Engineering with Dartmouth: Development of Engineering Modules for Middle School Students

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Abstract – This paper describes a new informal program, Engineering with Dartmouth, through which Dartmouth students – both undergraduate and graduate students – develop and run engineering modules for middle school students. The Dartmouth students work with the author as well as local teachers to develop activities that fit with the curriculum and expose middle students to engineering. Modules focus on hands-on, inquiry-based activities that are designed to foster creativity. The modules are adapted from existing, widely available curricula available online. The advantage of the program is that while the module descriptions are archived and available online, teachers may also contact Dartmouth to request that a faculty member or student come to their classroom to run the activity. All of the supplies needed for the modules are stored on campus through the Office of Outreach and Dartmouth students are available to run the activities and serve as role models for the middle school students.

Keywords: K-12, outreach, middle school, inquiry, and creativity.

BACKGROUND

Overview

For the past two years students at Dartmouth, both undergraduate and graduate students, have been developing engineering modules and teaching engineering in local middle school classrooms. While some of the modules were developed as part of the Dartmouth GK-12 Project, Fostering Scientific Creativity by Building Connections and Improving Science Communication Skills, others were developed as independent study and honors thesis projects. In all cases, the students developed the modules collaboratively with middle school teachers and were able to test the modules with local middle school students. Dartmouth students interested in developing engineering modules for middle school students are paired with local middle school teachers interested in incorporating engineering into their curriculum. The Dartmouth students then work with the local teacher and receive training and feedback from Dartmouth faculty and staff as they develop a module.

As part of the GK-12 project, we ran focus groups with local middle school teachers who reported that developing creative, inquiry-based projects and enriching existing curriculum were high priorities. They also told us that they seldom have time to develop longer-term projects and that help developing such projects from Dartmouth students and faculty would be very beneficial. The goal of these activities is not to replace the middle school curriculum but to enrich and enliven it and to build connections between engineering content and the real world.

Each module consists of a curriculum guide with explicit guidance as to how to run the activity, how it relates to state standards, and all supplies needed to run the activity. Curriculum guides are published on the Dartmouth web page through the Office of Outreach so that they may be accessed by middle school teachers anywhere (http://www.dartmouth.edu/~academicoutreach/gk12/inquiry.html). Local middle school teachers may request that a

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While many engineering lesson plans are available on-line including many on the ASEE website (http://teachers.egfi-k12.org/), these lessons still require teachers to collect supplies, test the activities, and research relevant background information. In contrast, through the Engineering with Dartmouth program the students collaboratively develop (or adapt) engineering activities with the teachers such that they fit the curriculum, do background research, collect supplies, and test the activities. In exchange engineering students gain teaching skills, while serving as role models for middle school students. Additionally, middle school teachers gain access to Dartmouth resources and Dartmouth researchers are able to develop more effective outreach plans for grants.

Middle School Students and Teachers

A fundamental problem in attracting students to engineering is a poor understanding of what engineers do [1]. A recent survey of over one thousand students ranging in age from 13 to 18 found that a lack of familiarity with engineering is a significant barrier to considering engineering as a career [1]. Teens who were considering engineering as a career were more familiar with engineering and reported perceiving engineering as interesting and gratifying, while those who were not considering engineering as a career were unfamiliar with engineering and the role of engineers [1]. The Engineering with Dartmouth program thus seeks to expose middle school students to engineering so that they are more likely to pursue engineering, as well as math and science, as a career.

The Engineering with Dartmouth program focuses on middle school students since student interest toward science and math, particularly among girls, tends to decline at these grade levels [2] as student attitudes shift toward viewing science not as a creative process of discovery, but instead as “facts to memorize” and “boring” [3]. The program seeks to foster in middle school students the engineering creativity and inquiry that is often lost in the emphasis on accountability and technical details.

Goals and Objectives

The main goals of the Engineering with Dartmouth program are to expose middle school students to engineering and provide opportunities for Dartmouth students to teach and improve their communication skills.

