Macro Analog to MEMS: A Program to Teach 8th and 9th Grade Students Science and Engineering

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Abstract

Micro-Electro-Mechanical-Systems (MEMS) was used as a vehicle to teach engineering and physical sciences concepts to middle-school students. Drawing on a University research program in MEMS as a resource, the program taught students the design process from solid modeling through manufacturing, and it developed a macro-scale analog to silicon micromachining that could inexpensively produce hand-held size planar layered structures to illustrate the kinematics and geometry of MEMS devices. This analog simulated the manufacturing process for MEMS without the need of a clean room or its highly volatile chemicals; it used soap and wax, materials found in local hobby stores. The students also learned to use the program *SolidWorks* to create solid models of simple machines. They translated their designs into kinematic models using a fused deposition of material rapid prototyping machine (Stratasys FDM1650).

The project also consisted of an assessment portion to see its effect on the students. At the beginning and end of the program, the twenty-three students filled out a questionnaire based on the Test of Science Related Attitudes (TOSRA). The test showed a significant improvement in attitude in two of its seven scales – Adoption of Scientific Attitudes and Attitude Towards Scientific Inquiry. An additional method of assessment, the students' comments in their personal portfolio, showed an overall increase in interest from the students. This program can be used as a model for other schools.

Introduction

Studies have found that children in the United States are very interested in science through their elementary years, but as they approach middle and high school, that interest wanes[1]. This becomes a more general problem as these students choose not to continue their study of science in college or are not prepared for SMET studies. The effect is that we have citizens without an in depth knowledge of science and technology just as that technology becomes more common and complex in their daily lives. As well, we have fewer and fewer trained scientists and engineers to fill the positions that are becoming available at an increasing rate[2].

The question as to why students lose interest in science in middle school has not been answered. Some experts believe it is how the school is structured[3], or that the material in middle school science has little or nothing to do with the reality of the students' lives[4]. Other experts believe that it is the nature of the teachers. Elementary school teachers frequently do not have advanced courses in the sciences, but demonstrate curiosity, interest, and a willingness to find the answers. Secondary teachers frequently have had advanced courses in their subject and seem to the students to be an expert, yet they no longer participate with the students to find the answers to their questions[5].

The project discussed here aims to work towards keeping students interested in science and engineering by exposing them to current topics and new research. This aim also stretches the teacher so that he or she is learning with the students, and helps let all of them, students and teacher alike, see how science works outside of the classroom. The goals of this pilot program are to continue to interest students in their middle years in science, technology, and engineering, give a middle school science teacher more background in engineering and current technology, and to assess how the program impacts the students' attitude towards science and engineering. The eight-week program focuses on Micro-Electro-Mechanical-Systems (MEMS), what they are, where they are used, how they are designed and manufactured, and how techniques used in MEMS manufacture are also used in other situations. Another objective was to develop a macro-scale analog to silicon micromachining that could inexpensively produce hand-held size, planar layered structures to illustrate the kinematics and geometry of MEMS devices. Additionally, the students are exposed to science and engineering in the ways that it is practiced + in groups, with collaboration, using software as a design aid, and focusing on communication.

The assessment consists of external panel judging on content and student attitude surveys as well as student contemplative essays. As a long term goal, we would eventually like to improve retention rates of students in the sciences as compared with national rates.

Approach

Although they have frequently had advanced coursework in the sciences, few middle school teachers have experience in engineering or science research. To give the teacher a better understanding of the practice of science outside the classroom, collaboration with a university engineering department is extremely helpful. This collaboration not only gives the teacher more research experience, it also gives him or her opportunities to connect with the research community. He or she has access to resources such as journals and books unavailable at public libraries as well as access to graduate and undergraduate students and faculty. These ties help to make the program more immediate for both the teacher and her middle school students. The teacher can start to answer the student's question of "what do engineers and scientists do" through first-hand experience. The National Science Foundation's support for K-12 teachers through the "Research Experience for Teachers" supplement (NSF01-18 program) was used to support a teacher in a University MEMS research program, and develop a middle-school program based on that experience.

