# Engineering Based Math and Science Curricular Units Implemented in 4th, 5th and 8th Grade Classrooms: A Case Study

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## 1.0 Introduction

Adventure Engineering (AE), launched in 1999 with funding from the National Science Foundation, is a middle grade science and math outreach initiative aimed at students who, without the benefit of a positive mathematics and/or science applications experience, will not otherwise consider technical careers in mathematics, science, and engineering. AE creates adventure-based curricular units designed to more effectively teach required math and/or science concepts. The curricular units are aligned with national and state math and/or state standards. Content is aligned with national concepts, standards and principles, and is fueled by engineering problem solving and design.

This case study describes the implementation of AE math and science curricular units in urban and suburban 4th, 5th and 8th grade classrooms during Fall 2002. The curricula implemented were *Lost in the Amazon* (4th and 5th grade), *Asteroid Impact* (8th grade), and *Volcano Engineering* (8th grade). Student teams were created in each classroom, teachers led the implementation of each unit, and AE Fellows (undergraduate and graduate engineering students) observed and assisted the teachers when necessary. AE fellows also conducted assessment of student attitudes, student content knowledge, and teacher perspectives. The paper will chronicle the implementation of each curricular unit and report on teacher and student experiences.

## 2.0 Adventure Engineering Overview

AE strives to (1) improve interest in and attitudes towards mathematics, science and engineering; (2) improve concept learning in science and math; and (3) provide a minds-on, hands-on, meaningful and enjoyable experience. The AE program involves the development and implementation of single day to four-week adventure-driven engineering-based curricular units for grades 4 through 9 science and/or math classes. Given a designated time period and concepts identified in national math and science standards, the AE team develops an adventure-based scenario filled with obstacles that require the learning and application of the desired science and/or math concepts. All curricula are inquiry-based and open ended; activities are designed to facilitate concept understanding and immerse students in the engineering design experience. The AE program is described in detail elsewhere (Mooney et al. 2002a,b,c).

## 3.0 Description of Curricula

*Volcano Engineering* is a 6-8 day curricular unit composed of seven obstacles described in Table 1. In *Volcano Engineering*, 8th grade students assemble into engineering teams and design a rover to obtain information from inside a volcano. Student teams are launched into the curricula by reading the following scenario:

> *Several engineers at Volcano Engineering Inc. have been injured in recent years attempting to investigate volcanoes. They have been attempting to develop technologies that can predict the exact time of eruption and the severity of eruption so that nearby towns can plan accordingly. You are now given the responsibility of designing an automated rover to go into the volcano and do the work of a human investigator. Your team must develop the features that your rover would need to determine, e.g., (1) is the mountain a volcano? (2) when will the volcano erupt? and (3) how severe will the eruption be? When your team has designed the rover, you will prepare a written report and a 5-minute presentation.*

Within the curricula, each student team uses a five step Engineering design process (EDP) to design the automated rover. Students apply the concepts they learn through an inquiry approach, a critical component of AE curricula. To accommodate different types of learning environments and to promote critical thought, the rover design activities are left open-ended for teachers to tailor for their students. Students will be able to build or draw a design.

**Table 1 – *Volcano Engineering* Activities**

| **Activity** | **description** |
|---|---|
| *Finding the Possible Source* | Map latitude and longitude data of known volcanoes and determine that the pattern they exhibit forms a Ring of Fire around the Pacific. |
| *Hot Spots* | Use shaving cream sprayed through a map of the world with holes cut into it to understand that volcanoes can form anywhere the earth's crust is thin or fractured. |
| *Gelatin Volcano* | Understand the structure of a volcano by looking through a clear gelatin model. |
| *Boom* | Create an explosive eruption by building up pressure inside a model volcano. Understand that pressure measurements could help predict the type of eruption. |
| *What are those Bubbles?* | Use a chemical reaction to measure the level of $CO_2$ produced by vinegar addition to baking soda. Learn that Chemical Engineers design reactions and reaction vessels to model natural phenomena like $CO_2$ level. |
| *Water and Honey: Sticky Race* | Pour liquids of different viscosity to see which one flows faster to model lava flows. |

| | |
|---|---|
| *Capstone* | Design a rover that carries the technology needed by scientists to investigate a volcano |

