

**The Design and Fabrication of a
Two-Handed Spring-Loaded Pool Cue**

by

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Submitted to the Department of Mechanical
Engineering in Partial Fulfillment of the
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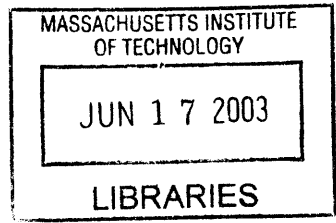
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ABSTRACT

A two-handed spring-loaded pool cue was designed and built for the developmentally disabled children at the Cardinal Cushing School. The pool cue was designed with the following characteristics in mind. It had to be safe, robust and reliable, easy to maintain, fun to use, and aesthetically appealing, all while promoting learning and assisting the lower-level developmentally disabled children in playing the game of pool. The design process was carefully documented. An alpha prototype was tested by developmentally disabled children, and it proved to be an effective and intuitive tool to use. The two-handed spring-loaded cue provided a fun way for disabled children to play pool while meeting all the functional requirements in the design.

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Introduction and Background

Four million Developmentally Disabled (DD) children between the ages of six and fourteen live in the United States today.¹ These children have difficulties in performing everyday tasks such as getting dressed, showering, and communicating with others. There are programs and schools such as the Cardinal Cushing School in Hanover, Massachusetts that provide help to children with mild or severe special needs.²

The Cardinal Cushing School encourages their students to develop motor skills through physical activities. Pool is one of the games available for the children to play. The game of pool is viewed by many experts as a valuable rehabilitative activity for DD children because it improves both physical coordination and verbal interaction.³ However, pool is inaccessible to many DD children because of the high level of physical dexterity required.

In the fall of 2002, the red team of 2.009, including myself, designed and built a pool table and pool cues to make it easier for the children at the Cardinal Cushing School to play pool.⁴ We delivered an interesting table with curvy rails to the Cardinal Cushing School in February 2003. The cues, however, needed a little more work before they could be given to the school. Most of the thought and energy in 2.009 went into designing and building the table, but by the end of the course, it was clear that the cues were what the children really needed to develop their skills. These mechanical cues could be used on normal pool tables to give the children the ability to play the game.

Two types of mechanical cues were developed during the course of 2.009. The two cues were very similar in design but slightly different in function. The basic cue as shown in Figure 1 is made up of eight functional parts: a soft cue tip, a wooden shaft, two Delrin bearings, a polycarbonate housing, an aluminum shaft, a spring, and a handle. The user holds the housing of the cue with his left hand and grasps the handle with his right hand. The user pulls the handle away from the housing to compress the spring and energize the cue. After the desired shot is lined up, the user releases the handle to fire the cue.

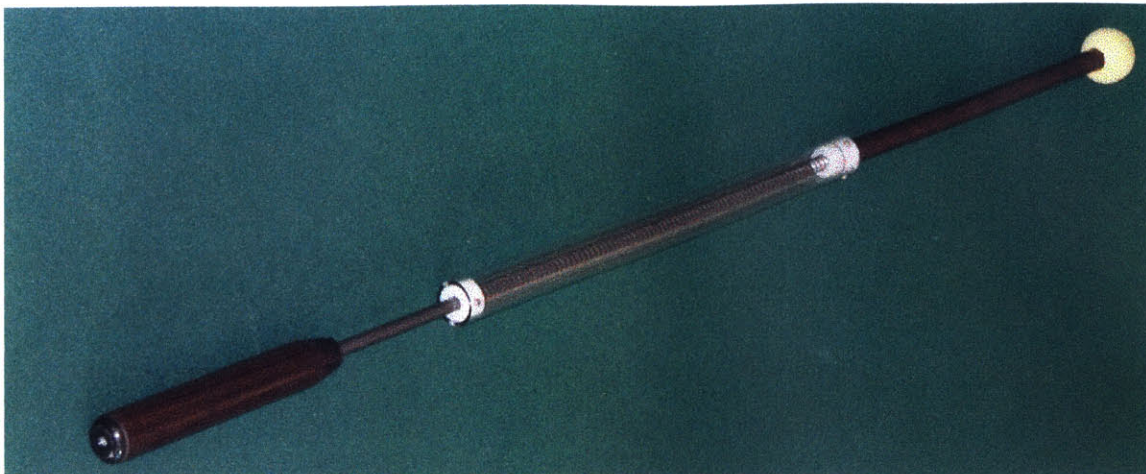


Figure 1 The basic spring-loaded cue developed by the Red Team in 2.009

A trigger cue was designed for lower level disabled students. The only difference in this device was the addition of a friction trigger at the front of the housing. This device was exactly like the basic spring-loaded cue except the energy stored in the compression spring was restrained with a trigger mechanism. The user would charge the trigger cue in a similar manor by pulling the handle back. But to fire the cue, the user would activate the trigger by pulling it back. The trigger cue is shown in Figure 2.

