AC 2007-917: EXCITING STUDENTS ABOUT MATERIALS SCIENCE AND ENGINEERING: A PROJECT-BASED, SERVICE-LEARNING MUSEUM DESIGN COURSE

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Exciting Students about Materials Science & Engineering: a project-based, service-learning museum design course

Abstract

A new course was developed for Materials Engineering students to design, create, and install interactive, educational displays on Materials Science & Engineering for a science museum at a local K-6 charter school. The course grew out of an ASM Foundation grant "to excite young people in materials, science, and engineering careers," and the challenge was put forth to Cal Poly students. A formal design sequence was applied to give the students the opportunity to learn about the design process, project management, and teamwork. User profiles were created for the stakeholders, and project values were established. The class partnered with the museum curator to develop functional and design requirements for the displays, and to gain valuable feedback during the project development. Guest lectures and discussions with museum exhibit developers, education specialists, and design experts assisted the class. Three different displays that highlighted materials were developed: "Metallic Trampoline" (amorphous metal), "Smart Materials" (NiTi shape memory alloys), and "Touch and See" (heat sensing liquid crystals). The final museum displays were well received by the client and end users. A survey at the end of the quarter revealed that the engineering students gained valuable design and project experiences.

A partnership with the SciTechatorium develops

This projects class grew out of the Cal Poly Materials Engineering department outreach efforts[1] and the desire to connect more with the community. The relationship between Cal Poly and the Bellvue Santa-Fe Charter School in Avila, CA was initiated through a colleague whose children attend the school. The SciTechatorium[2] (Figure 1a) is a 1900 square foot "hands on" science museum and discovery room that houses a plethora of science demonstrations, exhibits, reptiles, insects, etc (Figure 1b), and is quite a gem in the central California area. The SciTechatorium essentially houses all the show-and-tell items and treasures of Mr. Chick Fidel, a retired high school physics teacher who now acts as the part-time museum curator.

a) b)

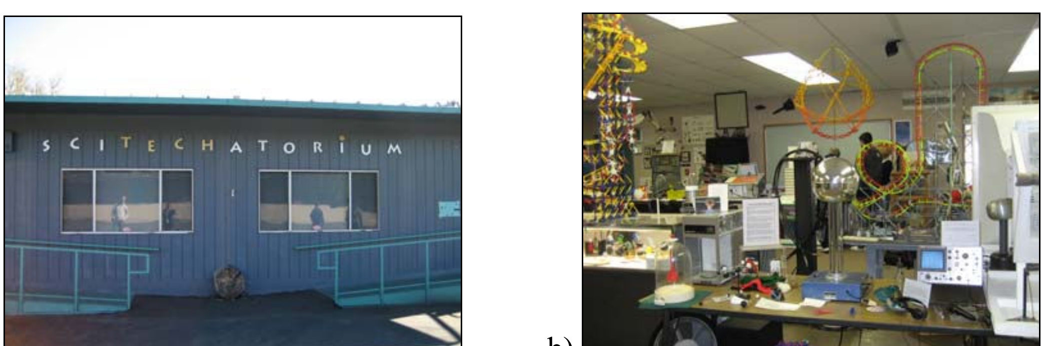

Figure 1. a) The SciTechatorium at the Bellvue Santa-Fe K-6 Charter school in Avila, CA houses b) numerous demos and items that promote scientific inquiry for all ages.

The SciTechatorium is open for a few hours per week (depending on docent volunteers), and is available to the K-6 students during recess and lunch. The children can come in and spend as much (or little) time as they wish to take out the reptiles, use the computers, look at displays, talk to Chick and the docents, and play with any of the numerous interactive items at the museum. The museum is an amazingly fun and inviting place, where the learning is not necessarily at the forefront for the students and is effectively covert. Chick's great enthusiasm for the wonders of science spreads to the kids and their parents by means of the museum. The school science teachers may also use the place to illustrate science principles as part of their lesson plans. The SciTechatorium also seemed like a wonderful place to highlight Materials Science & Engineering (MS&E) to young people.