*Asteroid Impact* is an 8th grade curricular unit composed of eleven activities, shown in Table 2. *Asteroid Impact* requires students in an earth science class to assemble into engineering teams and design an underground cavern to house and protect the inhabitants of their state. Student teams begin their learning adventure by reading the following scenario:

> *NASA astronomers have detected an immense asteroid headed directly for Earth. The asteroid diameter at the point of impact with Earth is estimated to be approximately 1 kilometer. NASA engineers believe the asteroid will impact the earth within the continental United States; however, they can not precisely determine where. Scientists have previously determined that the asteroid believed to have been responsible for the destruction of life on earth in prehistoric times was of similar size to the one heading for Earth. That prehistoric impact resulted in a dust cloud that covered the planet for an entire year, suffocating living organisms and blocking the sun's heat, causing a worldwide winter. State governors have been instructed by the President to develop a plan that will ensure the survival of all citizens. You have been chosen by the governor of your state to be part of an engineering team responsible for designing underground living quarters to house all the people in your State.*
>
> *There are numerous rock formations well suited for the construction of underground living areas. Your engineering team's responsibility is to determine the best location or locations. To accomplish this, your team will have to explore geological maps of your state, test rocks and identify important rock properties. Your main goal is to determine the best candidate location(s) for your caverns. Good Luck. Your state is counting on you!*

*Asteroid Impact* also uses the five-step Engineering design process. Activities use inquiry to allow students to discover facts they will need to use to draw a final conclusion. Upon presenting all possible locations picked by the engineering teams, the class will ultimately pick the best location to use as a safe place in case of an asteroid impact.

**Table 2 – *Asteroid Impact* Activities**

| ACTIVITY | DESCRIPTION |
|---|---|
| *Engineering Design Process (EDP)* | An explanation of the process engineers use in problem solving. |
| *What is Important?* | Define the problem. |
| *Initial Research* | Information gathering. |
| *Determination of Cavern Depth* | Develop cavern specifications. |
| *Mineral Identification to Help Determine Cavern Location(s)* | Mineral testing to determine suitable place for underground cavern. |
| *Reading Maps to Determine Cavern Location(s)* | Locating places suitable for underground cavern by analyzing geologic maps. |
| *Rock Identification* | Identifying rocks by physical and chemical properties. |
| *Determine Acceptable Rocks* | Analyze data priory collected to determine acceptable rocks. |
| *Solution Identification* | Analyze collected data and propose design solutions. |
| *Location Analysis* | Analyze data to determine acceptable locations. |
| *Decision Time* | Pick the best location to build an underground cave. |

The *Lost in the Amazon* curricula is written for 4$^{th}$ and 5$^{th}$ grade math and science classes. It is composed of five activities design to be implemented over a 7 to 10 day period. The curricula is introduced with the following scenario:

> *Your engineering firm has just spent a week in Brasilia, the capital of Brazil learning about the plants and animals of the rainforest and about how they can develops ways to save the rainforest. On your way home your plane crashes deep in the Amazon, at latitude 2 ½ °S and longitude 60°W. You must survive the hot, humid terrain using limited supplies and make your way to the nearest city of Manaus to save your team.*

Due to the fact that the *Lost in the Amazon* curricular unit is intended for younger students, the engineering design process was not explicitly enforced during implementation. Instead, more basic concepts of engineering were continually emphasized throughout.

**Table 3 – *Lost in the Amazon* Activities**

| ACTIVITY | DESCRIPTION |
|---|---|
| *The Crash Scene* | Determine the location and coordinates of the crash site, and approximate travel times to safety. |
| *The Need for Shelter* | Evaluate materials and supplies and determine what will be essential on the trip due to weight limitations. |
| *The Growling Stomach* | Specify and present various edible plants and animals based on group research. |
| *Where is the Water?* | Design and test water purification systems made from household items. |
| *Attack of the Raging River* | Selection of the best materials and methods for constructing a model raft capable of transporting students to the final destination. |

## 4.0 Implementation

Table 4 summarizes the key data of each implementation. Curricular units were implemented in 4$^{th}$ and 5$^{th}$ grade math/science classes and in 8$^{th}$ grade science. Only the *Asteroid Impact* was implemented in an elective science class. With the exception of the *Asteroid Impact* implementation, the male/female ratio was approximately one. Teaching styles of the participating teachers ranged from traditional lecture to inquiry.