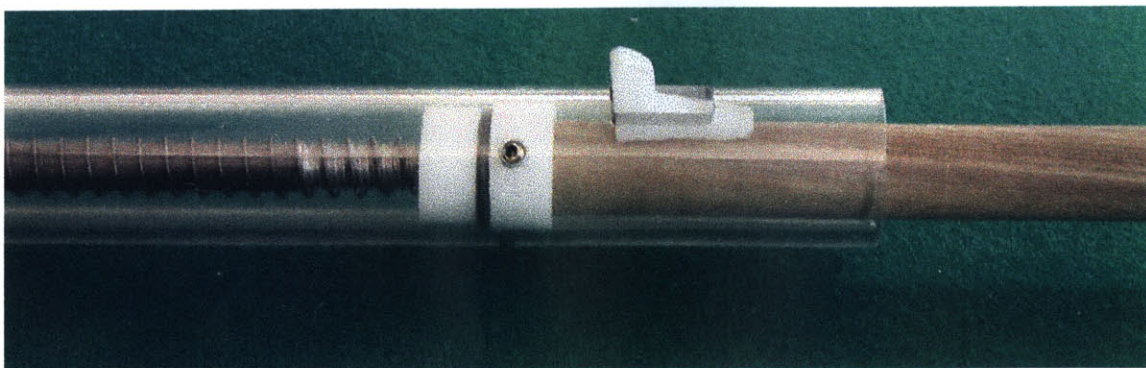


Figure 2 The trigger cue developed by the Red Team in 2.009

The goal behind the cues was to design a device that made it easier for the kids to play the game of pool. Such a tool would allow the students to concentrate on specific motor skills instead of using a normal pool cue, which requires the conjunction of many

complex skills. Once they mastered the skills of the trigger cue, the children could advance to the secondary, basic cue, which requires more physical coordination, and eventually to a real pool cue.

Through testing, these cues proved to be a substantial improvement over the traditional pool cue. Many children at the Cardinal Cushing School that couldn't accurately make a shot with a regular pool cue could now sink a ball in a pocket with the mechanical cues. Even though the cues were such a success, there were many details that still needed to be ironed out before they could be given to the school.

The major problem with the trigger cue was the trigger itself. The trigger was a free-floating wedge-shaped mechanism that used friction to restrain the energized cue. Because there wasn't any sort of mechanical advantage, the trigger was very stiff. It took a lot of force to release it. Another problem was that the mechanism relied on gravity to preload it. This made the device unreliable, and the cue could only be cocked in a certain orientation. Another problem with the trigger was made obvious through testing. The method of releasing the trigger was counterintuitive to the Cardinal Cushing students. To release the trigger, the wedge had to be pulled back and many of the children tried to push the trigger down. Only after hours of instruction did one of the children find the trigger cue useful.

The spring was a problem with both cues. Since the shaft was constructed out of aluminum, the spring made an unpleasant screeching noise each time it was compressed and released. Another problem surfaced because the wooden dowel was slightly warped. This caused the cue to vibrate when it was cocked and fired. The way children held and fired the cue could also be improved with an alternate design. The children held the cue up in the air, and they didn't have any rigid support while aiming and firing. This significantly decreased their expected accuracy. A tripod, which rested on the table, would have solved this problem. The cues also seemed fragile, and since they were one of a kind, Tom McElman, the recreations director at the Cardinal Cushing School, was reluctant to let the children use them. Even if all the problems were worked out, these cues would only help the higher-level students at the Cardinal Cushing School. They proved too difficult for the lower level students.

After seeing the two pool cues, June Smith, a sensory specialist at the Cardinal Cushing School, requested a two-handed spring-loaded trigger cue. She said that research has shown that developmentally disabled children function better when both hands simultaneously do the same task. She gave the example of throwing a ball. It is easier for the children to throw a ball over their head with both hands than it is to throw a ball with one hand, like a baseball.

Mission Statement

The goal of this thesis was to design, build, and deliver a functional pool cue to the Cardinal Cushing School that met the following functional requirements. The pool cue must promote learning, be safe, be robust and reliable, be easy to maintain, be fun to use, and be aesthetically appealing, all while assisting the lower level developmentally disabled children at the Cardinal Cushing School in playing the game of pool.

The pool cue should promote learning on many levels. It should help to develop motor skills and hand-eye coordination skills. These skills include pulling the trigger while keeping the cue steady and aligned, quickly removing the cue from the table after the shot is fired, and exerting physical strength in a controlled direction to cock the cue. The children will develop logic skills and achieve an understanding of simple physics by playing the game of pool. They will need to figure out where to hit the cue ball to make it travel to the desired location. The cue should also aid in the development of social skills by giving the children a new game to play with their friends. The game of pool will also encourage them to play with good conduct and to learn how to win and lose politely.

The pool cue must be safe. The power needs to be regulated to a safe level so that injuries will not occur if the cue is fired at another person. The cue tip needs to be large enough so it doesn't damage an eye. This can be accomplished if the diameter of the tip is large enough so it hits the bone structure around the eye first. It needs to be designed so that it won't shatter or splinter when it is thrown or dropped. The cue cannot have any harmful pinching points that could injure the user.

The cue must be robust and reliable. It must continue to work after being dropped or thrown. It should work for many years. It should be able to withstand abuse. Over-cocking the cue and squeezing the triggers too hard should not damage the cue in any way.

It should be easy to maintain. The cue should be designed so that no maintenance is necessary. None of the parts should be permanently attached, and a layman should be able to disassemble the cue using common tools. The parts that wear should be easy to replace.

The cue should be fun to use and aesthetically appealing. The children need to enjoy playing with the cue or they won't use it and learn any new skills. They should think the cue looks cool and that it is not designed for their special needs so they won't feel ostracized to use it over a normal cue. The cue should not make any noises that make the children uncomfortable.