The student coordinator of our outreach program was persuaded to write a proposal to the ASM Foundation Student Chapter Grants program[3] "to excite young people in materials, science, and engineering careers." Our grant was funded to purchase demos and build displays that highlighted MS&E for the SciTechatorium. However while the funding and the enthusiasm for the project was present, reality of college students is such that priority goes to classes, and extra curricular projects sometimes fall by the wayside. Thus, a brand new course was developed – "Design of Educational Museum Displays in Materials Engineering."

A new course is developed to incorporate service learning and design

The primary goal of the course was to establish a relationship with a local partner or organization where Cal Poly students could use their engineering skills towards a project to benefit the community. Objectives included learning and implementing a user-centered design methodology, gaining experience in project management, and improving communication skills. The inspiration to structure a course around the designing and building of educational museum displays was inspired by similar innovative class activities by Crone[4] and Pruitt[5]. MATE X424 was offered in the Fall of 2006, and was a 2-unit activity (i.e., cross between a lecture and laboratory type class). The class met for 4 hours a week, and much of the class time was devoted to actually working on the displays. The small class size of 6 students allowed us to truly work together as a team. Due to the service learning component of the course, the students were now working for their client, Chick Fidel and the school children. The instructor functioned more as the project manager, rather than the *judge* that determines their grades (although that task still existed).

The first half of the quarter was spent on brainstorming and going through a formal design process. Instead of immediately jumping to a design solution, we started out by trying to gain as much information on a variety of topics for several weeks. Reading articles on science museums[6,7,8] were assigned and discussed in class. Different "consultants" – such as a professor in the College of Education that specialized in K-12 science and an engineering professor with experience in design – visited our class to answer questions and to offer their input. We also took a class field trip to visit three Bay Area museums: The Exploratorium[9], The Tech Museum[10], and the Lawrence Hall of Science[11]. At each museum, we got the chance to experience different types and approaches of displays, and we also talked to professional exhibit developers.

Listening to the Client with User Profiles

One of the very first class activities was to develop user profiles or personas of our intended customers. The class identified the stakeholders and discussed the client needs. The class then came up with 3 imaginary students (and 1 parent) that might attend the school and developed their user profiles. Sitting around a table, each person was encouraged to contribute to the personas, which resulted in colorful and multi-dimensional user profiles. Different ages, gender, and personality types were covered. The user names, personalities, likes and dislikes, and reactions to school, were generated collectively and drawn on large Post-it notes (Figure 2). The engineering students really enjoyed this particular activity because they got to be creative and it was a departure from their usual classes.

We kept the user profiles posted on the wall to continuously remind us that these projects were not meant for us, but our clients. It was very useful for the instructor to respond to students' ideas by referring them back to certain user profiles, and asking them if their design features would be appropriate to the users or if their design catered to only one type of user. A student wrote on the end of the quarter survey* about the user profiles:

Building of the user profiles was key to learning what our target users wanted in a product, which also dictated the entire design phase. If we ever got stuck, it was always nice to refer back to the user profiles for ideas.

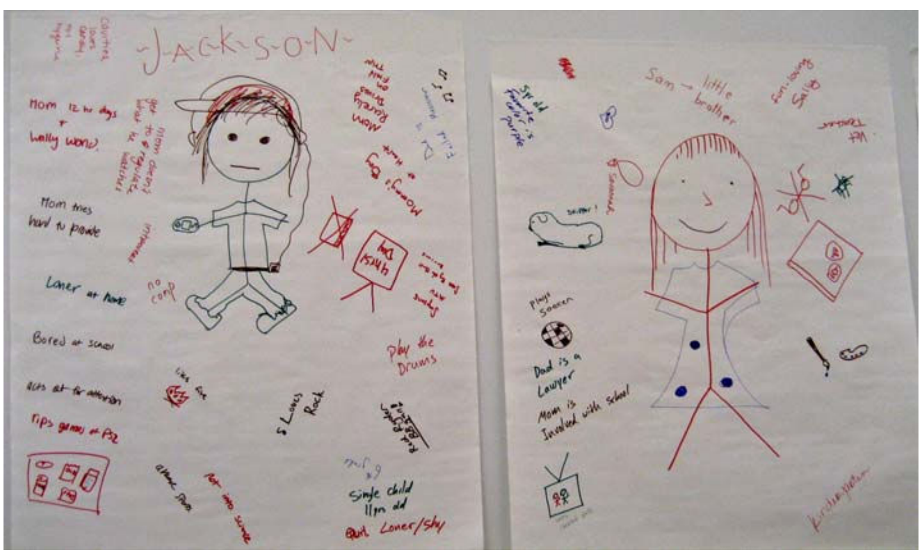

Figure 2. User profiles or personas were developed to understand the end users' needs and to consider how the children would interact with the museum display designs.