**Table 4- Fall 2002 Completed Implementations**

| Curricular unit | School (Grade) | Number Students | M/F | Teaching Style | Normal Format | AE Team Structure (# in group) |
|---|---|---|---|---|---|---|
| *Asteroid Impact* | (8th-elective) Discovery Science | 32 | 24/8 | Guided teamwork | Inquiry activities | 6 Boy groups (4) 2 Girl groups (4) |
| *Volcano Engineering* | (8th) Earth Science | 109<br>5 classes | 59/48 | Guided: 1/2 Team 1/2 Individual | Guided inquiry | 3 or 4 mixed |
| *Lost in the Amazon* | (4th & 5th) Math & Science | 24 | 13/11 | Strong mix - student driven | Inquiry | 6 mixed groups (4) |
| *Lost in the Amazon* | (5th) Math & Science | 21 | 11/10 | Structured, controlled | Tell them & test them | Mixed groups (2-3) |

## 5.0 Student Reactions

Prior to participating in the AE curricular units, 5$^{th}$ and 8$^{th}$ grade students were asked general attitudinal questions, including "Do you think most people should study science?" and "Describe what an engineer does?" The student responses to the first question in both 5$^{th}$ and 8$^{th}$ grades are shown below in Figure 1. Over 90% of the students believe people should study science and little difference was observed between these two grades.

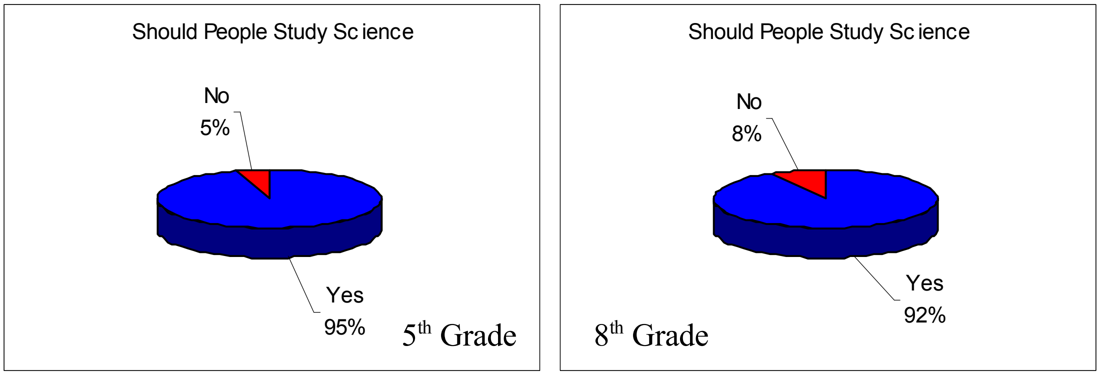


**Figure 1: 5th and 8th Grade Feeling that People Should Study Science.**

Student understanding of engineering at the 5th and 8th grade levels is depicted in Figure 2. The short answer responses of this question were graded on a four-tier scale from poor to excellent understanding (Laubach, 2002). The poor category of understanding implies a blank or "I don't know" response, as well as any reference to trains. Answers with references to "building" or "engineers build…" were categorized as fair. Answers that included "design" were considered as good, and specific examples of engineering design, e.g., "design an airplane, design a building" were categorized as excellent.