Design and manufacture of MEMS was used to teach students about the engineering and design process as well as teach standard curriculum for an 8th or 9th grade physical science class. After a semester of physical science—the study of forces, energy, and work—the students had a chance to put these concepts into action by designing their own simple machines. They spent some time learning and experimenting with the solid modeling package, *SolidWorks*[6] , and then broke into design teams to work on their designs. The collaboration allowed the students to see engineering and science in action. They had a chance to visit the mechanical engineering department as well as use the equipment there—specifically rapid prototyping machinery. The students were fascinated to see this machinery and realize that they were going to use it.

In the classroom, the approach always included student interaction. The students, without the direction of the teacher, acted as the design team, and there were no right answers. As in the practice of engineering, the students had to learn to trust their own knowledge, find resources to answer their questions, and if no resources were available, the students had to find answers to their questions through experimentation. The design team was the first resource for questions, but other teams, books, and the teacher were also resources. Since the material was relatively new to the teacher as well, the students mostly had to work independently.

The program had two segments. The summer before, the teacher spent eight weeks in the Department of Mechanical Engineering at the University of New Mexico, working with MEMS design in the lab of Professor Tran, learning about engineering, MEMS, and developing the curriculum for macro-scale analog to silicon micromachining and assessment methods. The second segment was the actual implementation of the program during the school year for a middle school science class.

The implementation of the program was at a private school (K-9th grade), with the participating students in 7th through 9th grade. The criterion for participating was either enrollment in, or completion of, either Algebra or Geometry. The student population included about 25% on financial support; no testing was performed for admission.

Curriculum

The engineering and design segment was designed to take eight weeks in the middle of an introductory physical science course. The students already had a semester of physics where they were introduced to forces, energy, work, conservation of energy, and simple machines before they started the engineering segment. A brief introduction to chemistry followed the module. Two classes, divided by whether they were taking Geometry or Algebra for their math course, participated in the segment. In total, this was about twenty-three students. Towards the beginning of the module one student left, and three more joined the class during the trimester.

The first task for the students was to learn solid modeling. Individually, they each went through the tutorial for *SolidWorks* and learned how to use the computer modeling tool to create three-dimensional solid models of their ideas. Every student completed the tutorial, and then each student was allowed to choose a design group from within their section. The only stricture on the design group was that it was bigger than two members but tried to contain no more than four. As more students came into the class, two groups contained five members.

A field trip to Intel Corporation's Fab-11 plant in Rio Rancho, New Mexico was scheduled; the learning objectives were how both MEMS and integrated circuits are built. It also gave the students a chance to see what engineers and technician do and the type of conditions they might work in. The teacher then posed to the students a design problem: *Design a simple machine that can be built with a layered deposition and etch process; and design it to a millimeter scale rather than micron scale*. The purpose for this challenge was designing a machine that could be built physically, and had functionality.

In design groups, the students looked at concepts and built cardboard, paper, and tape models of their ideas. After testing the feasibility of their ideas with the rough paper model, they worked on designing the part in more detail using SolidWorks. The program allowed the user to design moving parts separately and then assemble them as a machinist or assembly line would. This feature was a boon to designing parts for normal manufacture but presented some difficulties to build parts for the layered deposition manufacture of MEMS. The MEMS are built *in situ*, so the movable parts need to be aligned but separated by layers of material that can be etched away.

As the students finalized their designs, they were given an individual assignment to draw technical drawings with three views by hand. The students achieved a feel for the level of detail involved in communicating the information necessary to build the part. Many found it frustrating and difficult to imagine the three dimensional part in their mind and put a scale drawing on paper.

A second field trip was scheduled, to the University of New Mexico Mechani-

Figure 1: One group of students designed a trebuchet that threw skittles. This is their paper model. The counterweight contains pebbles and playground sand. This model did work, and students were able to shoot Skittles candy into their mouths.