- Dartmouth students will improve their teaching and communication skills through interactions with diverse audiences and the development of curriculum guides and modules for middle school students;
- Middle school students’ learning of and attitudes toward engineering (as well as math, science, and technology) will improve by working with role models on modules that encourage creativity;
- Middle school teachers will have access to Dartmouth resources; and
- Dartmouth researchers will be able to develop more meaningful outreach plans for grants.

DARTMOUTH STUDENT TRAINING

Introduction

Prior to entering the middle school classroom, the Dartmouth students are given basic training in effective teaching through workshops and classroom observation. Training is provided through the Dartmouth Center for the Advancement of Learning as part of the GK-12 project but all interested students are welcome to attend the workshops. The workshops focus on learner-centered teaching [4] using collaborative learning strategies [5] and topics include the principles of learning [6,7], classroom management, course design [8,9], inquiry-based learning, creativity, sharing, and microteaching. Workshops are run by Dartmouth faculty and staff (including the author) as well as local teachers. The Engineering with Dartmouth program was started as a pilot for extending the GK-12 project beyond the five years of the grant; four engineering students outside the GK-12 project have participated to date.

Module Development and Sharing

Training associated with the Engineering with Dartmouth program is focused on the development of engineering modules for use in middle school classrooms that are inquiry-based, hands-on, and foster creativity. Inquiry-based science, when carefully implemented, has been shown to increase student achievement [10]. Using inquiry-based learning, students engage in scientifically-oriented questions, formulate explanations based on evidence, evaluate their explanations in light of alternative explanations, and communicate and justify their proposed
Creativity is fostered by exposing students to a wide range of ideas and experiences that allow them to make connections and create novel ideas. While creativity is often associated with the arts, it is a critical element of engineering required in many aspects of the engineering process including the ability to reframe problems, interpret data, and create new processes and products [12]. The Engineering with Dartmouth program is designed to encourage Dartmouth students to share with middle school students not only an appreciation for the discipline and rigor of engineering but also for the individuality and imagination involved. The hypothesis is that fostering scientific creativity will improve middle school students’ and teachers’ attitudes toward engineering.

Dartmouth students work together and with local teachers to develop or adapt activities that fit with the curriculum in specific classrooms. The modules are typically short, one-hour activities but some include multiple sessions. By working collaboratively with the teachers, the modules may be tied directly to the curriculum and state standards. Modules, once completed, are listed on the Dartmouth web page through the Office of Outreach so that they may be accessed by middle school teachers anywhere (http://www.dartmouth.edu/~academicoutreach/gk12/inquiry.html). Local middle school teachers may request that a Dartmouth student or faculty member come to their classroom to run an existing activity or help them develop a new activity or they may use the materials posted to develop the activity themselves.

Each module consists of a curriculum guide and all required material to run the activity. The materials for each activity are currently stored with the Office of Outreach but as more modules are developed and space becomes an issue, module material may be stored with individual faculty. The curriculum guide includes the following sections:

- Overview – an overview of the activity;
- Focus Question – the main question that the activity addresses;
- Science standards – specific state standards for New Hampshire or Vermont that the activity;
- Objectives – what is the learner expected to learn or be able to do upon completion of the module?;
- Background – background information for the teacher related to the activity to provide them with some depth of understanding;
- Materials – what materials does the teacher need to collect for the activity;
- Vocabulary – definitions for key terminology used for the activity;
- Preparation – what does the teacher need to prepare before running the activity;
- Procedure – this provides a guide for the teacher running the activity;
- Assessment – how should the activity be assessed? How is student learning demonstrated?;
- Extensions – how could the activity be extended beyond the basics for students interested in further exploring the topic;
- References – any references used to develop the curriculum guide should be included especially if the activity was adapted from an existing activity;
- Handouts – any handouts that are needed to run the activity should be included in with the curriculum guide in a form that they may simply be printed out.

Prior to running their activities in middle school classrooms, the Dartmouth students teach their modules to their peers, Dartmouth faculty and staff, as well as local middle school teachers. Based on feedback from these microteaching sessions the students may change or adapt their modules and will often re-teach them on campus before moving on to the middle school classrooms. Microteaching and classroom teaching provide opportunities for the Dartmouth students to gain confidence in teaching and improve their communication skills.