An Overview of the Design Process

In the beginning of the design process, the first thing I thought about was how the optimal cue would be held, cocked, and fired. I created some rough sketches of what the cue would look like with different handles and triggers. I then considered different locking mechanisms and debated between using a ratchet and a friction lock. Then I looked at the trigger mechanisms and how to translate the desired hand motion to unlocking the shaft of the cue. With these considerations in mind, I drew up some sketches of the mechanisms that worked best with the ergonomics. I made a few CAD models in SolidWorks of the different designs and decided that vertical handles with a ratchet and rotating catch mechanism had more benefits than the other designs. I then worked out the details with my computer model and began constructing a working prototype.

While building the first prototype, I made a few design simplifications. I had to modify my design when I encountered problems with machining materials. I then designed another version of the cue keeping in mind the capabilities of the tools and machines in the Pappalardo Lab and the materials I had at my disposal. As I began to assemble parts, I discovered that the assembly procedures I had initially thought out would not work in practice. So I redesigned a few components for assembly. After building a few functional components and discovering minor problems, I modified a few parts once again. After several design and prototyping iterations, I ended up with a two-handed cue that met all the functional requirements.

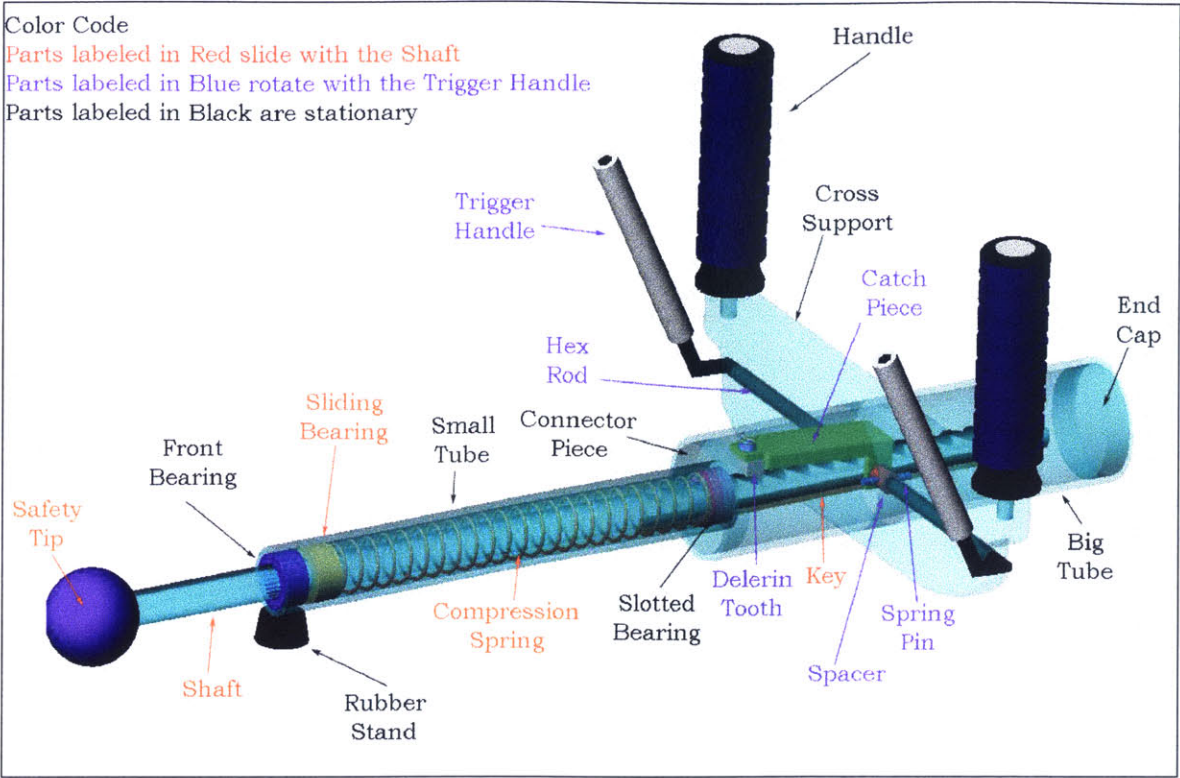


Figure 3 The final CAD model of the two-handed cue with all the parts labeled

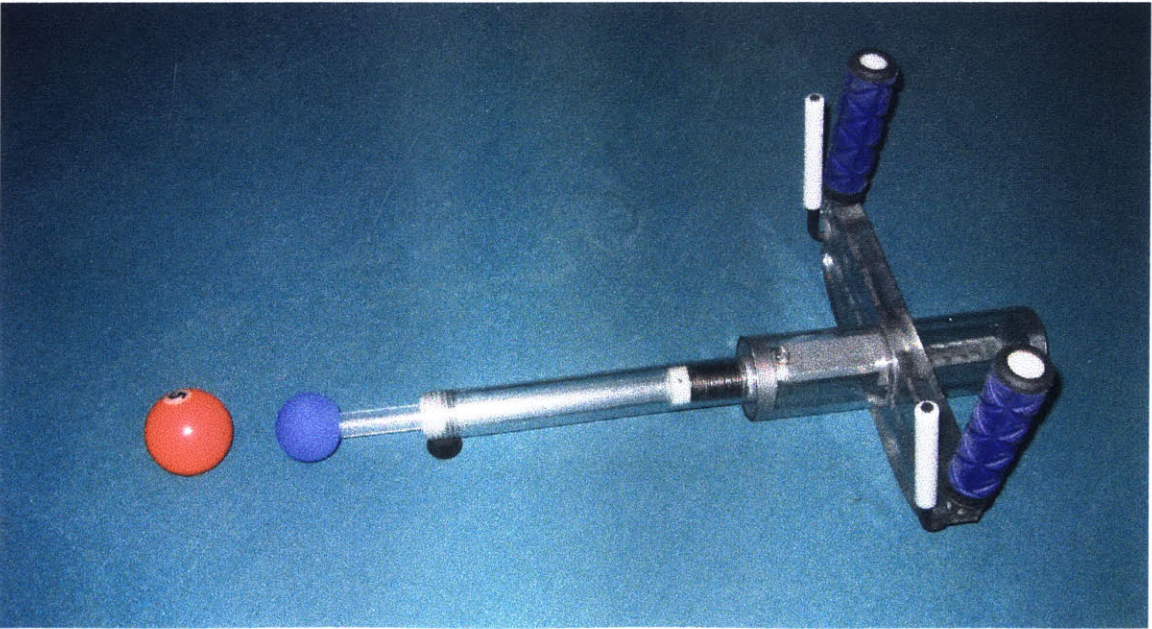


Figure 4 The final prototype

The Design Process

To begin the design process, I initially thought about how a two-handed cue would be fired. I asked myself how the children at the Cardinal Cushing School would hold the cue and activate the trigger. I stood in front of a table and pictured myself holding an imaginary cue with my fingers hovering over triggers. I quickly sketched out the cue that came to mind. I pictured a cue with vertical handles that was held and fired like a World War I airplane gun.

I then questioned if this was the optimal way for a child to hold and fire a two-handed cue. I quickly brainstormed other possibilities. I considered horizontal handles similar to those on a bicycle. But if the handles were in the back of the cue, it would be hard for the user to hold the cue horizontally. These types of handles seemed more natural for a jackhammer and other devices with the center of gravity directly below the handles. However, I still kept the idea for further consideration.

Then I began brainstorming different types of hand motions to trigger the cue. At first, I concentrated on the ergonomics and didn't consider how the actual mechanism would work. I looked at the most common trigger, the one on a handgun. With this device, an index finger activates the mechanism by pulling the trigger. I didn't think this was suitable for disabled children because they tend to prefer grabbing large objects and using their entire hands, not just their index fingers. I briefly considered a twisting motion similar to turning the throttle on a motorcycle handle, but I thought this was too difficult as well. I then thought that squeezing the handle would be the simplest motion. The trigger I had in mind was similar to the one on a garden hose.

Then I examined different ways of cocking the cue. Two methods came to mind from the cues designed in 2.009. The user could push the tip of the cue into the main body or pull the butt of the cue out of the main body. There were a couple of problems with pulling the shaft to reload the cue. To do this, the user would have to let go of both handles and reorient their hands to grab the butt of the shaft and the main body of the cue. While testing the cues made in 2.009, it was apparent that this is a difficult thing for the lower level students at the Cardinal Cushing School to do. Another problem with this design is that the shaft of the cue would protrude about a foot out of the back of the cue

