

Appendix B

Automata Created with MachineShop

This appendix presents the automata that the test users created with MachineShop. These eight examples display a wide variety of aesthetic and design styles but all are instantly recognizable members of the contemporary automata school and are whimsical and extraordinary objects.

B.1 Abbie - Drowsy Dragon

Abbie was 10 years 10 months old and in the fifth grade when she began this project. Abbie wanted to make an automaton featuring her favorite animal, a dragon. She brought a plush dragon to the initial design session that was roughly the size she wanted her automaton to be. She also brought a sketch she had made of what she hoped to build (Figure B.1). The plush toy was about twice the size of her sketch and the finished automaton figure ended up being roughly the same size as the plush toy. Abbie's initial goal was to have the dragon flap its wings, move its tail from side to side, and breath fire.

Because these three actions all appeared along the center line of the dragon's body, Abbie chose to use a single shaft to which she would attach a crank in order to power all of the motions of the dragon. She first set about getting the dragon's wings to flap. She decided to keep the dragon's body stationary and make the wings third order levers. The fulcrums would be located where the wings attached to the body and the force would be delivered somewhere near the middle of the wings. Her choice of mechanical advantage (ratio) and lift would determine how much the wing tips would move. Since she wanted the wings to move smoothly and at a constant rate she elected

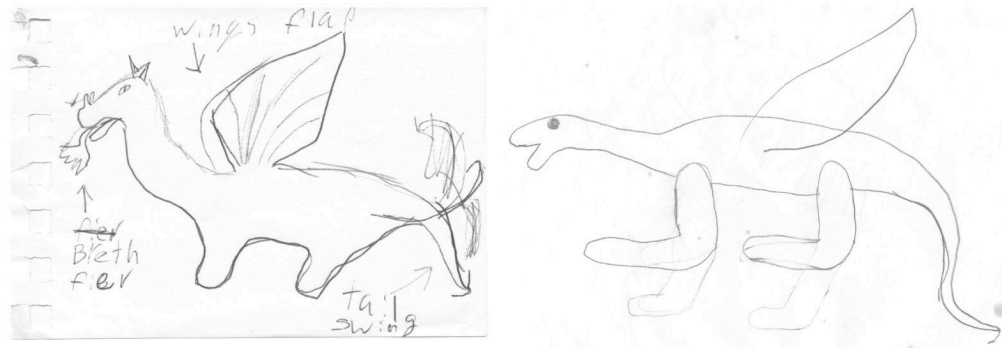


Figure B.1: On the left is Abbie's first sketch of her dragon. Notice that while she has behaviors annotated on the drawing, there is no indication of a mechanism or support framework included. This became the primary model for the finished dragon. On the right is Abbie's study for how the dragon might look lying rather than standing. Although this dragon has a substantially different appearance (it was drawn in the lab while the first sketch was done at home) you can see that Abbie is already starting to see that the legs and wings will be separate from the body. She hasn't yet discovered that necessity for the tail.

to use an eccentric cam to lift and drop a follower. This follower is a thick rectangular block that is wide enough to be attached to the wings by two pieces of small diameter music wire that pass through two small holes in the top of the support framework. The follower is thick so that its mass pulls the wings down as the cam rotates. To keep the follower properly aligned, it has two guide holes that ride on dowels protruding from the underside of the framework's top.

Abbie next turned her attention to the tail where she chose to use a Markey oscillator (see Section D.3 for a more detailed description). Not only did this provide the back and forth motion for the tail that she wanted, but it also introduced an up and down motion that she liked. To take strain off the oscillator, the shaft that rotates the tail uses two tabs at the rear of the body as bearings to hold it in alignment.