Assessment

Since two of the main goals of the modules are that they be inquiry-based and that they foster creativity, an assessment instrument that measures the level of inquiry and creativity is used. The instrument is based on one developed by the National Research Council [11] and is included in the appendix of this paper. The original scale was developed to measure the level of inquiry involved in classroom activities from those with more learner self-direction to less learner self-direction and less teacher direction to more teacher direction using a scale from 1 to 10 [11]. The instrument was adapted to include items to measure creativity; for example one of the items added to the modified instrument goes from “Learner given opportunities for creativity” to “Activity is prescribed.” Dartmouth students helped to develop the new items for the instrument during a workshop focused on assessment. It has been used to assess each of the modules to date. While there is no ‘correct’ answer and modules are not expected to be fully learner-centered, Dartmouth students are asked to justify why activities might need to be more prescribed
(students in classes where inquiry has never been used may not be ready to participate in an activity that is fully inquiry-based) and where they may be modified to encourage more inquiry and creativity. The instrument is really meant to generate conversation and reflection on the modules rather than being a definitive measure of the modules.

Reflection

Reflection is a key component of the workshops. The workshops are designed to give the Dartmouth students the opportunity to assess their own instruction and instructional materials and to consider how various methods of instruction affect learning. They also provide an opportunity to reflect on how their experiences contribute to a deeper understanding of their own future classroom teaching and research. Students are required to develop clear learning objectives [8, 9] for their classroom activities and to create an assessment plan to meet these objectives. In addition, they use Stephen Brookfield’s four lenses [13] — their perspective, the perspective of the learners (the middle school students), the perspective of their colleagues (other Dartmouth students as well as middle school teachers), and perspectives from the theoretical literature — to reflect on their experiences and to improve their teaching and the program in general. Sessions for reflection and discussion are built into the program to allow the Dartmouth students time to reflect on and share their experiences in the classroom and throughout the development process.

Modules

Engineering modules developed to date range from short, one-hour long activities to longer, multi-session activities that span full terms. The following modules have been developed: Building Motions in Earthquakes, Introduction to Light, Race Cars, Nanotechnology, Robots, and Wind Turbines. The wind turbine module is described herein as an example.

Overview

Nathaniel Brakeley, a Dartmouth engineering student who has since graduated developed a wind turbine module that as part of his senior honors thesis. The module includes a curriculum guide, all the materials needed to run the activity, and handouts for the students and a brochure for parents. The module is meant to be a short, one time activity that takes about 2 hours to complete. Nate chose to combine his interests in wind energy and education through the project. As an emerging green technology, wind power is an exciting and visual way for engineers and non-engineers to explore problem solving and engineering design. Not only are basic turbines easy and inexpensive to build, they require very little technical knowledge to make function, at least at a basic level. However, they provide many opportunities to explore engineering concepts and experiment with different variations on blade designs and configurations.

Designing simple and easy to use model turbines was a crucial element to the project. As these turbines would be used by both young students and unfamiliar teachers, it was important to create a mechanism that would be both durable and self-explanatory. Nate sought to build wind turbines for which middle school students could design and build blades to test which designs generated voltage and current.

While building a functioning wind turbine is a relatively simple task, there are few commercial off-the-shelf products that allow for fast switching of turbine blades and easy voltage and current readings. The internet has many resources for building one’s own turbine, but the various materials and construction techniques are often too time-consuming and involved for a single lesson. KidWind is a company that is seeking to change this. They have developed a number of wind and renewable energy products, including student wind turbines. Nate chose to purchase the KidWind hub, which is shown in Figure 1, but to build his own horizontal axis wind turbine using PVC pipe and plywood, as shown in Figure 1, to reduce the overall cost. He also bought and collected supplies for making blades including dowels, cardboard, paper plates, paper towel tubes, pieces of wood, and other materials. The total cost of the wind turbine he designed and built was less than $20, not inclusive of the material for the blades or wind source. He used a high-powered, variable speed fan to test the effectiveness of different blade designs.

