Teaching Teachers to Apply Engineering:  
A Tale of Two High School Classrooms 

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Abstract

Mathematics and science are two of the corner stones supporting the curriculum encountered by a typical high school student. Effective teachers of these content areas utilize a variety of techniques that enable all students in their classes to learn the content. This includes providing students with opportunities to engage in worthwhile tasks that incite meaningful mental involvement. For teachers to create such tasks, the teachers themselves must hold great facility with their content knowledge, as well as with the professional knowledge about the nature of teaching and learning. Engineering provides an excellent theme in which worthwhile tasks about mathematics and science can be considered. However, this requires that the teachers understand a great deal of basic engineering concepts. This paper describes the units that two high school teachers developed after they learned some engineering concepts. The mathematics teacher focused his lessons on vectors. The science teacher focused his lessons on forces. One important result is that the teachers were able to remain true to their districts’ curricular requirements while they imported engineering into their respective areas.

Introduction

Vectors and forces, which are two key foundations of engineering, are components of the typical high school curricula that most secondary students encounter. In order to effectively teach and learn about these concepts, their teachers must pose worthwhile tasks and structure meaningful inquiry for them. However, such teaching requires that teachers possess in-depth understanding of not only the mathematics and science content, but also connections within and between these disciplines. Furthermore, they must weave their extensive knowledge of content into a rich fabric of professional knowledge about how students learn mathematics and science.

Clearly, engineering provides an exceptional field of study in which to study mathematics or science. And, sagacious faculty of engineering colleges know that high school teachers who are knowledgeable in engineering would likely use that knowledge to better prepare incoming students with strong understandings of important concepts, such as vectors and forces. In order for teachers to make meaningful connections between engineering and school curriculum areas, the teachers themselves must understand engineering. Moreover, they must experience this content in ways consistent with how they will one day teach it in their classrooms. In other words, they must learn about engineering through inquiry, problem-solving, and laboratory investigations. They must see the content through multiple representations and, in the end, be able to connect the content to the curriculum they will teach to their students. However, most
teachers’ collegiate experiences do not include study of engineering concepts and likely did not provide a foundation for them to make these sorts of connections between mathematics and science.

The purpose of this paper is to describe some of the classroom activities about vectors and forces that were developed by two high school mathematics and science teachers after they formally studied some engineering ideas. These activities illustrate the kinds of meaningful teaching secondary teachers can provide when they know engineering concepts.

Best Teaching Practices

Learning, in general, results from students’ efforts to make sense of their surrounding situations. In a best case scenario, the learners are actively involved in satisfying their curiosity or puzzlement about resolving a situation or completing a task related to a specific idea (concept or procedure). As learners make sense of these environments, they construct connections between, among, or within ideas. In this way, learners manipulate their existing knowledge. This manipulation may take the form of using existing knowledge as a foundation for building new knowledge, abandoning existing knowledge found to be a misconception, or making connections between pieces of existing knowledge.

The weight of facilitating the learners’ manipulation of knowledge falls upon the shoulders of teachers. When teachers fully understand the learning process, “teaching becomes a matter of creating situations in which children actively participate in scientific, mathematical, or literary activities that enable them to make their own individual constructions.” To this end, teachers must pose worthwhile tasks and interesting situations that will enable their students to learn.

A worthwhile task or situation requires students to accommodate new mathematical or scientific ideas. Often, the situation is somehow new to the students and they do not already know a strategy to resolve it. After students wrestle with resolving such a task, the stage is set for them to reorganize their knowledge. The teacher designs tasks so he or she can help the students tease out the intended mathematics or science inherent in the task.

This clarification of the mathematics and science content enables the students to connect important information to their existing knowledge. Although this clarification often plays out in a whole class discussion, the fact of the matter is that each individual student must participate in the discourse. The act of doing an activity is insufficient to ensure the process of learning. It is when each student individually reflects on his or her experience with resolving the task that the real learning occurs. Therefore, teachers must grapple with the notion that each individual student will have individual needs which, when met, will enable him or her to learn most effectively. Clearly, the teacher’s job is not easy. However, as teachers come to better understand how students learn content, the nature of the content itself, and even their personal beliefs about the content, they are able to simplify their jobs, somewhat.

The problem solving approach to teaching uses a variety of contexts to ground the planned inquiry. This approach also requires that teachers hold a deep and richly connected understanding of the content and how students construct knowledge about the content. During
college, as undergraduates, future secondary teachers often take some courses in the exact content they will one day teach. And, teachers will teach as they have been taught. So, of particular concern are teachers who experienced stagnant, isolated mathematics content, assembled a collection of unconnected science information, or experienced content through inappropriate teaching styles. If, once they become teachers, they are to teach topics in depth, then they must understand the content in depth. If teachers are to teach so that all students learn, then they must know how to integrate their knowledge about content, curriculum, learning, teaching and students. This specialized professional knowledge can be achieved when teachers experience inquiry, problem solving and investigations during their mathematical and scientific learning.