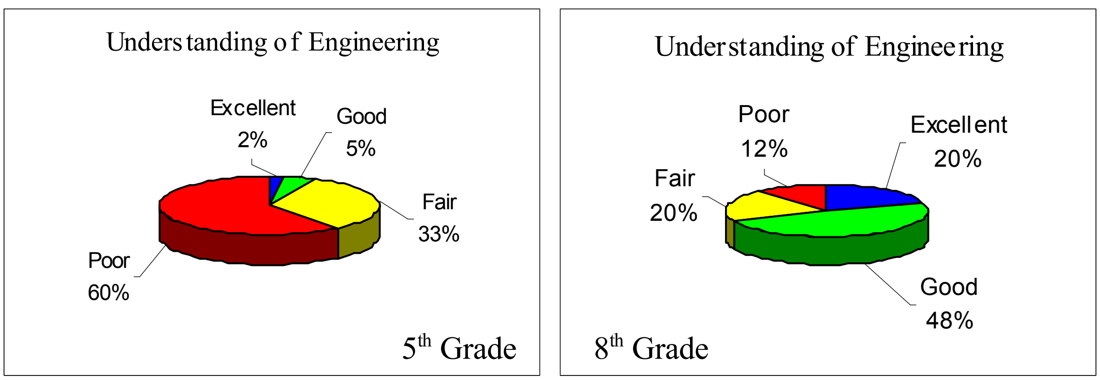


**Figure 2: 5th and 8th Grade Pre-Implementation Understanding of "What Engineers Do."**

Sixty percent of the 5th grade students had a poor understanding of engineering compared with 12% of 8th graders. Further, only 7% of 5th graders exhibited an excellent or good understanding of engineering compared with 68% at the 8th grade level. While limited in number, these results illustrate the importance of the middle grade levels to engineering outreach. To this end, the 4th and 5th grade curricula focus more on explaining engineering to improve better student understanding. At the 8th grade level, the curricula emphasize the methods of engineering via the EDP.

Despite the limited 5th grade knowledge of engineering, the thought of doing extensive hands-on activities excited the majority of the students, resulting in significant interest in the *Lost in the Amazon* curricular unit. Students commented that they had “never done fancy experiments” and were wondering how “engineering can be fun?” This excitement towards the hands-on projects was maintained throughout implementation, and created initial student interest in the required worksheets. By having fun with *Lost in the Amazon*, students seemingly changed from their conception that engineering “can’t be exciting,” as exemplified when students occasionally skipped recess to do extension activities and frequently asked if they could “take [the projects] home.” One limitation to the 4th and 5th grade curricula was the amount of worksheet activity. Students soon found the worksheets to be ‘boring’ and ‘not as fun as building.’

Eighth grade students demonstrated strong interest in the *Volcano Engineering* and *Asteroid Impact* scenarios. The brainstorming activities revealed a genuine interest in the subjects. Enthusiasm was evident in student responses, as well as the passionate manner in which they pointed out the important aspects that would be required for the design projects. In the beginning it was thought that the students would need significant guidance to achieve the same important properties for design, however, after fifteen minutes of brainstorming, writing potential design factors on the board, and voting on the best responses, they had obtained the EXACT same list that AE fellows had come up with upon creation of both the *Asteroid Impact* and the *Volcano Engineering* curricula. The 8th grade teachers involved in the *Asteroid Impact* implementation indicated that the brainstorming exercise was the first lab that they had done that each and every student in the class contributed, paid attention, and seemed interested in the outcome.

The rover design project in the *Volcano Engineering* curricular unit gave the students an opportunity to express their creativity through drawing a rover for data collection in a volcano. Two examples are shown in Figure 3. To both the AE Fellows and the teachers, the drawings were impressive. There was not one drawing that did not take all of the important design factors into account. The parents of one normally distant student phoned the teacher to say that their son was so interested in the project that he spent many hours at home on the rover design. This type of enthusiasm was non uncommon, as there were many of the teams of students that took much pride in their final products. Some of them wanted to take them home after they were done to show their parents and siblings.