The most important — and fun — aspect of the wind turbine lesson is understanding and designing the turbine blades. There are a phenomenal number of variables involved with this process, including length, material, shape, pitch, and number of blades.
Blade Design

The KidWind hubs allow for quick insertion of 0.25" dowels, so any material that can be hot glued or duct taped to a dowel can be used. These include cardboard, foam core, pyroxyrene insulation, and cardboard tubes. With the small size and relative instability of the generator, material weight is a big concern. Another way to make effective blades for a turbine this size is to mimic the design of a basic pinwheel by using a paper plate or pie tin. This design ends up being more akin to older windmills used for grinding grain or pumping water, but it is useful in further helping students understand wind flow and wind power. Sample blades were developed both to test the turbines and to give students, especially younger ones, a jumping off point in their engineering design process. One set was made from foam core and one was made from cardboard tubing:

Output Measurement

To measure output from the turbine, it is important to have a visual way for students to see the relative merits of their blades. While a multimeter is certainly the most accurate way to measure generator output, it simply provides a number, which will often be meaningless to a student who has not been exposed to “volts” or “amps” before. Therefore, a visual voltmeter, which is shown in Figure 2 was purchased. The voltmeter has a strip of multicolored LED lights that indicate the measured voltage. Thus the students have the visual objective of lighting as many of the LEDs as possible. In this case voltage is also directly proportional to power, so more lit LEDs corresponds to more electrical power.
**Student Activities**

The most important goal of the wind turbine activity is that the students experience a fun example of engineering problem solving. There are a large number of variables associated with blade design. The students are encouraged to isolate one variable, for example, blade angle. A hypothesis is posed as to both the effects of altering this variable, and to the optimal value. The student then experiments with varying values, which are input into the activity sheet that is provided. At each value, a multimeter is used to measure voltage and current, from which a student can solve for power developed. A blank graph is supplied for this data to be graphed, so that any trends in the data can be visualized.

Following this, the student is asked to recount in words what s/he has experienced, in an attempt to develop an engineering vocabulary. Further, the student is asked to explain why the observed phenomena happened. If he or she cannot explain what happened, hopefully an overseeing teacher or moderator will be able to help discover the explanation. Finally, the student is asked to think about lingering questions for the experiment, either to be the subject of future experimentation or future inquiry.

**Trial**

On May 25, 2012, the activity was brought to the Lyme After School Program (LASP) at the Lyme Elementary School in Lyme, New Hampshire, where students aged 5-12 took part in the wind turbine activity. This was part of a general after school program, so no prior engineering knowledge was assumed.

Students were first given a primer on wind turbines—how they work, what they produce, and the difference between horizontal and vertical axis turbines. Because of the younger audience and their shorter attention span, the implications of green energy were not explored. A brief discussion of turbine blades was held, describing some good and bad practices, and then the students were allowed to begin the design process.

**Student Blade Designs**

Some of the early blade attempts, as predicted, performed quite poorly. Students made blades with the most material at the outer radius, and many with almost the whole dowel exposed between the hub and the start of their blade. However, the iterations began to improve, and with some coaching the students began to improve their blades. After all students had a chance to try their blades, the most voltage developed was 0.75 V. At the end of the activity, one student had achieved 3 V, for a 400% increase in voltage. Predictably, the concept of voltage was beyond the scope of many of the students, so rather than try to explain it—even with the water analogy—the students were simply encouraged to “light as many lights as possible.” The best example of the design process occurred with one student who began at 0.75 V and ended by achieving 3 V. The blades iterations are pictured in Figure 3.

![Figure 3: Student Blade Iterations](image-url)
down the turbine’s rotation. Further, the blade radius was larger than that of the fan. Looking to shrink her blades, the student made the mistake of seating the blade too high on the dowel and therefore further away from the hub. The blade still had stiffness problems as well. The last iteration shrunk the blade way down, and also eliminated much of the material far away from the supporting stiffness of the dowel. Further, the number of blades was increased to eight. It was this arrangement that led to the 3 Volts.

Teacher Reaction

The teacher in charge of the students was Megan Wilmott. She assisted in the activities, largely in the role of helping students construct their blades. As a professional educator, she has witnessed and experienced a number of similar science-based outreach activities, and is therefore in an excellent position to comment on a particular program’s strengths and weaknesses.

