INTRODUCTION

Waterjet Technologies, or Edgerton Center course SP.777, is a six-unit class which teaches students how to use the waterjet through a service learning project. The course is taught by Ken Stone (BSAD, 1972) and Alea Teeters (Electrical Engineering, 2001) and is in its third year of existence. During the spring semester, four students were enrolled in the class: Ariel Rideout (Computer Science, 2004), Greg Schroll (Mechanical Engineering, 2008), Mike Short (Nuclear Engineering, 2005), and Matt Zedler (Mechanical Engineering, 2007).

This class is unique, combining design and rapid prototyping to allow well-tested development of final products. Students engage actively in the entire design process, learning about the needs of the class's community partner and then developing ideas at MIT. The Protestant Guild Learning Center, a center for children with mental and physical disabilities located in Waltham, has been the community partner for the last three years.

FEBRUARY – IDEAS DEVELOPMENT AND REFINEMENT

The class, which meets from nine to eleven in the morning on Mondays and Wednesdays, started with a large enrollment of approximately ten students. Unfortunately, that number declined when several of the students discovered that there was a final design project. The four of us who remained began with a basic introduction to the shop and the problems of the handicapped. We saw a waterjet demonstration and learned how the ingenious machine worked by forcing water at a extremely high pressure through a small crystal nozzle, forcing in an abrasive, and then blasting through almost any material that was placed in the stream's path. Ken also taught us how to use the relatively basic OMAX computer-aided drafting (CAD) software package that is used to control the machine.

Within a few weeks, we were on our way to visit with the Protestant Learning Center. Once we arrived, we had a few short hours during which the staff introduced a half dozen project ideas. The presentations were excellent, with the technical challenges outlined and the staff fielding our barrage of questions. The projects ranged from a scooter to assist with physical therapy to a better coffee-carrying tray for the student run coffee shop, from a drum holder for the African drum used by the music classes to an insert that would prevent food from sliding around on a cafeteria tray. We took notes and drew many sketches as the raw ideas were given to us, leaving with a better understanding of the needs of our community partner.

During the next week, we spent a lot of time researching different products and ideas on the Internet. Some relevant products were found and ordered, such as a picnic cup and bowl holder and a non-slide surface mat, so that we each saw how existing designs worked and could be modified. As we worked on looking for pre-existing technologies on the market, we also continued to think about how we could develop a new solution to the problem.

Brainstorming creative ideas was our next step during the class. Each of us sat down and explored possibilities to accomplish one of the given tasks. No ideas were disregarded, not even the crazy and impractical ones such as screwing the cups and bowl to the cafeteria tray. We discussed our ideas as a group and then started deciding which ideas would work best and on which projects to focus our energy. Since there were only four of us, we decided it would make the most sense to work together to create one or two products rather than divide our efforts and potentially end up with no finished products. We decided that the coffee tray seemed like a pressing need, especially after having seen how the students had difficulty handling the degrading Dunkin' Donuts tray that was currently being used. The development of the improved coffee cup holder is detailed below.

//NEED NAME OF PRODUCT

During February, we also worked on improving our waterjet skills by completing smaller assignments. Ken had us draw and then cut a snowflake modeled on pictures of actual snowflakes, and some of us also practiced by using the waterjet on personal projects. As March arrived, we were deep into the process of designing the new coffee tray.

MARCH – DESIGN AND ENGINEERING

As March began we started developing a set of drawings and cutting files for each of the components of the coffee tray. Rough sketches and cloudy ideas became clear CAD drawings as we went through four successive prototypes to reach our end goal of an improved coffee cup carrying tray. Even though the final product employed a relatively simple design, there were still several design concepts that had to be tested, approved, and implemented. All of us were involved with both the design and the prototyping, which meant that we all got to all sides of the design process.

The iterative, rapid prototyping allowed us to try out design changes almost immediately. Even a solid model is not as useful as an actual object, and being able to instantly see what worked and what did not allowed us to move rapidly through this stage of the design process. Within a few weeks, we were ready to move our final prototype into the next stage – testing and deployment.

We managed to give it a few good tests for durability and strength in the hobby shop, but the real test came from the student workers at the Protestant Learning Center. While we could step on it, swing it around, and drop it here at MIT, we could not entirely foresee how our design would be received by the students and staff - the end users. Ken delivered the final prototype of

the tray to our community partner about halfway through March, and we developed a simple user survey to collect feedback about this design.

Once the product had been tested in a real-world setting, we decided to focus our attentions on the cafeteria tray insert because the technology and primary concepts seemed similar. Of course, several unique problems emerged, as described in the section detailing the development of the cafeteria tray insert.