Professional Development for Teachers

Most practicing K-12 teachers are vigilant in their watch for opportunities to improve the instruction they deliver to their students. They might attend conferences, take courses at a local university, or collaborate with colleagues. Often, secondary mathematics and science teachers have earned bachelor’s degrees fully in their content areas as well as added the educational course work required for a teaching license. That is, they have flat content expertise well beyond the content they are teaching in grades 9–12 and the educational courses were likely isolated from those content courses. So, the assistance they seek often centers upon learning how to integrate their respective knowledge about content with their respective professional knowledge about curriculum, learning, teaching and students.

As a result of quality professional development, teachers often learn how to integrate their professional knowledge with content knowledge. Consequently, teachers might deepen their content knowledge in ways that will allow them to enhance their school curriculum. As they strengthen their understandings of how their curriculum might best be interconnected, they will likely incorporate a wide variety of interesting and worthwhile problem contexts, including engineering. Or, they may learn new and innovative teaching strategies, which better guide their students toward understanding of that curriculum. They might learn new ways to negotiate classroom discussions as an avenue toward development of student thinking. High school students should learn more when they study in the classrooms of teachers who create such learning opportunities.

There are several strategies teacher-leaders must follow in order to provide successful experiences for practicing teachers to learn how to integrate professional knowledge with content knowledge. First, the experience should be founded on some sort of content-based experience and include related teaching practices as well as educational research. Attempts to teach teachers about successful teaching strategies in isolation from any sort of content base are usually not successful. Second, the experience must model best teaching practices in order for the teachers to connect the content to teaching strategies. Third, the content itself must be of sufficient difficulty that the teachers actually experience the learning of new concepts or procedures while experiencing those innovative strategies. Recall that teachers will teach as they were taught. The practicing teachers should be expected and encouraged to “take intellectual risks in doing mathematics.” Their exceptional scientific and mathematical minds must be
challenged. When these factors are met, teachers are more likely to transfer the experience into their individual classrooms.

Learning Engineering Ideas

The two teachers described in this paper studied about engineering and education in a one-week, workshop-type, summer course. They encountered a variety of engineering ideas including compression, tension, strength, load, and buckling. Through a laboratory, hands-on approach, the teachers learned about these and other engineering ideas. As indicated earlier, how teachers learn new ideas must be consistent with how they will one day teach these ideas.

For one of the experiments in that course, the professor used a small, plastic (hobby-store) I-beam. The teachers tested the I-beam for its critical buckling load. For a different experiment, the professor used some latex rubber tubes. The teachers used those tubes to learn about Young’s Modulus. In so doing, the teachers used mathematics (vectors) and science (forces) among a plethora of other mathematics and science concepts. However, these were the two most obvious concepts to the teachers and the ones on which they chose to focus their upcoming transfer of ideas into their high school classrooms.

The Mathematics Teacher

Mr. Petersen teaches high school mathematics at a large suburban high school. In this, his eleventh year of teaching, he has settled into an environment in which he truly enjoys teaching. He maintains active involvement in his students’ extra-curricular lives as a basketball coach. He used his summer workshop experience with the I-beam experiment to design a series of mathematics lessons to teach his pre-calculus and trigonometry students about vectors and right-triangle trigonometry.

I will present this unit after the students have already had some previous experience with vectors and trigonometry. Then, I will start at the concrete level by letting them bend, twist, and pull on the plastic I-beams. This will give them a cursory understanding of compression and tension.

Next, we will talk about how a (simple) bridge is put together. I will give an example of how to find forces within the truss using vectors and right triangle trigonometry. The students will use vectors and right triangle trigonometry to determine the force that is exerted on a beam, within such a bridge.

The students will run experiments, similar to those from my workshop, to explain how they might select a beam, based on information from our charts [table of cross-sectional and weight properties of I-beams]. They will use either a different bridge and/or a different load, then will have to find a correct beam.

Finally, the students will determine and justify, using mathematical principles, how they would select the most cost-effective beam.
For an assessment, the students will write a report in which they:

- describe tension and compression
- provide a diagram of the entire bridge
- provide partial diagrams of each individual joint, (including the vectors and how they found the force vectors)
- correctly find forces using right triangles
- accurately explain a reasonable defense for how they selected the most cost-effective beam(s)

It is important to note that Mr. Petersen has maintained the integrity of his school district’s curriculum, which he is responsible to teach. Vectors are a standard benchmark of Geometry studied from an Algebraic Perspective. Right triangles are a standard benchmark of Trigonometry. These two content strands are also clearly outlined by the National Council of Teachers of Mathematics as important topics to be learned by any high school student. However, Mr. Petersen successfully planned an innovative approach that allowed him to connect these ideas by integrating some engineering ideas into the lessons on vectors and trigonometry. Once he knew enough engineering to expand his own content knowledge and his own professional knowledge, he was able to create a meaningful and tightly connected unit for his high school students.