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* Note that all student comments are in *italics* throughout the paper.

Another early activity involved the students each writing down as many ideas as possible on the features of what their museum displays should be like (e.g., colorful, interactive) on 2"x2" Post-it notes. They then shared their ideas with each other and grouped them into themes onto the larger Post-it sheet (Figure 3). Overarching themes were developed from these groupings, and these themes became the basis for the project *functional* and *design requirements*. The project goals naturally resulted from this team brainstorming session. Input from the client and consultants also helped shape the project goals. Again, the project goals and requirements were kept posted on the wall for easy and continual reference.

Figure 3. The class demonstrated great teamwork in developing goals, functional and design requirements.

The functional and design requirements guided the brainstorming and project selection sessions for the museum displays. Some of the major requirements were:

- inspires scientific thought or inquiry
- provides a discrepant event or surprising incident that asks “why?”
- must be interactive, fun
- incorporates different senses
- be colorful and appealing
- showcases Materials Science & Engineering
- is memorable, something to talk about later with family
- is social, can experience or share with friends
- does not have too many words or technical words
- is simple to grasp main concept (but could be multi-leveled for different audiences), doesn’t rely on long explanations
- has low maintenance (since things that don’t work are very frustrating and leave a bad impression)
- is safe

Pitching the ideas to museum curator and school principal

The service learning aspect of the course allowed the students to develop their communication skills. One of the course objectives was to interact with the community, and the class visited the school to talk to the clients (Chick, docents, and the school children). They also observed how the young children interacted with the existing museum displays. The students later had to communicate with outside vendors and companies while building their displays.

The class also realized that Chick should be heavily involved with the design process and not just at the very end. Chick had terrific ideas and great insight into children's responses. He also stressed the importance of safety, maintenance, and the possibility of unintended uses of museum displays (e.g., every object turns into a hammer).

After finally brainstorming and developing some ideas for the museum displays, Chick and the school principal were invited to visit the class to hear the ideas (Figure 4). The students build some crude prototypes, drew up colorful designs, and had some demo materials on hand to present. After all the pitches were made and the feedback received, the class's most popular ideas were thrown out for various reasons and some of the more simple display ideas rose to the forefront. Although the students were disappointed and frustrated at first, in due course, they realized that it was much better to change their course of direction now rather than building an unsuccessful display. As a valuable lesson, one student later wrote:

…not everything planned happens the ways it was intended. And sometimes the ideas and concepts that you like the most, don't always agree to what the end user likes or wants.

In the end, we were producing the displays for both Chick and the children. The meeting with Chick gave us a good idea of what projects he thought would be most appropriate in the setting of the Sci-Techtorium. Then, watching the interactions with the children allowed us to truly evaluate what would be a fun and exciting experience that they could both enjoy and learn from.

During the quarter, the students were required to use a lab notebook to record ideas and discussions. They were given a budget and had to keep track of all expenses. Data from various testing of the displays was also recorded in the notebooks, as well as the numerous revisions to their designs and display posters. In addition, the students had reflection exercises as homework. They were asked questions such as:

- Discuss any difficulties or unexpected events that you have come across during the design and building of your museum display. How were you able to respond? How often did your design change?

- How well are you sticking to your original project goal and the initial timeline that you set? What can you learn from these experiences to help you in the future?

- If you could start all over again, what would you differently? How might your own actions change? How might you change your design?

- What did you learn about the engineering design process through this class? What were the most important aspects? Please be specific.

- Which, if any, materials engineering concepts did you learn from your experiences in building the museum display.

- How did meeting with the client (Chick Fidel) and observing the end users (school kids) affect your level of performance for this *service-learning* class?
- Discuss your motivation level to work in this class, as opposed to other courses. Elaborate.

Figure 4. After the students pitch their display design ideas to the school principal and museum curator and getting lots of valuable feedback, they end up drastically revising their project designs.