By the time March had ended, Mike had also developed a web site for our class. This site serves to help us communicate among ourselves while also distributing our ideas to a larger community.

APRIL – SECOND PRODUCT

We went back to the drawing board in April, now with a new goal in mind. Having gone through the design process once before, it was slightly easier to come up with one or two good designs for the cafeteria tray insert. Instead of just developing a single prototype as we had done before, we decided to develop two models in parallel to see which one would prove most viable and easy to manufacture at the end. Several new manufacturing techniques were also learned, and we followed up with our community partner by conducting a site visit.

Some time was also dedicated to creating multiple copies of the both products, as we hoped to get samples out to the testing site as soon as possible. Finally, we started as a group to document our design process and drawings.

MAY – DELIVERY AND FUTURE PLANS

In May, we finished up the second product as well as our documentation. In addition to presenting our products to the MIT community, we gave them to our partner and watched as they started to be used. Final adjustments were made, just as the semester came to a screeching halt.

Product Deployment Details

COFFEE TRAY HOLDER

With the water jet mastered, our first challenge was to design a coffee cup holder for the coffeehouse at the Learning Center. One of the main problems with the way their coffee shop is run is the cup holders. The cheapest and therefore the most viable option is using cardboard cup holders from Dunkin Donuts, which are flimsy, disposable, and hard to hold. We came up with an improved design. Here are some pictures of the work in progress:

The first prototype is the design on the left. It allowed for six cups to be held with a handle in the center. Placing the holder on a table top caused the cups to disengage from the holder, allowing them to be easily removed. However, there were a few flaws with this design. First, the handle opening is quite small, suitable only for small children. Second, spilling coffee is an issue when using any cup holder, and this design did not lend itself to easy cleaning. This design was more for proof of concept than anything else.

The second design (middle) had a few noted improvements. First of all, the handle is an open design, allowing for any sized hand to hold it. The cup holder itself is made out of polycarbonate, making it easier to clean, cut easily on the water jet, and bend supporting feet out of the material as shown. Finally, any sharp edges were eliminated, making it safer for the students of the Learning Center to use. However, it was noted than in addition to carrying coffee the students must also carry envelopes of change for the customers. This led to the rubber bands on the handle as shown in the picture.

Our final design (right) includes a more ergonomic handle, a clear slot for change envelopes as well as a gap for easy cleaning and removal of spilled change. The cups in the middle are further spaced from the handle to allow for more radial symmetry, so it is easier to carry with some cups removed. This design is on site undergoing its first field tests!

Initial survey results have told us that it is much easier for students to hold with only one hand, resulting in far fewer burns. Also carrying coffee no longer poses an issue when navigating through doors, as one hand is completely free to open the door.

CAFETERIA INSERT

We learned that one of the biggest issues faced by the learning center is spilling of food and drink. Nowhere was this more of a problem than in the cafeteria. When we visited the learning center, they showed us the cafeteria, described the general process of how meals were served, and explained how the most likely time for spilling to occur is during the short walk to a table. We also learned that some students have more trouble than others, so our solution would be used by a select few rather than everyone. We were able to get a pretty good understanding of the problem, and we were even able to take a cup, bowl, plate, and tray back with us.

Our first step was to brainstorm ideas. We came up with many possibilities that included reorganizing the whole food serving process and various cafeteria tray add-ons. We realized that reorganizing the serving process would be difficult and doesn't help with the problem of spilling during the students' walk to a table. We concluded that to some kind of tray insert, add-on, or replacement that would help reduce spills would be best.

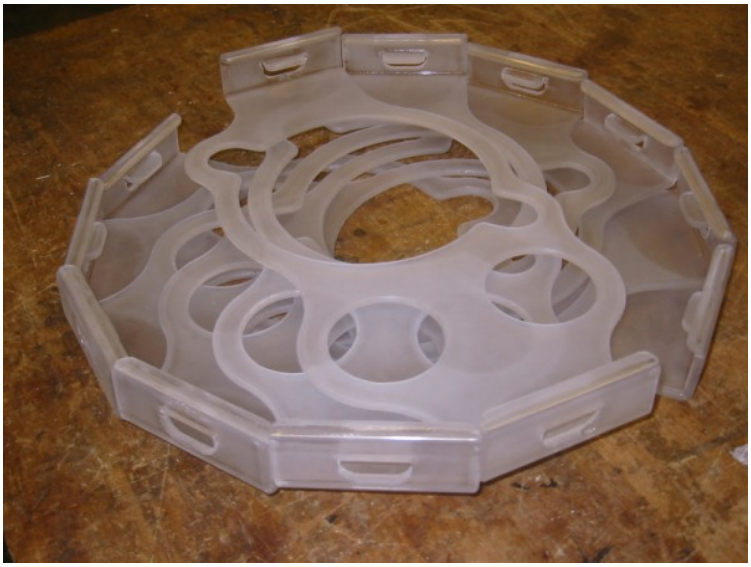
While the overall issue is spilling, we found that the real problem was that items could slide too easily across the tray. Even a small bump or tilt can jostle things enough to cause a spill. With this in mind we tried to come with ways to help reduce the sliding, or at least prevent spills from ending up on the floor. When we started this project, we had just completed our coffee cup holder, which taught us a good deal about using the water jet and how to work with polycarbonate plastic.