The fire breathing proved to be the most difficult motion to design. Abbie considered a number of possibilities from among the simple mechanisms that she had access to and was fairly certain that she could do it with one of the types of crank-slider (Figure D.9). This presented her with two major problems. First, how could a crank-slider be made small enough to fit inside the head and neck of the dragon while still moving the fire the distance she wanted? Second, how

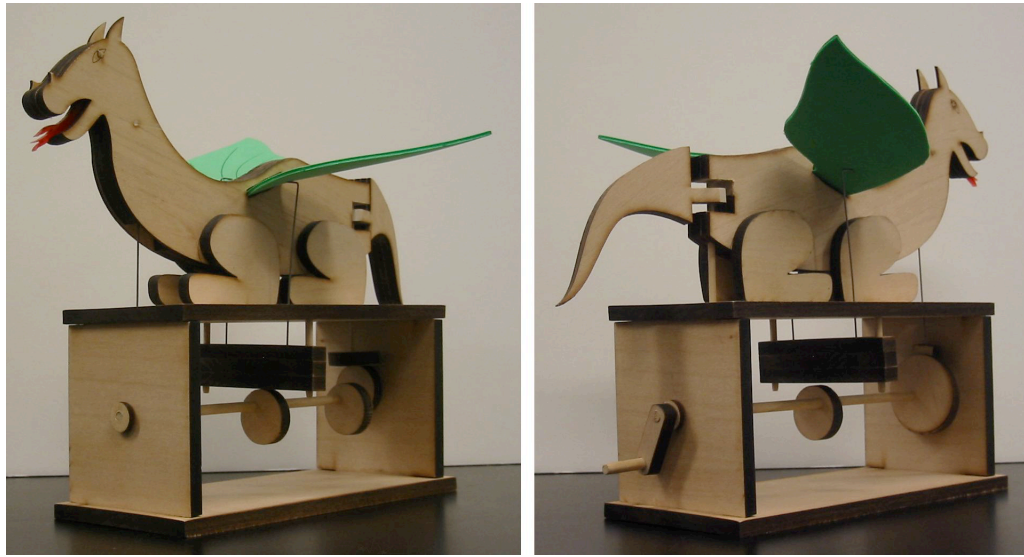


Figure B.2: Two views of the dragon. On the left, the follower for the wings and the Markey oscillator for the tail can be seen. On the right, the eccentric cam and ring follower for the fire are visible. The wires that move the wings can be seen in both views.

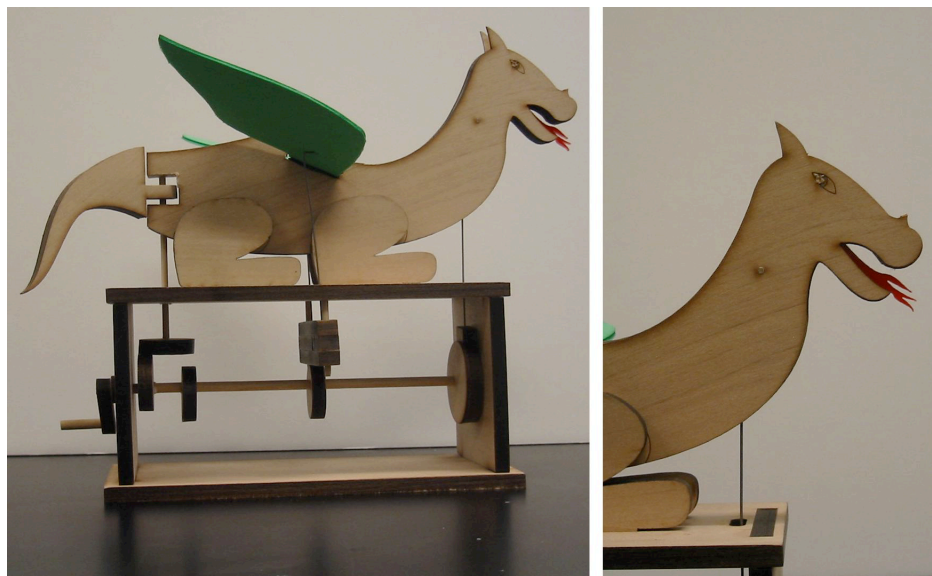


Figure B.3: Two views of the mechanism for the dragon. The left view shows the complete mechanism: the Markey oscillator for the tail, the eccentric cam and block follower for the wings, and the eccentric cam and ring follower for the fire. The close-up view provided detail of the fire breathing. The wire that actuates the lever inside the dragon's neck can be seen passing through the top of the framework and the fire can be seen coming out of the mouth. Not visible is the lever that translates the vertical motion of the wire into the horizontal motion of the fire, although the shaft on which it pivots is visible to the left of the mouth.