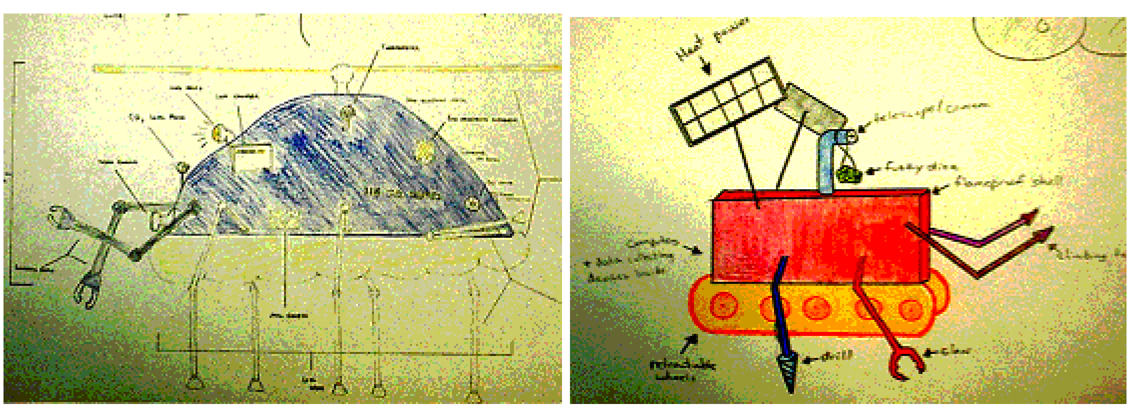

**Figure 3: Examples of Rover Designs in the 8th Grade Volcano Engineering Curricular unit Capstone Design**

We found that the interest and excitement towards *Lost in the Amazon* did little for the 5th graders' retention of knowledge about engineering, unless the lessons were explicitly reinforced following implementation. Without prompting the students with specific examples as to how the activities related to engineering, responses similar to "an engineer builds things" were still offered. Natural competitive instincts enhanced group work experiences, highlighted by "high-fives" between team members and incredible pride taken in product performance. While difficulties frequently arose amongst team members, a simple explanation of interpersonal issues as common and valuable to engineering helped the teams. This culminated in students referring to "good team worker" as a valuable engineering trait as opposed to the initial "good with calculators."

While the 5th grade students might not have fully retained knowledge regarding specific engineering practices following implementation, they did receive extensive exposure to engineering. Most students seemed to grasp basic engineering principles such as planning, designing, and investigating alternatives. Moreover, the importance of teamwork in engineering seemed to become more familiar to the students as the activities continued. Students were capable of noting that a good engineer "plans before building", investigates alternatives, and knows that "there is no wrong answer" when designing. This noted improvement is supported by post-implementation assessment (see Fig. 4). The percentage of students with a poor understanding of engineering decreased from 60% to 20% as a result of the AE curricular, and the percentage of students with a good or excellent understanding of engineering rose from 7% to 26%.

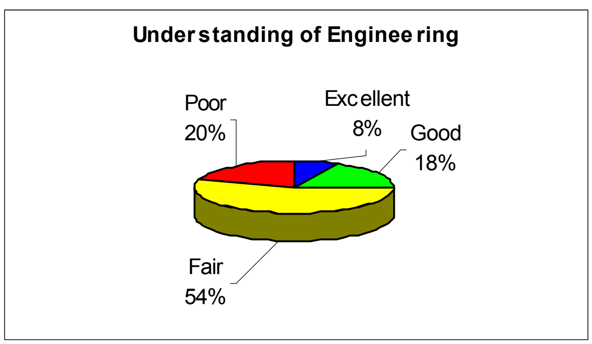


**Figure 4: 5th Grade Post-Implementation Understanding of "What Engineers Do"**

Post-curricular assessment was not conducted in the 8th grade classrooms. However, we found that 8th grade students successfully used the EDP to guide them through inquiry lessons on earth science topics. This hands-on approach made the students search for the answer rather that being handed it. We found that the engineering based approach was very effective in relating the science concepts to real life. For example, in *Asteroid Impact*, the students were required to determine the properties of the rocks that are located in their home state. Properties like strength and density were abstract to the students until they were required to use them in their cavern design. This application of abstract terms to a real problem reinforced concept understanding. In *Volcano*

*Engineering* the abstract term viscosity was reinforced for the students by illustrating that a volcano would be much more dangerous to the surrounding areas if the lava has less viscosity. This made the term a real property and connected it with the students' current understanding.

**6.0 Teacher Feedback**

Prior to the implementation of each curricula, the teachers who voluntarily participated in the program expressed varying opinions concerning the attitudes towards engineering, engineers, and the projected outcome of the program overall. Even though the teachers were not completely familiar with the subject of engineering, they showed interest in learning and expanding on the topic in their classrooms. One particular teacher demonstrated an overwhelming positive attitude towards the subject of engineering and how her students would benefit from being exposed to it at their level. Both teachers who implemented *Lost in the Amazon* had previously had a role in offering input during curricula development and were therefore excited about incorporating it into their math and science classes.