Project displays exhibit unique and exciting materials properties

Three different displays were finally decided upon the students. By this point, the students were quite used to using the whiteboards to sketch out plans and ideas, as well as discussing pros and cons with each other. Since there were so few students in the class, there also appeared to be a fair amount of accountability to contribute in some way. Even when the students divided into 3 different display projects, the students still relied on each other for feedback and help.

While the final designs seemed to be quite simple at first, there turned out to be a variety of challenges that had to be overcome. The "real world" aspects to the projects and the need and desire to have the displays actually work impacted the students, as revealed in their reflection assignments and end of the quarter survey.

Metallic Trampoline

The "atomic trampoline" demonstration (Figure 5a) has been a standard in our outreach program[1] to show the impressive coefficient of restitution of amorphous metals. The demo can be purchased through the Institute of Chemical Education[12], and takes only a few minutes to perform. The plastic tube sleeves are lifted up to grab small steel ball bearings (BBs), and the tubes are placed back around the steel base and the amorphous metal base. The ball bearings are then released from the top of the tubes at the same time and bounce on the different metal bases. This simple demo often elicits giggles as the BB bounces for a much longer time on the amorphous metal base. The effect is visual and audible, and the demo is quite memorable to all ages.

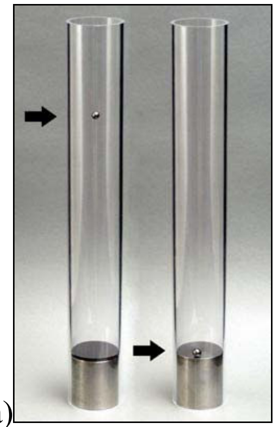
a)  b) 

Figure 5. a) The Atomic Trampoline demo compares the effect (i.e., coefficient of restitution) of a steel and amorphous metal base when ball bearings are dropped from the top of the plastic tubes. b) The Metallic Trampoline display was designed to be all one piece and uses magnetic wands to transport the ball bearings to the top.

The challenge to using the atomic trampoline in the SciTechatorium was the high probability that the BBs could get lost, or worse yet, put into the mouths of small children. The different parts also were susceptible to being knocked over or separated. Thus, this project's main functional requirement was to build the whole display as one unit so that no pieces could come apart or lost. Therefore, a different means of retrieving the ball bearings from the bottom and releasing them from the top had to be devised.

The two tubes were fitted into a larger wooden block to lower the center of gravity and help avoid the tubes being knocked over (Figure 5b). A plastic top was designed in a Solidworks[13] program to enclose the two plastic tubes, and was submitted to various machining shops. The students learned firsthand in how to deal with job orders, quotes, deadlines, and actual delivery dates. Different design solutions were proposed for the ball bearing retrieval and release: mechanical gripper, electromagnet, and finally a magnetic wand. The stick with a magnetic end attracts the BB at the base, drags it up the side of the tube and finally to the top. A quick slide along and off of the top surface releases the BB. In the meantime, the students also learned about the power of rare earth magnets. Despite all the forethought and dedication of the students to complete the display in time for the launch date, one of the very last steps resulted in a slight unexpected problem. After the machined plastic tops were glued into the tubes, the epoxy glue outgassed and fogged parts of the plastic tubes.

The students also created a colorful and appealing poster to go along with their display. The display was renamed "Metallic Trampoline" to bring the focus to metals and to cause a conundrum in that one doesn't normally think of metals as trampolines. The demo feeds nicely into the engineering applications – namely sports equipment and surface coatings. Early on, the students wanted to make sure that the scientific inquiry was also followed by practical engineering applications. Very few words were used and several colorful pictures were employed. After lots of deliberation, the students decided not to post any directions, and let people either explore on their own or have them told what to do. The actual directions are quite easy and take only a few seconds to explain verbally. Two questions are also poised on the poster for the museum attendees:

- Which base causes the ball to bounce <u>longer</u>?
- Which base causes the ball to bounce <u>higher</u>?

The questions are to get people to first make a prediction before trying the display, and to direct them to the fact that the base metals are the important materials to consider (not the BBs). Only a visual explanation of a schematic of the atomic arrangements of the bases is given. There is very little text associated with the numerous items in the SciTech-atorium, and the docents and Chick often carry on conversations with the young children.