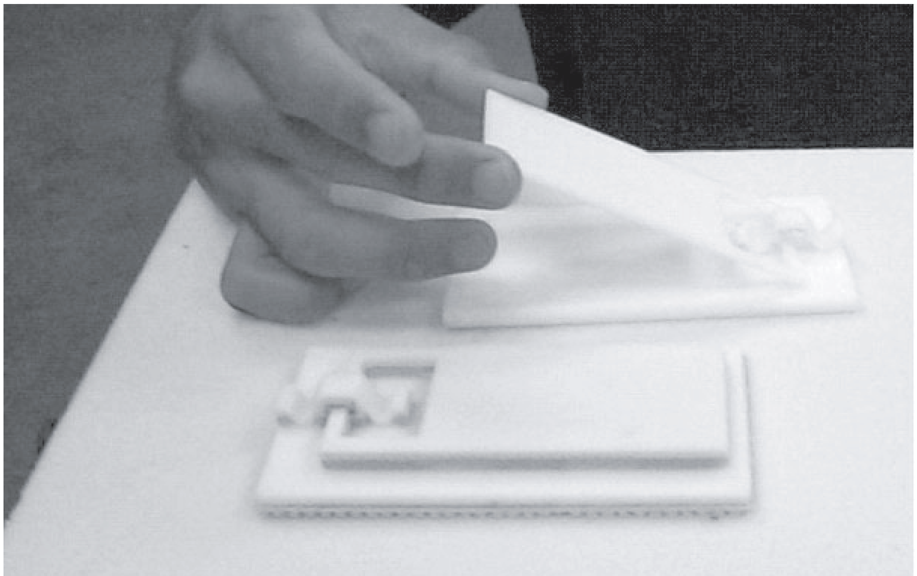

Figure 2: A picture of the design as realized by the Stratasys FDM1650. The hand shows the released part; below it is the part as built by the FDM 1650. The gray is a sacrificial support layer.

cal Engineering department. There the students met Professor Tran and some of his graduate students. The students had a chance to see what academic engineering is like, see the laboratory and the rapid prototyping machines that would build their designs. There was an added bonus; the students visited the University Science and Engineering Library (Centennial Science and Engineering Library). To introduce the students to the library, they conducted a small treasure hunt looking for the oldest journal they could find as well as a journal that had articles about topics of interest for them. Never having seen a technical library before, the students were fascinated.

The students' final designs were realized using the University's fused deposition of material rapid prototyping machine (Stratasys FDM1650).

At this stage, the students in each class came back together to present their designs to their peers. The different design groups had to come to a consensus about which part to build with the MEMS process analog. The manufacture of MEMS uses the same technology as silicon semiconductor IC fabrication. Silicon is deposited, parts of it are masked while other parts are etched away, and new layers are deposited[7,8]. A simple process was found using materials easily available from hobby stores. Paraffin wax and glycerin-based soap[9] are good analogs to the silicon and sacrificial oxide layers in the process. The wax + which does not dissolve in water, alcohol, or even mineral spirits which are easily available and mostly non-toxic + is analogous to the silicon from which the part is made (the white ABS in Figure 2). The soap, which easily dissolves in water, is analogous to the sacrificial silicon oxide layer used as supports during the process (the gray layer in Figure 2). Once the first layer of wax is laid, using cardboard forms so that it is poured into the right places, a layer of soap is laid. The second layer of wax goes down, and then the part is put in water to dissolve the glycerin soap and release any moving parts.

The students knew that they had to build the part out of wax using soap as support layers, so this played heavily into their decision about which part would be easiest to build and most likely to succeed. After each group presented their simple machines, the groups discussed the merits of each part and generally chose the simplest machine to build. Figure 3 shows a picture of all of the models. Although some of the parts were quite complex and interesting, the two different classes chose the simplest parts to build. Figure 4 shows the door and the seesaw that the two classes chose to build. Figure 5 shows a released wax part after the soap has been dissolved (analogous to release etch).

In small groups, the students devised procedures to make the soap and wax

Figure 3: Group picture of all ABS plastic, paper, and wax models. The students chose to model two of the designs using the soap and wax process – the seesaw seen in the center of the drawing and the door shown in the center right.

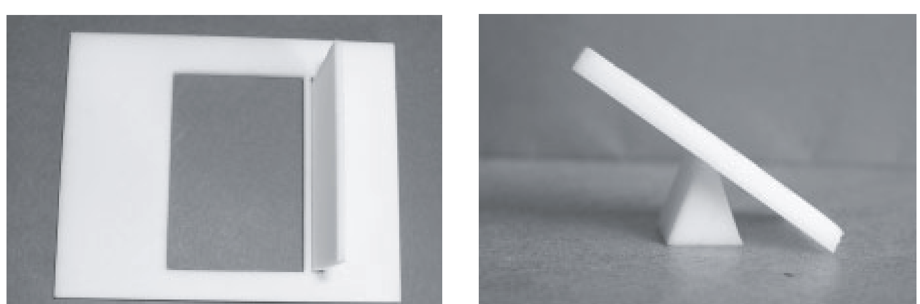

Figure 4: (a) Door and (b) seesaw in ABS plastic prototypes.