and be in the user's way. This wasn't a problem with the previous mechanical cue designs, but it is a problem for a cue with two handles on either side of the shaft. For these reasons I decided that the cue should be cocked by pushing the tip into the body of the cue. The children could reload the cue without changing their grip by resting the tip on the felt and pushing the cue toward the table. I also wanted the cue to be as small and lightweight as possible. In previous product tests, the Cardinal Cushing students were given a modified spring-loaded umbrella to use as a pool cue. They preferred this device to a spring-loaded cue that was shaped like a pool stick because it was much smaller and easier to handle. This feedback confirmed my design decision to not have the shaft extend beyond the back of the cue.

After considering the ergonomics of holding, cocking, and firing the cue, I began to look at the mechanisms and figure out how everything would work. First, I debated how to store the energy. The two obvious choices were a compression spring and an extension spring. I looked at the advantages and disadvantages of each spring. It is difficult to design a cue for an extension spring because the spring needs to be attached to the moving shaft and a stationary point on the cue's body. A cue with an extension spring would have to be longer because there would need to be room in the cue for the spring to expand when it was stretched. On the other hand, a compression spring doesn't need to be attached to anything. It can be put in the cue over the shaft between the sliding and stationary bearings. However, a problem with a long compression spring is that it tends to buckle when compressed. This is why long and soft compression springs are uncommon. So it is very difficult to find a spring with the characteristics desired. Conversely an extension spring can be bought off the shelf with all the desired qualities. Weighing the benefits of each option, I decided it would be easiest to special order a compression spring with the exact specifications I requested. The spring needed to fit inside a one-inch diameter tube and had to be eight inches long. The spring constant had to be soft enough so a child could compress it but powerful enough to hit a pool ball a significant distance. I estimated that a fully compressed spring should provide around 10 pounds of force. So I ordered a compression spring with a constant of 1.4 pounds per inch.

After the type of spring was determined, I considered different locking mechanisms. The three locking mechanisms that initially came to mind were the pin and hole lock, ratchet and catch lock, and a friction wedge lock. With a pin and hole lock, the hole would be on the shaft of the rod and the pin would be connected to the trigger. When the trigger was activated, the pin would be pulled out of the hole and the shaft would be free to move. This mechanism had the disadvantage of only having one power setting on the cue. So I quickly eliminated this type of mechanism. The advantages of a friction lock are that it doesn't make the sound a ratchet mechanism does when cocking the cue, and it has infinite resolution. The ratchet mechanism could only have a limited number of power settings. The disadvantage of the friction lock is that it is more complicated to design. I would have to tweak the angles of the wedge and consider the friction coefficients of each material. The friction lock also has a greater tendency to wear, so the materials would have to be carefully chosen. I couldn't eliminate either lock based on these factors. I had to consider how the desired hand motion of activating the trigger would translate into unlocking the shaft to make an informed decision.