could she transmit the rotational motion needed by the crank-slider from the main shaft? This would require it to be rotated 90 degrees since the shaft of the crank-slider would need to be orthogonal to the main shaft to fit in the body.

These problems forced her to look for another solution and she ended up placing a lever of the first order in the neck of the dragon. She inclined the lever at about 30 degrees from the vertical to match the upper slope of the neck. To the lower end of the lever she attached another piece of music wire that terminated at a ring follower surrounding an eccentric cam on the main shaft. To the upper end of the lever she attached the fire so that it could move in and out of the dragon's mouth. By inclining the lever, she was able to change the vertical motion of the cam follower into a horizontal motion for the fire.

Abbie drew her inspiration for the mechanism she designed from two of the sample automata she had access to. Ralphie the flying bison (Section D.1) suggested her initial ideas on making the wings flap, even though the way in which this happens in the dragon is quite different. Celia the sea lion (Section D.3) provided the techniques used to move both the tail and the fire. Abbie used basswood of various thicknesses for all of the wooden parts except the dowels, music wire operates the wings and fire, the wings are cut from craft foam, and the fire is cut from red acrylic plastic.

B.2 Calum - The Commute

Calum was 11 years and 8 months old and in the sixth grade when he began this project. Calum was already an experienced Macromedia Flash programmer and had become interested in understanding the elements of human locomotion for a project he was working on. To expand on this, he decided to construct an automaton that would focus on people walking by representing three men on their way to work. To add variety to the figures, he chose to have one carrying a briefcase, one carrying an umbrella, and one carrying a coffee cup.

Since the walking motion was the key element of this automaton, Calum chose to design a single mechanism to create that motion and to replicate it. This decision simplified the prototyp-

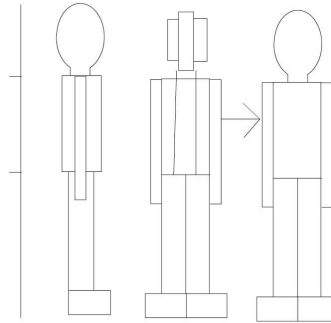


Figure B.4: Calum's first sketch of a commuter. Unlike the other users who drew their sketches with pencil on paper, Calum was already an experienced Flash programmer and drew these figures using his computer. Note the scale at the left of the drawing which is divided into thirds to provide the proportions for the head, torso, and legs.

ing since only one instance of the mechanism needed to be refined and that mechanism would then be copied for all of the figures. This automaton also presented some special challenges as the legs are also components of the mechanism.



Figure B.5: The commuters head to work. These views highlight the large number of mechanical components that all work together to provide the user experience. Each figure carries an item of importance: an umbrella, a coffee cup, a briefcase. The figures were colored using water base markers and the shirts and ties were cut from magazine advertisements.

Calum's sketch of the figures was used to create cardboard mockups to help in determining the size of the automaton and a cardboard framework was built to those dimensions. Since the mechanism contained so many components that needed to work together, no cardboard mechanical components were created. Instead, it was decided that one complete mechanism, up to and including the figure's torso, would be constructed from wood. Calum began by analyzing his own walking gait and looking for examples in the simple mechanisms that would provide a similar motion. He picked the offset crank version of the crank-slider mechanisms (Figure D.9) because he thought it would have an interesting look.