Figure 5: Seesaw wax model after releasing the structures by dissolving the soap.

structures. In microchip or MEMS manufacture, each stage in the process is determined by masks which show where silicon is either deposited or etched away. The students had to determine where wax (structural material) or soap (etched material) needed to be laid. Each group wrote down their process, reviewed it, and then used their process to build the structure.

The final activity of the module was the presentations. Each design group had to make a fifteen minute oral presentation of their design to their peers, the other class, and an external panel of judges. Here the students had to explain not only their ideas but what modifications or changes they would make to both their simple machine as well as their soap and wax process.

Overall, the goal in the curriculum was to have the students do as much hands-on work as possible and work together in teams. There was as little lecture and note-taking as possible; although there were a couple of days of discussion about MEMS uses and manufacture. Other discussions focused on the field trips to make sure students saw the relationship between microchip manufacture and MEMS manufacture.

Assessment

Prior to the unit, students took a modified version of the Test of Science Related Attitudes (TOSRA). TOSRA is a well documented instrument that has proven to be effective in evaluating students' attitudes[10,11,12,13,14,15,16,17,18]. The only modifications made to the test as published by Fraser in 1978 changed the word science or scientist to include engineering and engineers. The TOSRA is a 70 statement test with five possible responses to each statement ranging from "strongly agree" to "strongly disagree". The student need not answer all the questions, but any that are unanswered are assumed neutral; any that contain two answers are also assumed neutral. The test covers seven different aspects of attitudes towards science – social implications of science, normality of scientists, attitude toward scientific inquiry, adoption of scientific attitudes, enjoyment of science lessons, leisure interest in science, and career interest in science.

Students were given the test in January 2002, prior to starting the eight-week MEMS module. Students took the test again in May 2002, two months after the end of the program, during the final week of classes, to see if there had been any change in attitude. The hope was that there would be improvement in four areas—enjoyment of science lessons, leisure interest in science, career interest in science, and normality of scientists. To insure that students answered honestly without concern for their grades, the tests were given completely anonymously. The students were asked not to put any identifying marks on their papers. This also precluded tracking individual's attitude changes.

A second method of assessment particularly oriented towards what specific knowledge or methods the students had learned was an external panel of judges for the oral presentations. The judges included a professor of mechanical engineering and an expert in MEMS, a working engineer whose area of specialty was not MEMS, and the headmaster of the school with forty years experience teaching students of this age group. The panel completed technical evaluations about each groups' presentation. The members of the panel were asked to rate the students' knowledge in certain areas as excellent, strong or an area of growth. The judges could then give comments to the students. The panel judged how well the groups understood the processes of MEMS manufacture, the soap and wax analog, and the relationship between the two. They judged how well students had assimilated the information by giving examples of MEMS as well as the motivation for studying them. Finally, the students were also judged on their presentation skills, such as explaining jargon, speaking clearly and effectively, and aiming the talk at an appropriate level to the audience.

The final method of assessment included the students' written reaction to the program. Each student wrote an essay detailing his/her growth through the project. Specific questions included "How has doing the engineering and design segment affected your ideas about science?" and "Do you think working in groups is helpful?"