The next step was to pair the locking options with the two different handle orientations. The vertical oriented handles with the squeezable trigger worked best with a ratchet mechanism, while the bicycle style horizontal handles worked better with the friction lock. To get a better idea of each design, I made some CAD drawings in SolidWorks.

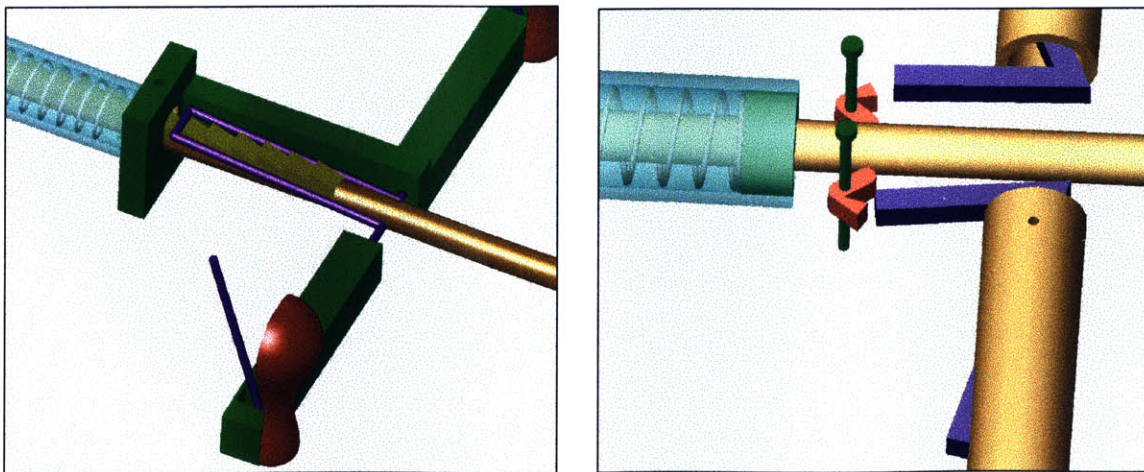


Figure 5 The ratchet mechanism is pictured on the left with the vertical handles, and the friction lock is on the right with the horizontal handles.

The ratchet mechanism seemed much less complicated. It had fewer parts and much less dependence on minor design details like friction coefficients and wedge angles. The friction mechanism needed to have four pivoting parts whereas the ratchet mechanism needed only one. Unlike the friction lock, with the ratchet design the two triggers are physically connected so if either trigger were pulled, the shaft would unlock and the cue would fire. This is a better design for the children. So I made the decision to use a ratchet lock with vertical handles and a squeeze trigger.

Once I had a basic idea of the cue design, I began to make material decisions and started ordering parts to build a prototype. I ordered several wooden dowels from McMaster Carr for the shaft of the cue. But all the dowels were slightly warped and none were straight enough to slide through two concentric bearings. Instead of using wood, I decided to use a half-inch polycarbonate shaft. This material glided more smoothly through the bearings and also complemented the polycarbonate theme of the final product. Polycarbonate was the material of choice for this cue because of its optical clarity and shatterproof properties. I thought it was important that the cue was clear so the children at the Cardinal Cushing School could see how it worked.

Once I made the decision of which mechanism to use, I began to simplify the design by eliminating parts. I decided that a concentric polycarbonate tube could replace the two horizontal supports. This decision also aesthetically agreed with the cue design. I debated whether or not to have a separate ratchet piece or to cut serrated teeth out of the polycarbonate shaft. With a half-inch diameter shaft, I thought the rod wouldn't be rigid enough if I cut ratchet teeth out of the shaft. So I initially decided to make a separate ratchet piece out of Delrin. The ratchet would also act as a key and the shaft wouldn't be able to rotate through a slotted bearing. The triggers for the ratchet mechanism needed to be preloaded with a small spring. At first I decided to use two torsional springs, one on each trigger, but then I thought it would be easier to attach a single compression spring to the catch piece.