Megan spoke highly of the strategy to allow students to “jump-in” with minimal step-by-step guidance other than general turbine blade strategies. This allowed students to take ownership of the project, and to take their design inquiries in a direction of their choosing. Further, during the testing process, students were asked for input as to what speed to run the fan, which Megan praised as a simple way to involve them in the process. As to the feedback given to students, Megan thought:

It was also great how you spoke with each child on their design and why it may or may not be working well. This got them thinking about how they could make changes to get more lights to light up and they would turn to immediately make the changes that you talked with them about.

With this age range, it was important to give specific blade feedback such as “try moving your blades closer to the hub,” rather than speaking in more general engineering terms such as “your blades are creating too much drag” as the students are not yet equipped to make connections between the two phenomena.

Megan’s main criticisms dealt with logistical shortcomings, such as a dearth of construction materials. The students often desired to make completely new blades rather than modify their originals, thus using supplies quickly. In the future it will be important to make sure there are enough materials for each student to make several complete sets of blades. A large variety of materials seemed to help foster creativity.

DISCUSSION

Overall, the wind turbine activity was a success. The youngest students found some success with their blade design, while the more experienced and knowledgeable students were able to graph their results and use equations to predict the response.

Using the assessment tool included in Appendix A, the activity scored highly on the continuum for inquiry as it allowed the students to generate their own questions related to blade design as well as for creativity by allowing them to choose the materials they used to create their blades.

The author has since had two requests from teachers to visit their classrooms to run the wind turbine activity and in one case a teacher borrowed all of the materials and ran the activity herself.
The Engineering with Dartmouth program is just beginning, the hope is to grow the program to include many more modules that may be used in local schools providing opportunities for local K12 students to learn about engineering and opportunities for Dartmouth students to gain teaching experience. The main goal of the program is to expose middle school students to engineering while providing opportunities for Dartmouth students to gain teaching experience. The collaborative development of the modules by Dartmouth students and local teachers has helped to strengthen the program and make adoption of the modules more likely.

REFERENCES


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APPENDIX A – MODULE ASSESSMENT

Assessment of Module Activities

Activity: ___________________________________________

Circle a number from 1 (more learner-centered) to 10 (less learner-centered).

<table>
<thead>
<tr>
<th>More Learner Self-Direction</th>
<th>Less Learner Self-Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less Teacher-Direction</td>
<td>More Teacher Direction</td>
</tr>
<tr>
<td>Activity is focused on questions</td>
<td>1 2 3 4 5 6 7 8 9 10 Activity is focused on content</td>
</tr>
<tr>
<td>Learner poses the questions</td>
<td>1 2 3 4 5 6 7 8 9 10 Teacher provides the questions</td>
</tr>
<tr>
<td>Learner determines what constitutes evidence and decides how to collect it</td>
<td>1 2 3 4 5 6 7 8 9 10 Learner given data and told how to analyze it</td>
</tr>
<tr>
<td>Learner independently determines connections between evidence and scientific explanations</td>
<td>1 2 3 4 5 6 7 8 9 10 Teacher provides connections</td>
</tr>
<tr>
<td>Learner given opportunities for creativity</td>
<td>1 2 3 4 5 6 7 8 9 10 Activity is prescribed</td>
</tr>
<tr>
<td>Learner is encouraged to generate multiple solutions</td>
<td>1 2 3 4 5 6 7 8 9 10 Learner focuses on a single, 'right' solution</td>
</tr>
<tr>
<td>Learner may choose different materials and approaches</td>
<td>1 2 3 4 5 6 7 8 9 10 A single set of materials and approaches are provided</td>
</tr>
<tr>
<td>Learner is encouraged to try different approaches even if some of the approaches fail</td>
<td>1 2 3 4 5 6 7 8 9 10 Failure is discouraged</td>
</tr>
<tr>
<td>Learner is encouraged to come up with a unique or crazy solution</td>
<td>1 2 3 4 5 6 7 8 9 10 Conventional solutions are encouraged</td>
</tr>
</tbody>
</table>

Comments and Observations: