to add more gears and make observations about the system, the complex system will not be as intimidating. Cross-referencing can also be a powerful tool, in which you use one topic that has already been covered to teach another unrelated topic. This can be particularly useful when working in schools where there is collaboration between the various subject teachers. For example, a social studies unit on ancient Rome can be followed up with a technology activity in which students devise methods of delivering water to ancient Roman cities and build models of aqueducts. The previously described methods offer alternative techniques for conveying engineering concepts to students. These methods can be used independently or in conjunction with each other.

Development of Communication Skills for the GK-12 Fellow

Upon completing a graduate engineering program, one should have a solid engineering knowledge base to work with. This is obtained through coursework, lab work, research and thesis work. This is an important aspect in becoming an effective professional engineer; however the majority of engineers realize that they need more than just a solid working knowledge of engineering principles. In order to advance in the professional world, one must have the ability to effectively convey his/her ideas to a wide range of individuals, in a similar way to which a GK-12 fellow must. Developing solid verbal and written communication skills is arguably as important as the technical knowledge gained in school. The nature of the Tufts GK-12 program provides experiences and opportunities for developing these communication skills that prove vital in the engineering world.

Technical industry is predominantly team oriented, and engineers commonly work with colleagues of various educational backgrounds. Design teams can consist of individuals from all engineering disciplines in addition to business managers, legal representatives, industrial designers and marketing personnel. Similarly, a classroom is made up of individuals with a wide variety of academic interests and strengths. In industry and in the classroom it is important to communicate ideas in a manner that will be interesting and comprehensible to a wide range of personalities. Communicating exclusively with engineers requires technical descriptions with high levels of detail; however this is not the case with all individuals on a project team. A manager wants to know how much money you are spending, and why you are spending it. This information is directly related to your design, but warrants a completely different explanation than you would give members of the engineering team. In the K-8 classroom, it is often necessary to use various approaches when explaining a topic to students with distinctive interests and strengths. Adapting presentation styles based on the recipient is a useful tool for engineers to possess. Thus the graduate experience for a fellow working with grade school science classrooms can nurture the attainment of communication skills crucial in the professional world.

Working with K-8 students to communicate a new idea involves the challenge of gaining and keeping the attention of the class. In these classrooms, attention spans can be limited and keeping students' attention is a daunting task. To overcome these issues, the GK-12 fellow relies on interactive and "fun" instruction techniques. Science and engineering education allows for lab work and other instruction aside from traditional lecture formats. Seeking out these alternatives and using such things as physical representation and inventive real world analogies helps to keep the students interested in what is being presented. Gaining and keeping the attention of the target audience is an issue that does not necessarily disappear with age. Technical concepts are often dry and unexciting to those without training in technical fields or any interest in technology, thus attention levels remain an important issue in the professional world as well. By being in the classroom and having to think on one's feet, the fellows prepare themselves for presenting material throughout life in an interesting and engaging manner. This is a communication skill having little to no presence in the typical graduate student experience.

When discussing issues of sustainability, it is important that the teacher feel comfortable teaching the material to the students without the aid of the GK-12 fellow. Communication of engineering concepts and principles must be a goal, but the teacher must also be able to teach those same concepts to their students. This becomes another role that the fellow must take on, teaching the teacher to teach. To achieve this, the teacher much first understand the material and become comfortable with it to the point where he/she feels confident teaching it to a classroom of students. Engineering concept integration then becomes somewhat of a communication process for the fellow, not simply presenting it but ensuring an understanding and leading the teacher in instruction methods and ideas. In the professional world, delegating responsibilities and training employees is an essential management tool, thus the training similar to this received by the fellow better prepares him/her for work in industry. A management mind set is further experienced with project based learning, either individually or in small groups. In this case, the fellow becomes the managing body of the entire class, responsible for monitoring their progress, helping them overcome hurdles without doing the work for them, and making decisions on what is acceptable. Although the context and demographics are completely different in education than in industry, the skills attained working as a fellow can still develop a sense of management and responsibility for use in the professional world.

When infusing engineering into the K-8 environment, organization and verbal communication are obvious issues, but writing is also crucial. In addition to discussing his/her ideas with the teacher and presenting them clearly and effectively to the students, a graduate fellow must also document the lesson/activity in such a manner that lends itself to effective reproduction. These documents are provided to the teachers and the students, both addressing similar concepts in varying degrees of complexity and depth. Writing to different skill and knowledge levels is just as valuable a skill as verbally communicating across these gradients. Extending the enrichment of communication skills for the fellow to include writing skills increases the dividends of working with this less traditional graduate school program.

The experiences of a GK-12 fellow offer valuable training that is not normally seen in an undergraduate or graduate engineering program. The fellow is given the opportunity to vastly improve his/her communication skills, both verbal and written, through the everyday interaction with teachers and students. The fellow grows accustomed to using various presentation methods outside of traditional derivations and proofs. The fellow learns to recognize an audience's level of understanding for a given topic, which increases the effectiveness of his/her subsequent explanation. The K-8 classroom is excellent preparation for delivering presentations in a professional environment. The questions from students in the classroom always keep the fellows on their toes. Further, to keep the attention of students, the fellow learns to always present material in an interesting and engaging manner. The fellow also gains exposure to various aspects of professional management. Managing a K-8 classroom presents a wide array of professional parallels: monitoring progress, offering assistance without actually doing the work, and making decisions on what are acceptable solutions.

Through the various methods of interaction and education employed by fellows in the Tufts GK-12 program, useful skills are attained that provide the fellow with a solid foundation to approach the professional world. Increased content knowledge and engineering experience is a foremost goal in graduate work, but through alternative programs such as GK-12, graduate students can develop additional skills that help them become a more effective and marketable engineer in the future.

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