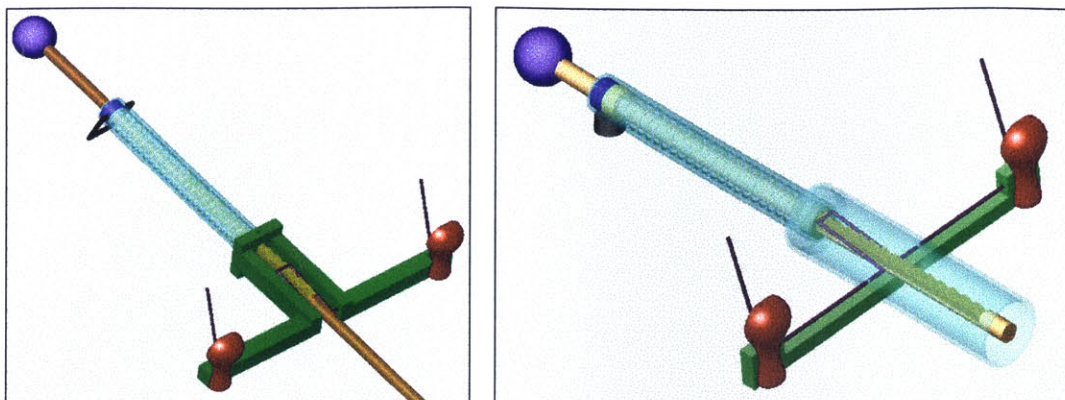


Figure 6 The cue before and after preliminary design changes

I designed the cue so that it could rest on the table while a shot was made. An optimal shot occurs when the middle of the cue tip strikes the middle of a pool ball. In order for this to happen, the bottom of the small tube needs to be a half-inch above the felt of the table. Initially, I pictured a retractable wire stand to prop the cue in the correct position. I later decided that there was no reason to retract the stand and that a retractable one would be less robust. So I decided to use a half-inch rubber stopper as the resting point. I drilled and tapped a hole in the small polycarbonate tube and fastened the rubber stopper with a screw. After using the cue with the rubber stand, I concluded that this wasn't the best material to use. The rubber grabs on to the felt of the table and makes it difficult to slide the cue to line up a shot. Another problem with the material was that it deteriorated around the threads of the screw. After prolonged use, the threads on the screw would destroy the rubber, and the stopper would loosen itself. A half-inch polycarbonate cylinder is a better solution for a stand.

When I began to construct a working prototype, I ran into many problems that forced me to modify my design several times. When I machined the ratchet piece out of Delrin, the internal stresses in the material caused the piece to bend after it was cut.

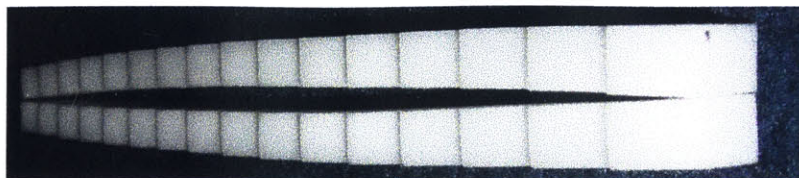


Figure 7 The bent ratchet pieces

Because the ratchet piece wasn't straight, it would not slide through the slotted bearing smoothly. To solve this problem, I decided to use a 5/8-inch diameter shaft instead of a half-inch diameter shaft and cut the ratchet out of the shaft. But I ran into similar problems with the polycarbonate shaft. After the ratchet teeth were cut out with the water jet cutter, the shaft bowed slightly where the teeth were cut. I decided to insert a brass square extrusion underneath the teeth to straighten the rod. This brass extrusion also acted as a key and stopped the polycarbonate shaft from rotating.

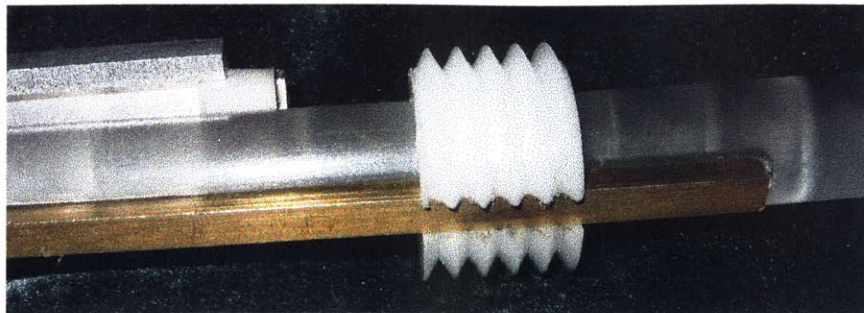


Figure 8 The brass key constrains the shaft from rotating.

Throughout the fabrication process, I changed the design of the cross support a couple of times. Initially it was a square polycarbonate extrusion bar that went through the big tube. For aesthetic reasons, I changed the piece to press fit around the big tube rather than to penetrate through it. In the next design iteration, I made the handles separate pieces so they could be round and more comfortable to hold. The handles consisted of rubber bike grips that were press fit onto Delrin rods. The Delrin rods were threaded into the cross support piece.

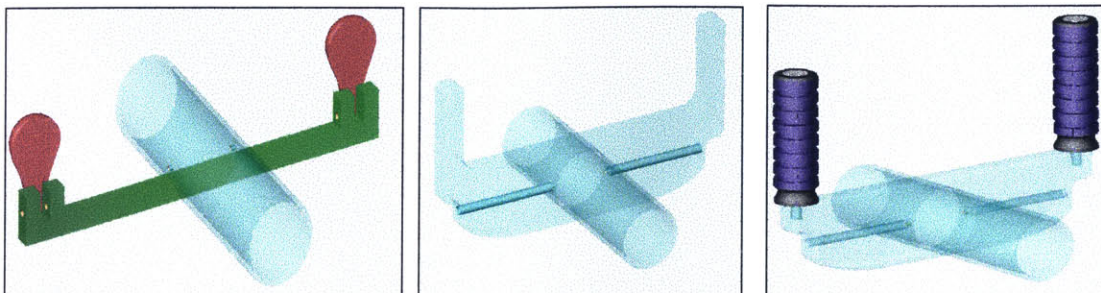


Figure 9 The three design iterations of the cross structure piece

I originally decided to fasten the bearings inside the small tube with setscrews like the bearings in the cues designed in 2.009. But using setscrews was not a good solution for the slotted bearing. If the setscrews were too tight, the bearing would pinch the key, and the shaft could not slide freely. If the setscrews were too loose, the bearing would pop out when the cue was cocked. So I decided to use an alternative way of attaching the bearings. As shown in Figure 10, I tapped the inside of the small tube and threaded both stationary bearings. I attached the sliding bearing to the shaft with setscrews because it was pointless and impossible to thread it on in the middle of the shaft.