Smart Materials: *It Remembers!*
The display on shape memory alloys was inspired by a display in the Strange Matter Exhibit[14] that is touring in many museums. The students first thought they could recreate the entire display of an enclosed system with a boot that comes down to stomp on and flatten out NiTi grass. A hot air gun is then activated to resurrect the grass wires to the starting positions. However, the students in the class did not have any particular expertise in building electronic or mechanical systems. Furthermore, there would be a large footprint with the display, as well as possible problems with continued maintenance for the elaborate construction.

We discussed the essence of the particular display by stripping away all the clever packaging to get to the basics. They realized that the museum attendees needed to be given control over deforming NiTi wire and then heating it back to the "remembered shape." The complicated project suddenly became more manageable. The students decided to attach some NiTi wire to a wooden block and have the display open for individuals to use their own hands to deform the shape memory wire.

a) 

b) 

Figure 6. a) The NiTi shape memory alloy display is very colorful and interactive, and b) was designed with several safety precautions in mind for young children.

Several designs for the "trained" shape were proposed, but due to time issues and the difficulty in training complicated shapes, the wires were either straight or star shaped. Two different stations with 4 separate wires were built (Figure 6a). Paying heed to the functional requirements to have the displays colorful and fun, the students used bright colored felt pieces to cover up the wood pieces. Small balls of epoxy were attached to the ends of the wires as a safety measure. A small and quiet hair dryer was selected as the mechanism to heat up the wires (Figure 6b). Additional functional requirements for this display required that the hair dryer was not heavy or large enough to be used as a hitting device, and that the sound would not be a nuisance to others in the museum.

Their poster is also colorful and shows some interesting applications of NiTi shape memory alloys. After many draft versions were critiqued by the class, the poster was written in very simple terms and does not go into very much technical depth.

Touch and See: *Heat Sensing Materials*

Liquid crystals can be thermally activated from body heat to produce temporary color changing imprints[15]. Many mood rings and flat aquarium thermometers work on the similar principle[16]. The students first proposed to have a thermal tic-tac-toe game board where different hand prints could be used as the traditional marks of "X" and "O." However upon testing their prototype, they found too many variations in the response due to different hand temperatures, ambient temperatures, time that the hands was applied to the liquid crystal panel, and time the imprint lasted. In addition the concept of the game, although social, would result in losers and winners.

The liquid crystal display ended up going through several different design revisions. The students finally decided to show differences in the response if the liquid crystal panels had backings of materials with different thermal conductivities. Two easily recognizable materials were selected: copper (a conductor) and Styrofoam (an insulator). Handprints on the panel with the copper backing disappear much faster due to the more rapid heat transfer. This particular display actually had two major scientific topics – colorful imprints due to the liquid crystals and heat transfer of different materials with different conductivities.

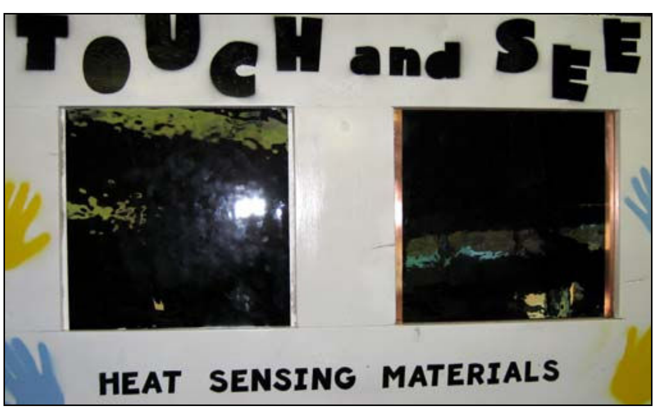


Figure 7. The two liquid crystal panels show different backings: Styrofoam (left) and copper (right) produce different effects due to different thermal conductivities and heat transfer rates.

The display board exposes the backings such that individuals could see the difference (Figure 7) and would hopefully start wondering why one hand imprint stays longer than the other or why it is easier to put a print on one side versus the other.   The name of the display, “Touch and See” was selected to invite the museum attendee to do just so! No further directions were necessary, and only a 8.5″x11″ information sheet was developed mainly for the docents or older visitors.

