Teaching Engineering and Science Using the Toilet: The Dissect and Discover Approach

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Abstract
In order to improve science education in the formative grammar school years, we combined the principles of constructivist teaching with the natural curiosity of the students in an engineering-based curriculum. This curriculum allows the students to take apart and discover for themselves how various objects work. By capitalizing on the natural curiosity of the students, and by emphasizing group, hands-on engineering, we tried to make science do a better job of bridging the gender and social barriers. At the end of the we had students “discovering” concepts ranging from levers and forces to pressure and suction.

I. Introduction
In an effort to increase student interest in science and engineering, Tufts University Mechanical Engineering and Education Departments developed a “dissect and discover” curriculum based on how various objects work. Over 50 teachers have since successfully integrated this curriculum in their classes - from kindergarten to 3rd grade. The dissect and discover approach has students learning fundamental engineering concepts by taking apart something familiar and discussing how it works. For instance, in the toilet they discovered and discussed concepts of buoyancy, pressure, and velocity. This pedagogical method teaches them how to critically examine an object - and they gain confidence that they can figure out how things work on their own.

One of the primary goals of this work is to increase female interest in science and engineering. A recent AAUW report\(^1\) found less than 4% of girls taking the SAT plan to major in engineering - this compares to almost 18% of the boys. Even among the high school students in the advanced math and physics classes the dichotomy remains: in one state more than 60% of the boys in calculus and physics planned a career is science, math, or engineering - less than 20% of the females did. What causes this dichotomy? Most likely the way in which science is currently taught. Further, the report found that the most successful science programs for females 1) were based around hands-on activates and projects, 2) minimized individual competition, 3) provided opportunities for the girls to meet and talk with women in science and engineering, 4) limited the classic lecture-style teaching, 5) emphasized individual learning through questions, and finally 6) which
actively included parents. The dissect and discover approach automatically satisfies most of these “remedies for reform.”

The basic concept behind the dissect and discover method is that the students are given a common object and a tool-box and are asked to take the object apart in order to discover how it works. The teacher acts only as a facilitator, never telling the students anything but periodically posing leading questions and working with the students to discover the underlying physical principles. The teacher also must form appropriate student groups to encourage full group participation - this step is critical in letting all students actually involved in taking the object apart. At Tufts, we have applied this pedagogical technique to a number of different objects, from the sink to the bicycle. By far the most popular, however, was the toilet. Therefore, below we have outlined the technique specifically as it applies to the toilet - but it can be used effectively on almost any household object - from the stereo set for teaching electronics to the hand-held drill for teaching gears and simple machines.

II. The Design

In order to bring the toilet into the classroom, we designed an built a wooden stand. This allowed us to drain the toilet into a bucket. Figure 1 shows a schematic of the toilet and stand assembly. The wide flat base makes it difficult for the toilet to tip over and allows shorter students to see into the toilet. The total cost of all materials was about $60 per toilet station. We were able to reduce this price even more through donations of a local hardware store.

Along with the toilet, we also supplied the students with a number of tools, including screwdrivers, wrenches, safety glasses, and then some tools which would hopefully not see much use - such as a file and a hammer. Many of the participating teachers for the younger grades developed successful lesson plans based simply on the tools: what they did, where might one need them, and did the parents have them at home?

III. Working With the Teachers

We developed the curriculum jointly with 10 science coordinators for schools around Tufts and a host of graduate and undergraduate engineering and education students. The science coordinators helped in identifying interested teachers and in developing methods to present the material to the teachers. The students were in charge of designing and building the toilet setups and for staffing the toilets when the teachers were trying them out. By
including a large number of engineering students we hoped to increase interest in teaching among the engineering students.