During our brainstorming process we settled on a few specifications that our solution needed to have. It had to be durable and reliable, easy to clean, easy to use, and somewhat easy and inexpensive for us to make. These guidelines helped us focus and we came up with a couple of valid solutions to pursue and test. These ideas included a rubber or plastic insert with cutouts

for the bowl and cups and a completely new tray with higher sides and better handles. We ultimately decided to proceed with the idea of making a plastic add-on that would attach to the existing trays to support the bowl and cups a small distance above the surface of the tray.

The next challenges we faced were how to arrange the items on the tray most effectively and how to attach the add-on securely to the tray. We ultimately decided to allow for a bowl and two cups to be secured while leaving half of the tray open for a plate, utensils, and anything else one might use. To secure this add-on to the tray, we utilized the water jet to rapid prototype various clip designs and tested each one to see which worked best. Through this experimentation, we found that tabs that clasp the edge of the tray worked best and having the add-on span the whole width of the tray proved to be most secure.

Through this process of rapid testing and making improvements, we ultimately developed product we were happy with and confident would address the spilling problem effectively. The final product is shown below:



WHAT WE LEARNED

USING THE WATER JET EFFECTIVELY

The water jet allows for a new design to be immediately tested with a quick, easy prototype. and the prototype can be remade with minimum effort as the design is tweaked. Using this technology in the most obvious way (always cutting the whole design) is not the most efficient course of action. Many times a piece of a design can be cut and tested separately, saving the raw material that would otherwise be used to repeatedly cut the parts of the product that are not under revision. The power of the design software allows a project to be divided into arbitrarily small pieces, refined to perfection, and rejoined and tested as a whole. For example, we designed several prototypes of the tray clips for the cafeteria project, but we did not have to cut an entire tray to test each design.

FINISHING CUT POLYCARBONATE

Most of the work we did was with polycarbonate sheets, and we made several discoveries about working with this material. It cuts very well on the water jet, but the cuts are left with square edges that we would like to round off in the easiest way possible. The best way we found to do this is to use a concave half circle router bit in the table router. In order to guide the bit, we used the water jet to create a plywood copy of the polycarbonate item. We glued the polycarbonate to the plywood with a little bit of carpet tape, which peels off easily afterwards.

In order to make sure the edge is fully rounded off, the plywood guide should be slightly bit smaller than the Polycarbonate.

The smooth, clear look of the polycarbonate may be desirable for some aesthetic applications, but it is prone to scratches, and can be easy to misplace. In order to give the surface a frosted look, we used an orbital sander. Contrary to expectation, coarser grit paper was not quicker to frost the surface. In fact it was very difficult to get any frosting effect from it at all. For best results, a fine finishing grit should be used.

BENDING

We did a great deal of bending. Some of the bends were long and went all the way across the piece. Other bends were small and surrounded by parts that were not supposed to bend. Thin polycarbonate bends easily when heated with either a long heater or a heat gun. The heat gun is ideal for small bends. Quality bends in thicker polycarbonate are difficult. In order to make it work, the material along the line should be cut about half way through with a 90 degree pointed router bit. The cut side should be towards the inside of the bend. After cutting the groove, it helps to heat one side on the long heater and the other side with the heat gun at the same time.

When heating the material, it reaches a bendable point shortly before bubbles appear. To avoid forming bubbles, watch the surface from a sideways angle with an overhead light reflecting off the heated area. It changes its reflection when it is ready to bend, and if you catch it quickly it doesn't bubble. Whenever possible, the actual bending should be done against a solid object with the desired angle to press against, rather than free-handing the angle.

CONCLUSION

Working in this class was definitely a learning and development process for all of us. In addition to learning the water jet and our way around the hobby shop, we learned how to design for real-world clients. Going from raw ideas to a final product was impressive and inspiring, and we managed to do so twice. Finally, all of us gained a better understanding of the special needs faced by the children at the Protestant Learning Center. Ken's and Alea's class was a great experience, and we collectively recommend it to anyone interested in learning how to use the waterjet for community improvement opportunities.