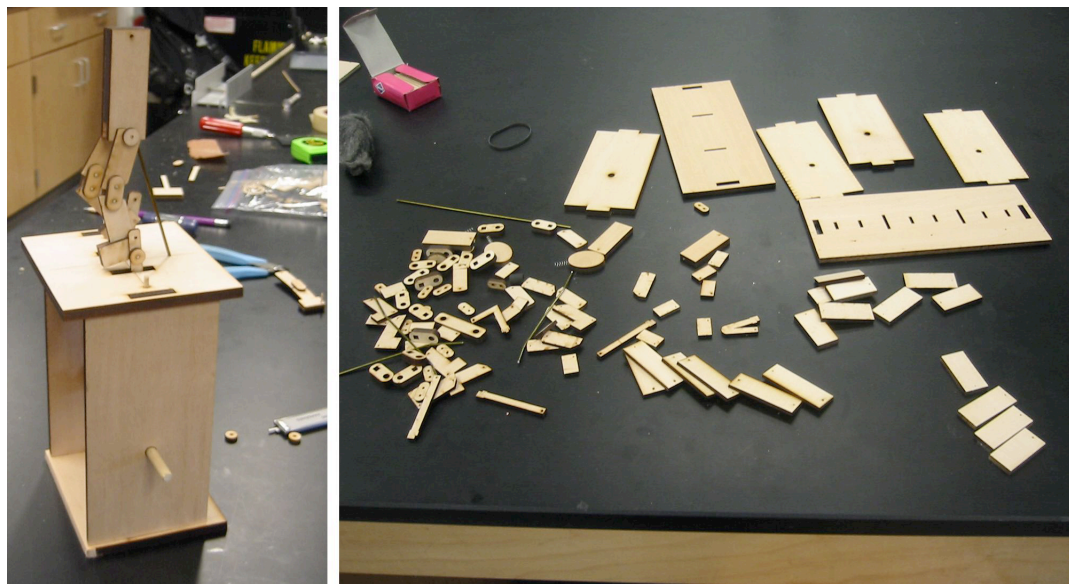


Figure B.6: On the left, the wooden prototype built to refine the mechanism. On the right, of the 130 pieces in the automaton, 107 pieces were fabricated with the laser cutter. Calum and his parents found the assembly process quite challenging.

The upper end of the slider rods attach to the figures' heels and move them in an oval path. As each heel moves up and forward, the upper leg also moves because of its connection to the lower leg at the knee and to the body at the hip. The knee provides two pivot points, one for the lower leg and one for the upper. Calum found the design and assembly of the legs required that he insure that the knees would never lock or be allowed to move to the rear. He accomplished this by tapering both leg pieces so that at full extension the knees were very slightly

flexed. The cranks for each figure were rotated 180 degrees during assembly and these assemblies were rotated 120 degrees when attached to the crank shaft.

The body of each figure is supported by a piece of coat hanger wire that is inserted into a hole in the top of the framework. This provides a non-rigid attachment and causes the bodies to twist slightly as the legs move. By allowing the arms to move freely at the shoulders and by using small springs to attach the head to the body, a number of motions secondary to the leg movement are provided that give the figures a feeling of life.

The majority of the pieces for the automaton were cut from basswood on the laser cutter. Birch dowels were used for the main crank shaft and square basswood strip was cut to keep the halves of each crank aligned. Coat hangers were cut to provide the support and attachment for the bodies and the necks of the figures were made from ballpoint pen springs. Calum made the umbrella from construction paper and a toothpick, and the coffee cup was made from a section of the body of a pen. The figures were colored with markers and the shirts and ties were cut from magazine advertisements and glued on.

B.3 Dylan - The Leaping Lion

Dylan was 10 years and 6 months old and in the sixth grade when he began these projects. The lion was his first automata and was inspired by a chance encounter some of his classmates had with a mountain lion while on an overnight camping trip. The initial concept was to have been a mountain lion but the more obviously leonine profile of an African lion was substituted early in the design. Dylan wanted the lion to be ferocious, and to convey this menace he wanted the lion to leap forward towards its prey while opening its mouth. Dylan felt that the lion would be far less threatening if it were allowed to leap backwards and this became an additional constraint for the mechanism.