Our first step after testing the setups ourselves, was to teach the students the art of teaching by asking questions - the constructivist approach\(^2\). They then used each other to gain experience in asking the “right” questions. Next, we brought in the science coordinators for a test run. We then further refined the setups and then brought in 56 teachers on a Saturday morning. After the usual coffee and donuts, we immediately started them off with the toilets. They were paired up into groups of four and were given one toilet, one engineering student, and tools. We also supplied food coloring for flow visualization. After one and a half hours, we then re-assembled and discussed the results of the exercise. The biggest discussions were centered about concepts of pressure and siphons. Among the teachers, we saw little difference between the two genders, both attacked with equal vigor, although the males on average were quicker to start taking the toilets apart and the females tended to spend more time analyzing. We did see a big difference in the way the teachers treated the engineers, however. They saved the technical questions almost exclusively for the male students, using the female engineers only for assisting in refilling the toilet.

Each district was then given a toilet and we had two poster sessions where the teachers discussed their various methods of bringing the toilet into the classroom and the gender differences in approaching the toilet disassembly. Below, we describe some of the results seen by the teachers in their various grades. All the teachers made an effort to include parents in the project through letters and volunteers.

**IV. Results**

Even the kindergartners reflected the adults in that the boys were taking things apart without thinking of how to put it back together, whereas the girls were more hesitant, and worried about making a mess. Before actually examining the toilet, the students authored a book on tools, illustrating the tool and defining its purpose. The students then guessed how the toilet worked, took the toilet apart, and finally re-examined their predictions. One school used their first graders as “master plumbers” and gave them the task of coaching the kindergartners: the first graders had had the toilet the week before.

First graders also started by guessing what was in the toilet and how it worked. Guesses ranged from an internal engine to electricity to some relatively accurate drawings. Then they attacked the toilet with tools. Again, the girls tended to be more methodical in
dismantling the toilet, and were more likely to put everything back together. The boys were faster to take apart but had problems with reassembly. Further, the girls tended to work more effectively as a team, whereas the boys preferred working individually.

Second and third graders followed the same pattern. The student pre and post assessments of how the toilet worked improved with age. Toilet tanks went from a nest of pipes to the simple ballcock mechanism. It was interesting to note that generally, the girls tended to have less mechanic detail and more to their picture than just the toilet. The boys pictures centered around the inner mechanics of the toilet.

Some classes concentrated on the concept of invention - letting the students create new and “better” toilets. Others looked at the environmental aspects of the toilets - how many flushes per day per person at home? They examined water usage and where the water went (sewer and septic systems). A third group integrated it with literature - reading books on plumbers and engineers or writing and reading poetry on water usage and toilets. Some even composed and sung songs - performed in plumber clothes. In general, the overall response was that the children truly enjoyed taking the toilet apart and comparing what they guessed with what was really there. Parents - too - responded very favorably to the project - as long as the toilets at home were left untouched. In fact, the program inspired some parents to learn about the toilet on their own.

V. Conclusions

The most successful part of the program was not the toilet, but rather introducing the idea of learning by taking things apart. Teachers continued these projects with radios, toasters, and many other old household appliances. Further, they found the technique of facilitator over lecturer was very effective. The students learned faster and better if they came to the solution on their own, being guided along the way with probing questions.

At Tufts, we continued the project the next year, applying the same technique to the bicycle in an effort to teach the fundamentals of force and torque. The teachers enthusiastically built over 30 bicycles to take into their classrooms for their students to dismantle and try and reassemble. The number possible science and engineering concepts that can be taught through this dissect and discovery method is enormous. We hope that more and more teachers will adapt a hands-on, group learning method to interest more of the next generation - especially females - in science and science-related fields.
Acknowledgments

The authors would like to acknowledge the support from the Dwight D. Eisenhower Mathematics and Science Education Act. They would also like to thank Mark Carletti for putting together more toilets than most plumbers, Sherrill Cook for assembling the an excellent teaching manual, and the numerous undergraduate and graduate students associated with the project as well as the science coordinators and the teachers for helping taking and idea and bringing it into the classroom.

References


Figure 1: A Schematic of the Toilet