Results

TOSRA

A total of twenty-two students completed the program; one student who started the program left the school. Twenty-three students took the test before the beginning of the unit, but only nineteen took it afterwards. Table 1 shows

		Pretest		Post test		
Scale		**mean**	**st. dev.**	**mean**	**st. dev.**	**Δ mean**
Adoption of Scientific Attitudes	A	31.2	8.9	33.9	5.7	2.8
Career Interest in Science	C	26.4	9.7	27.6	6.7	1.2
Enjoyment of Science Lessons	E	27.4	9.8	28.6	7.0	1.2
Attitude toward Scientific Inquiry	I	33.2	6.7	35.8	5.2	2.7
Leisure Interest in Science	L	24.4	10.3	25.7	8.0	1.3
Normality of Scientists	N	32.1	6.1	32.4	5.5	0.3
Social Implications of Science	S	34.0	8.6	34.1	6.5	0.1
Mean of Seven Scales		29.8	8.6	31.2	6.4	1.4

Table 1: Results of the modified TOSRA attitude assessments given to the students.

the mean results of the students' answers for each scale as well as the overall mean of the seven scale means. The possible score range on each scale is from a minimum of 10 to a maximum of 50. The values of the standard deviations indicate a reasonable spread of scores in each scale.

While the students showed some improvement in their attitudes towards science and engineering, the numerical change is small compared with the standard deviation. It should be noted that students started with an overall positive attitude towards science and engineering.

Notice, however that overall, the standard deviation became smaller from the first test to the second, showing that as the year progressed, although the average attitudes did not change a great deal, the attitudes converged.

Panel Evaluation

Overall, the panel of judges was favorably impressed with the students' knowledge of the subject of MEMS as well as engineering design principles. The professor of mechanical engineering felt the students' understanding about MEMS – the manufacturing process and motivation for looking at them – needed some growth, although the older groups of students seemed to have a better grasp of the concepts. The working engineer was impressed with students' presentation skills. Not an expert in the subject, she was also impressed with the students' knowledge about MEMS. The headmaster, the least technical member of the panel, was very impressed by students' knowledge about the subject and the work they had accomplished. He found the students' engineering designs and fabrications fascinating.

Student Reaction Essays

Perhaps the best form of evaluation was the students' own reaction to the program, through their contemplative essays. Out of twenty-three essays, twenty were strongly positive, two were neutral, and only one expressed negative reactions. Many of the students were surprised that they enjoyed the material, and they found working in groups to be extremely beneficial. One student wrote:

> *I thought that working in groups was very helpful and it made it easier to solve problems that way. Another good thing about working in a group is that you can get feedback from your ideas and decide together what methods to use and so forth. . . . I used to think that science was just chemistry and a lot of lab work. This is not true, because science can also include building models of simple and complicated machines. I also used to think that building and designing models would be boring as I am into nature and not technical things. However, after doing this project, I found out that engineering and designing was just as interesting as nature is to me.*

Almost all of them were surprised to find the collaborative effort in science, and they liked it. Another student commented:

> *I learned a lot easier in this segment [than I would learn by myself] because there were groups…there is someone helping me all the time [rather] than just every once in a while.*

The one negative essay expressed disinterest in this one area of science:

> *My ideas about science have undergone very little change due to this segment. Science has always been of great interest to me, particularly astronomy, chemistry, and zoology. My background in physical science has been very general, so this project was my first introduction to the practical aspects of physics. In this sense, therefore, my eyes were opened to a new field. I liked doing the projects, but I am not intrigued enough to pursue this course.*

All of them liked the hands-on aspect of the course and expressed a desire to continue open-ended experimentation in future classes. Two excerpts were:

> *I feel that while doing this segment I have learned more than I normally would taking a regular science course. The reason for this is that we did everything hands on and it was really fun. When I am learning something out of a book, however, it is sometimes hard for me to concentrate as I get bored quickly. The other part that made this way of learning much better was I actually got to do the things they were talking about in the book first hand, instead of just imagining in my mind what it looks like and making a guess as to how it feels. I think that this has been one of the most worthwhile science classes I have ever taken, and I would definitely like all of my science classes to be like this one was.*

> *I think working in a group made it a lot easier because if we had trouble we asked each other and usually were able to explain it to each other very well. I personally think that the way that we have been learning for the last trimester is a lot better than just reading out of the book because we actually got to experience and see what we were doing and we had to solve our own problems along the way. I personally learn a lot more that way when I can actually do the experiment and not just read about it. I also think it's a lot more interesting to actually be able to experience it yourself and explore and learn new things you didn't know before.*

Many of them were proud to have created something:

> *When we finally got our simple machines finished and back to us as plastic, it was so cool because we knew that we had finished something challenging…In all of this I came to understand that if you keep trying and don't give up, you really will succeed. When you do succeed you feel so proud, you just want to pat yourself on the back.*