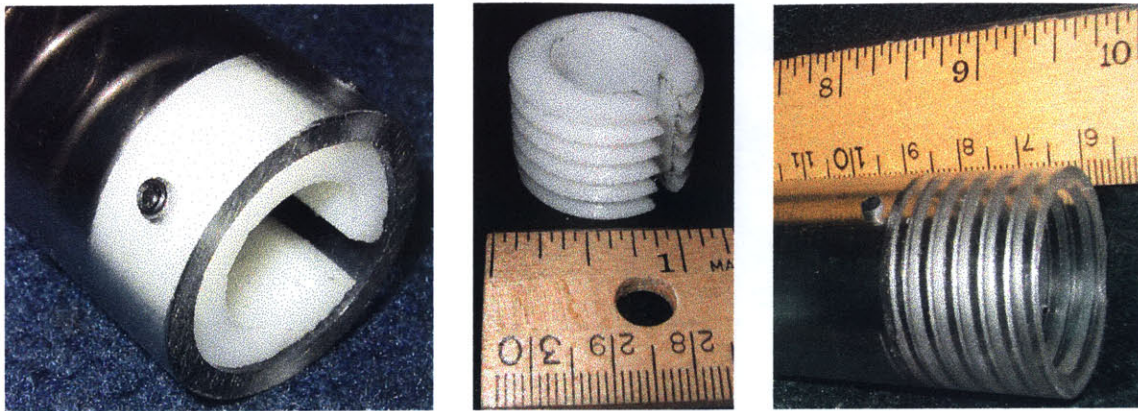


Figure 10 The original bearing with setscrews is on the left. The new threaded bearing is in the middle. The threaded small tube is on the right.

One of the components that changed significantly from the original design was the ratchet catch mechanism. In the preliminary design, I used a single welding rod for both the trigger and catch mechanism. I bent a welding rod to form the trigger handles and a C shaped section to grab onto the ratchet, as shown in Figure 11. The design didn't work well for many reasons. First, the eighth-inch welding rod was not rigid enough and would flex when the trigger was pulled. There were also issues with the assembly. To get it through the cross structure, I used two rods. I first inserted straight rods through the cross structure. Then I bent each rod to the desired shape and welded the two sections together in the middle. But this process could not be done when the cross structure was around the large tube. So I needed to come up with a different design.



Figure 11 **The original trigger and catch piece**

In the new design, I used two stiffer quarter-inch hex rods instead of the welding rod. These hex rods were bent in two places to form the desired trigger shape. I covered the exposed hex rod with a thin four-inch Delrin sleeve to make a trigger handle. I designed a separate piece out of aluminum to catch the ratchet shown in Figure 12 below. I made a hexagonal hole in the catch piece and pressed fit the hex rods. I tried to bend the tip of the catch piece to grab the ratchet but the aluminum was too brittle to bend without breaking. I decided it would be better to use a Delrin tooth instead of an aluminum one because it wouldn't wear down the polycarbonate ratchet. I machined a wedge out of Delrin and attached it, along with a load spring, to the catch piece.

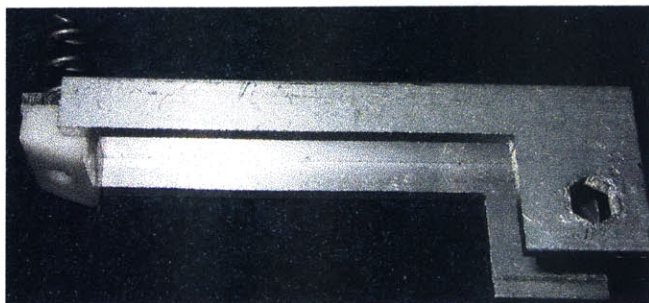


Figure 12 **The final catch piece with the load spring and Delrin tooth**

The problems with this design were that the hex rod trigger handles could be pulled out of the cross structure, and the catch piece had the freedom to move from side to side. To fix this flaw I added two Delrin spacers that forced the catch piece to be exactly in the middle of the big tube. I drilled a hole through the spacers and hex rods and inserted a spring pin so the handles couldn't move from side to side.

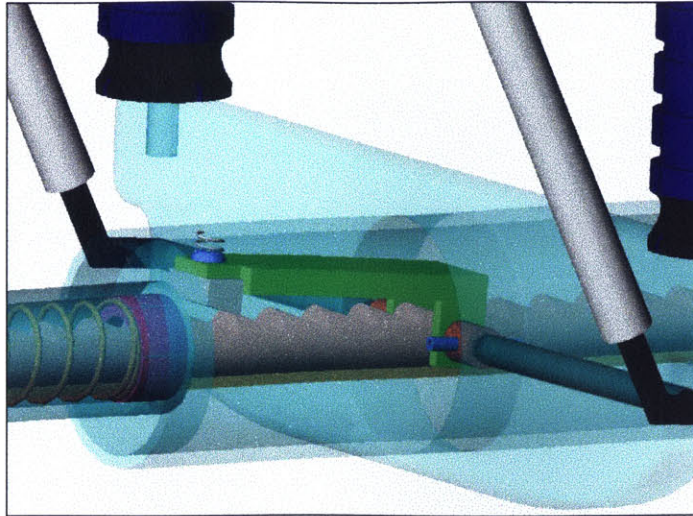


Figure 13 The spacer in red and the spring pin in blue constrain the motion of the handles.