The Science Teacher

Mr. Chandler teaches high school science at a very small rural high school. In this, only his second year of teaching, he is continually working to improve his developing teaching skills. He also maintains active involvement in his students’ extra-curricular lives as a softball coach. He used his summer workshop experience with the latex rubber tubes experiment as a model for designing a series of lessons to teach his physics students about forces and load. In a typical high school physics class, students often learn about force merely as the equation: “mass times acceleration.” It is therefore difficult for students to understand the concept of force on an object that is not in motion. He felt engineering ideas related to statics offered a context in which students’ knowledge of force could be enhanced.

I will present this lesson after students have already had some previous experiences with force. They will explore several types of latex rubber tubes, to get an intuitive feel for how the materials act. This concrete level experience is an important first step in a science lesson.

I will demonstrate how to attach weights to the ends of the tubes and how to measure the change in gage length. The students will then repeat this procedure at each of three stations. At the first station, I will have same sized (equal cross-sectional area) tubes, with different gage lengths marked on each of them. At the second station, I will have different sized (different cross-sectional area) tubes, with equal gage lengths marked on them. At the third station, there will be different sized tubes with different gage lengths marked on them. The students will record their data and look for a pattern between the cross sectional area and the ratio of the gage length and the change in gage length. They will discover the impact of the cross-sectional area on the change in gage length.
Together, we will plot the stress (load ÷ area) versus the strain (change in length ÷ original length). With this graph, they will then determine Young’s Modulus. The goal of this portion of the lesson is for each student to know that each material has its own physical properties. And, that changing these properties also changes Young’s modulus. Load is weight, which is a force. Students should learn that the results from applying force to an object are dependent on the material itself.

After they have found a value for Young’s Modulus for the latex rubber tubes, (using a best-fit line on the graph), I will point to the place where the graph ceases to be linear. I can introduce the term "proportional limit" of a material using their existing knowledge about the importance of graphs in scientific inquiry. Although this is as far as we will go with proportional limit on this unit, I will be able to use it in future lessons about other engineering ideas.

For an assessment, the students will be given an unknown tube (of a different material). First, students will predict whether Young’s Modulus for that material is greater or less than the value we found in class for the latex rubber tubing. They must defend their prediction before they do the experiment. Then, students will repeat the experiment to determine a reasonable value for Young’s Modulus. We will check this experimental value against the published value.

Students will also write a report in which they explain their thinking:
• about the impact of different loads on a given type of material
• about the impact of same load on different materials
• describing, in general, the impact of load on any material

Mr. Chandler also maintained the integrity of his school district’s physics curriculum. Load and force are already part of his teaching responsibilities. They are also components of the Physical Science content standard suggested by the National Research Council to be included in all high school science curricula. Through hands-on laboratory experiences, similar to those with which he learned, Mr. Chandler was able to use his new-found engineering knowledge to create a unit on force and load that he extended to include specific engineering concepts. Several basic engineering ideas served as a basis for him to ground his students’ learning of force and load.

Conclusions

Both of the teachers cited above used engineering contexts and ideas as a basis from which they taught about the content of their respective mathematics and science curricula. They carefully planned their lessons, taking great care to actively involve the students, physically and mentally. Mr. Petersen built on students’ existing knowledge about vectors and trigonometry, while Mr. Chandler asked students to apply ideas about forces.

Both teachers posed interesting tasks, which were worthwhile in terms of the mathematics or the science content. In both classrooms, the students were active participants during their observations about the behavior of the I-beam or the latex rubber tubing. Both teachers planned
time for serious student reflection, in which the students thoughtfully drew conclusions about their earlier observations. This critical element of the learning process for both groups of students took the form of structured writing about the experience. The teachers’ abilities to include meaningful engineering ideas in their teaching of pre-determined curricula appears to have increased these teachers’ repertoires for presenting students with unique opportunities to learn mathematics and science content.

As predicted, for both Mr. Petersen and Mr. Chandler, their experiences with the way they learned engineering eventually defined how they would teach it. They learned new engineering ideas from a professor who practiced appropriate teaching strategies. They integrated these new content ideas into their professional knowledge base of learning, teaching, students, and curriculum. So, they were properly prepared to successfully transfer their professional development into their respective classrooms.

References

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