This display proved to be very popular, interactive, and social. We were pleasantly surprised when people interacted with the display in ways that hadn’t been anticipated. During a prototype testing session with a group of visitors to the department, several girls worked together to try to color the entire liquid crystal square panel (Figure 8a). In another instance, Chick got the young students to try to warm up their hands first by rubbing their hands together quickly (with an additional lesson in friction) or blowing into their cupped hands before applying their hands to the display (Figure 8b). Some individuals would also go looking for another object to place on the panel. One of our measurements to evaluate the displays was the amount of time individuals spent at a display, and this one did very well.

a)  b) 

Figure 8. a) A prototype test group worked together to change the color of the liquid crystal panel. b) Chick gets young students to warm up their hands first before applying them to the Touch and See museum display.

Assessment and Future Plans

Although no formal assessment on the museum displays was administered (due to lack of time), comments from the museum curator and visitors were very positive. The next time this course is offered, the class might first start out by evaluating the displays in meaningful and quantitative ways. The assessment of the class was in the form of reflection questions on periodic assignments and an end of the quarter survey.

From conversations during the class, the students realized that little kids are quite smart and are not as inhibited as college students are with their enthusiasm or willingness to try out something new. They also concluded that there is a need and responsibility to be able to relate science to others in laymen terms. They discovered that simple ideas can be more powerful than expensive, high-tech gadgets.

From the survey, the students had extremely high levels of motivation to do well since they wanted to please the younger children. Many other studies have shown that the success of service-learning project is due to having real clients[17]. The students did put in tremendous amounts of time towards the end to be able to complete their projects and install them in the SciTechatorium.

My motivation level was extremely high for this class. Although just a two unit class, I felt it was the class I put the most effort and outside thinking. Because the end result was more about producing a display that was going to be used by children in the Sci-techtorium, it was much more important to me. I knew that this was going to be for a good cause and how well we performed was not just going to be a reflection of ourself, but of our school as well. Seeing how much spare time Chick gives to the school and to the children gave me the motivation to produce something that I was proud of and was hoping he would be proud to have in the Sci-techtorium.

This class was extremely beneficial. The end result of the class made me take the class as a whole much more serious. Producing something that was going to be a reflection of my effort made me want to take the whole engineering experience much more serious. Seeing the benefits of utilizing each aspect of the engineering process, makes me see the importance of putting effort into the small steps leading to construction, rather than just jumping straight into the building aspect. Not only will this be valuable in other projects, but it was the kind of experience we are going to need when working as an engineer in the field.

The students also noted how the class enabled them to learn and experience the design process. Through their projects, they felt that they gained valuable, "real world" experiences.

I learned to plan ahead and to work around problems and solve them. I learned it is important to have a schedule and work with it. Don't waste time. I also learned trial and error works, but it takes ten times longer than having the question answered in the first place.

The entire process from start to finish was a valuable engineering experience. We started with an initial problem. We then set out our functional requirements; and defined our user. To gain knowledge in the field that we would be working, we sought out who had been successful in the field and got advice from them. Upon compiling information on the topic, we began brainstorming ideas and carefully planning design methods. Next, we started the construction of our project and got to experience the obstacles and problems associated with the construction of our displays. All the while we developed timelines that allowed us to stay focused and on time for the project. This is exactly the kind of situations we will facing in the real world of engineering.

I will definitely look at what appear to be "simple" or "easy" projects in another light. Alot of things can go wrong and many things can and will change from a projects design to the time when it is finally implemented. I definitely feel that we have had some experiences in this class that are very similar to those we might encounter in the real world.

Real world learning experiences gained through this class were, the ability to plan, being aware of unexpected problems, staying organized, and dealing with other people whether or not you share the same ideas.

Conclusions

A new projects-based, service learning course was developed to build displays for a science museum at a local charter school. Students went through a formal design sequence that involved developing user profiles, meeting with experts, establishing functional and design requirements, testing prototypes, and revising their projects. The interactive museum displays featured amorphous metals, NiTi shape memory alloys, and color changing liquid crystals. The students were highly motivated and found the course to be very valuable in gaining design and project management experience.

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