I designed the cue so that a layman with common tools could remove all the parts. The only part that I attached permanently was the brass key because it doesn't need to be removed. I used a tight press fit to attach the end cap to the inside of the big tube. The only way to remove the end cap is to insert a tool through the hole in the cap and pull the piece out from the inside. I attached the connector piece to the small tube and big tube with press fit and three setscrews. I threaded these setscrews all the way into the slotted bearing. If the setscrews didn't penetrate into the slotted bearing, the bearing could rotate by twisting the shaft. If this happened, the ratchet teeth wouldn't align with the catch piece and the cue would not work.

After I built a working prototype, I noticed a few flaws. When the cue was fired, the sliding bearing would compress the air inside the small tube in front of the sliding bearing and create a vacuum behind it. This difference in pressure caused the shaft to slow down. To fix this, I drilled two air holes on both sides of the small tube. Another small problem occurred when the cue was fired without hitting a pool ball. The slide bearing would smack against the front bearing and produces a strong impulse force and a loud bang. To soften the impact, I put two rubber o-rings between the sliding bearing and the front bearing. This greatly reduced the impact but was not enough to deaden all the vibrations.

Results and Conclusion

To confirm that the two-handed cue was safe and robust, I dropped it from six feet onto a concrete floor. The cue did not break or chip and still functioned without flaw. I tested the cue with two developmentally disabled children at the Cardinal Cushing School. The cue was well received by the children. The testing showed that it was very intuitive to use. But nonetheless, one of the children did have problems loading the cue. He would forget to let go of the trigger from the previous shot, and the ratchet would not catch. But after using the cue several times, he started to remember to release the trigger while loading the cue. Tom McElman thought the cue was wonderful and agreed that it would help the children play pool. He said the cue met their safety standards but would be used only under supervision.

The two-handed cue that I designed and built meets all the desired functional requirements. It promotes learning by developing hand-eye coordination skills. It is a safe toy because of its limited power and large and soft cue tip. It is robust and will continue to work after it is dropped or thrown. Each piece can be taken apart with the appropriate tools, so it's easy to maintain. Most importantly, it was obvious through testing that the children enjoyed using the cue.

There are a few improvements that can be made to the two-handed cue. A polycarbonate stand needs to be built to replace the rubber stopper and fix the problems I addressed earlier. Another imperfection involves the sounds the cue produces during use. After the cue is fired, the spring continues to rattle and makes a noise that could be discomforting to the students. The two children at the Cardinal Cushing School that used the cue did not seem to mind, but further testing should be done on a greater population to see if this noise is a problem. There are a couple of solutions that would reduce the noise and vibration. If an extension spring were used, the spring would not vibrate after making a shot because all the coils would be touching one another. But this solution would require the cue to be eight inches longer. Testing would need to be done to see if the children prefer a longer silent cue or a shorter cue that makes a little noise. Another solution would be to dampen the vibration of the compression spring. This could be done

by modifying the outer diameter of the spring so it slightly rubs against the inside of the small tube.

After these improvements are made, the cue will be donated to the Cardinal Cushing School and will be used by developmentally disabled children.

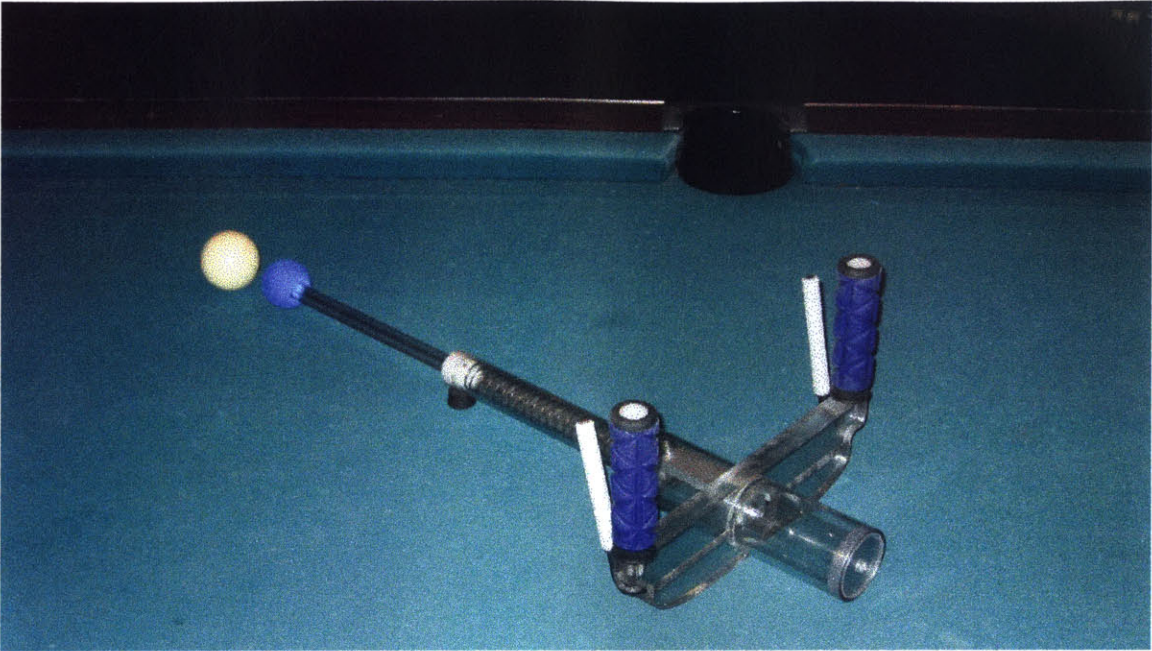


Figure 14 **The final working prototype**

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3. June Smith, a sensory specialist at the Cardinal Cushing School
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