Still other students enjoyed the material itself, and liked the engineering process. Three different students had this to say:

> *MEMS were so fun – I had never heard of them. It was fun seeing how they were built up and how they work.*

> *[The] Engineering and Design Segment affected my ideas of Science because before I learned about this, I thought it was boring*

> *to come to science class. I thought all you did was write notes, but when I learned about engineering, I learned most of it was hands on and being able to do physical stuff. We got to build, create and do a program on the computer. I learned how to build and design structures starting with computers, then I used paper, cardboard, soap and wax. I learned that every little detail counts, and that you need to have exact measurements in order to design and build a structure. I learned that you do not need to be a genius to design and construct a structure.*
>
> *I think it was a good idea that we learned about MEMS because it was educational and it will help all of us have a better understanding of what is going on around us.*

Finally, this student states what every teacher hopes to achieve with his or her students.

> *Before this engineering and design segment, I never did too many experiments or anything hands-on with science. I worked in a book answering the questions at the end of each chapter. Now I realize in engineering and science people do more than they read about it. It is different to work with engineering and science than to read about what people do. That is how doing the engineering and design segment affected my ideas about science. It changed my point of view.*

The students did extremely well in understanding these new concepts. They learned the computer programs quickly, and easily worked in groups. Attempting open-ended hands on laboratory work was new to them and produced many challenges including making masks that would stand up to the heat of melted wax or soap. The soap and wax analogs ended up being much cruder than the students had hoped.

In the future, having the students design masks for the different layers and building them with the rapid prototyping machine could make the soap and wax structures much more precise and structurally more sound.

Conclusions

Overall, this was an extremely successful program. The students attitude towards science were bolstered, and they learned more about science and engineering in the real world. The class had more impact, and actually changed a few students' attitude towards science. The collaboration with the university gave both the students and the teacher access to resources that they would not have in any other way. It will take a few years to see if there is any direct advantage to the university or mechanical engineering department specifically; however a more informed public with a more favorable view to technical careers can not hurt. The students found the ABS plastic models extremely helpful in visualizing their designs. The soap and wax analogs also gave the students a general feeling for the complexity of any fabrication process.

For the teacher, the summer portions of the NSF-RET program, provided an excellent chance to learn more about how engineering teams work together. The opportunity to attend the ASEE (American Society for Engineering Educators) Conference was an excellent chance to get ideas for curriculum as well as make contacts with interested professionals. The opportunity to work with academic engineers also gave a much broader view of what engineers do, and some more ideas of what students might do if they were interested in engineering. The chance to work with scientific concepts, instead of just teaching about them, also was a good refresher of the point of the science classes taught in middle school. It was also good to have a chance to plan the school year with a focus.

For the students, they have opportunities to explore both engineering and some specific technology concepts that are not usually added to the curriculum at this level. In middle school, before they have to choose what science classes to take, the students can see what the science is "good for." Even if the students still choose not to pursue science in later schooling, they may see how science and technology affect their lives and have a better understanding of what they are doing.

For the future, the hope is to expand the program to include younger students, 7th grade, as well as more teachers and students. The program could be easily expanded to larger classrooms with the help of undergraduate engineering students. Many of the programs, although feasible in a large, public school classroom, would benefit from additional expertise in the room. Having undergraduate or graduate engineering students familiar with the software programs and able to help coach the design teams would help the middle school teachers a great deal. It is the desire of the authors to repeat this program, both in a private and public school settings, to evaluate change in attitudes with a broader spectrum of students.

Acknowledgements

This project was funded in part by the NSF01-18 Program as a supplement for NSF Award ECS-0093966. The authors would like to thank Dr. Teresa Kokoski of the UNM School of Education for her help in finding pre-existing assessment tools and acting as a general resource for middle school science teaching. The authors would also like to thank Patty Wormington and Charles Como for their participation and interest. Most of all, the authors wish to thank the students for their participation in this project.

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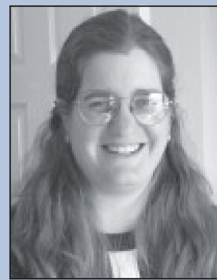

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