The teachers valued the initial introduction to engineering that the students were given prior to implementation. At the $4^{th}$ and $5^{th}$ grade levels, the teachers felt that it was important to link topics together and have the students be able to relate the adventure they were about to embark on with the basic principles of engineering. The introduction, which teachers nationwide will ideally be able to conduct on their own, provided a solid foundation that allowed the continuity throughout the adventure and kept the attitudes of the teachers and students positive and with anticipation throughout. Teachers particularly expressed their appreciation for the mix of conceptual and hands-on engineering based activities. Teachers commented on the active involvement of both male and female students and they also shared in their students' excitement in testing the final products of their obstacles. Teachers took an active role after the activities had been completed to reinforce the concepts that had been covered and answer any questions the students had and encourage extension ideas as well.

After implementation, the $5^{th}$ grade teachers felt confident in teaching the unit on their own in the future without assistance from the Adventure Engineering fellows. This demonstrates that even though the fellows do provide support for the curricula, the units have the capability of standing on their own and provide the information needed for the teachers to conduct. Most significantly, the teachers interviewed strongly felt that the concept of engineering can be taught to $4^{th}$ and $5^{th}$ graders. They agreed that even though students in these particular grade levels are capable of learning about engineering but might not fully retain the connection between math, science, and engineering, that having been exposed to it at an earlier grade level will impact them when choosing classes in high school, aid in maintaining interest in math and science, and perhaps also influence future career choices.

The $8^{th}$ grade teachers were confident in the overall effectiveness and quality of the *Asteroid Impact* and *Volcano Engineering* units. Certain that engineering contributes greatly to the society and the discipline of science, they overruled their fear of implementing a new type of curriculum; they felt that their students would enjoy the new experience and that it was a great opportunity to learn about engineering. It was a great step for one particular teacher who, in reference to the *Volcano Engineering* unit, commented, “I did not know if the students would understand what was expected of them and worried about the final product.”

During implementation the teachers enjoyed the fact that the curricula was inquiry-based, which often differed from their normal mode of instruction. Student response was also far above the expectations of the teachers. Many students who do not participate in the classroom of their own volition exhibited a complete turn around. “I observed a number of students get meaningfully involved in class for the first time,” commented a teacher. It was also believed that the students and the teachers became comfortable and less intimidated with the Engineering design process (EDP) used in the curricula. During the *Volcano Engineering* unit, teachers found the hot spot lab difficult because the students wanted to play with the lab materials and it was difficult to clean up. To handle this situation, the teachers learned to go over their expectations before implementing this part of the unit. Overall, the majority of the teachers who implemented stated that they did not have any struggles during the execution of the units, and that only minor changes needed to be made to make the curricula more suitable for their classroom.

## 7.0 Conclusions

Three Adventure Engineering curricular units were implemented in four different schools. The students enjoyed the adventure-based approach and became involved in the class discussions and design projects. The teachers were excited by new material and spoke very positively about their students’ interest in the activities and projects. We are pleased to note that each of the teachers is continuing to participate in the AE program. Results indicate that concept of engineering can be taught to the respective grade levels. We found that a general introduction to engineering was most appropriate at the $4^{th}$ and $5^{th}$ grade level, while more details about various engineering disciplines proved effective at the $8^{th}$ grade level.

## Acknowledgements

Adventure Engineering is supported by a grant from the National Science Foundation (GK12-0086457). We are extremely grateful for their support. We also acknowledge the effort and contributions of the middle grade teachers who helped develop and implement the AE curriculum.

## References

Mooney, M.A. and Laubach, T.A. “Adventure Engineering: A Design Centered, Inquiry Based Approach to Middle Grade Science and Mathematics Education.” J. Engineering Education, ASEE, 2002, 91 (3), 309-318.

Mooney, M.A., Nicholas, S. and Laubach, T.A. “The Development and Operation of Adventure Engineering, A K-12 Curriculum Development Program.” Proc. 2002 ASEE National Conference. CDROM, #3453, 2002.

Mooney, M.A. and Laubach, T.A. “A Template for Engineering Based K-12 Math and Science Unites.” Proc. 2002 Frontiers in Education Conference, November 6-9, 2002, Boston, MA.

Laubach, T.A. Personal communication, December 2002.