To provide the leaping motion for the lion Dylan chose to use a crank-slider mechanism. Of the three that he was able to work with, he decided that he wanted to use the disc with offset pin (Figure D.9). He had already determined that he could constrain the motion of the leap to

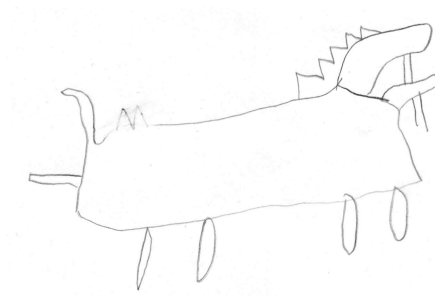


Figure B.7: Dylan's sketch for the lion shows a mane like that of an African lion. Also note that it appears that the operating mechanism for the jaw is intended at this early stage to move the upper jaw rather than the lower as in the final design.

forward only through the use of a ratchet and pawl (Figure D.8). While designing the crank-slider components in the software he concluded that he could reduce the number of components in his mechanism by eliminating the disc for the crank-slider and attaching the offset pin to the ratchet instead.

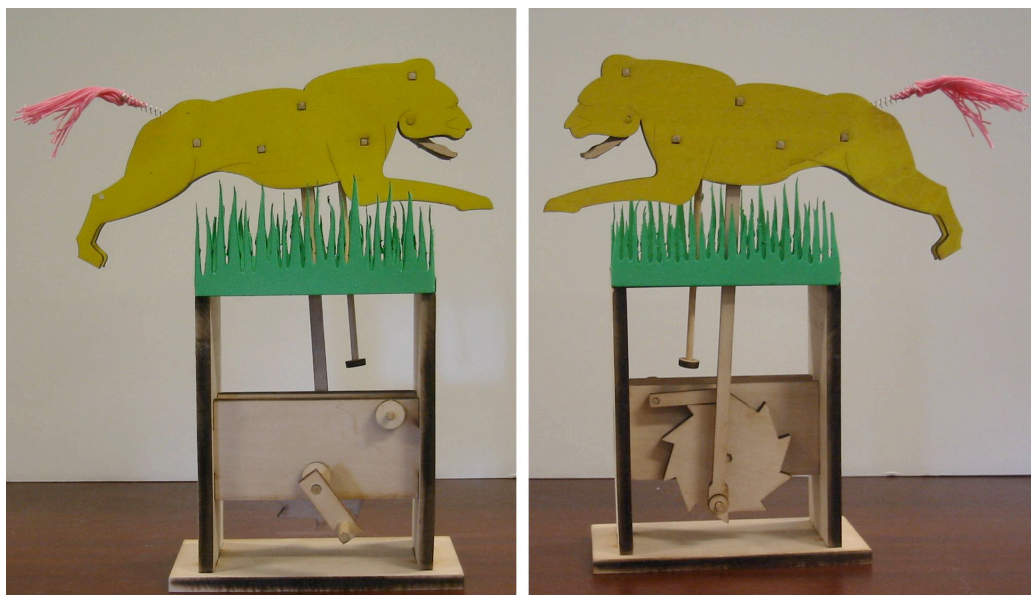


Figure B.8: The back (crank side) and front (ratchet side) of the Leaping Lion. In the front view, note the pawl which constrains the ratchet to turn only clockwise, and the pin affixed to the ratchet to which the slider arm is attached. The pushrod for the jaw and its lower stop can also be seen in both views.

While the leaping motion was accomplished quite easily, getting the jaw to open and close

posed a number of problems. Dylan considered a number of possible methods before deciding to integrate the lower jaw into a lever of the first order that would be placed inside the lion's body. By taking advantage of the up and down component of the leaping motion he was certain that he could make the jaw open and close.

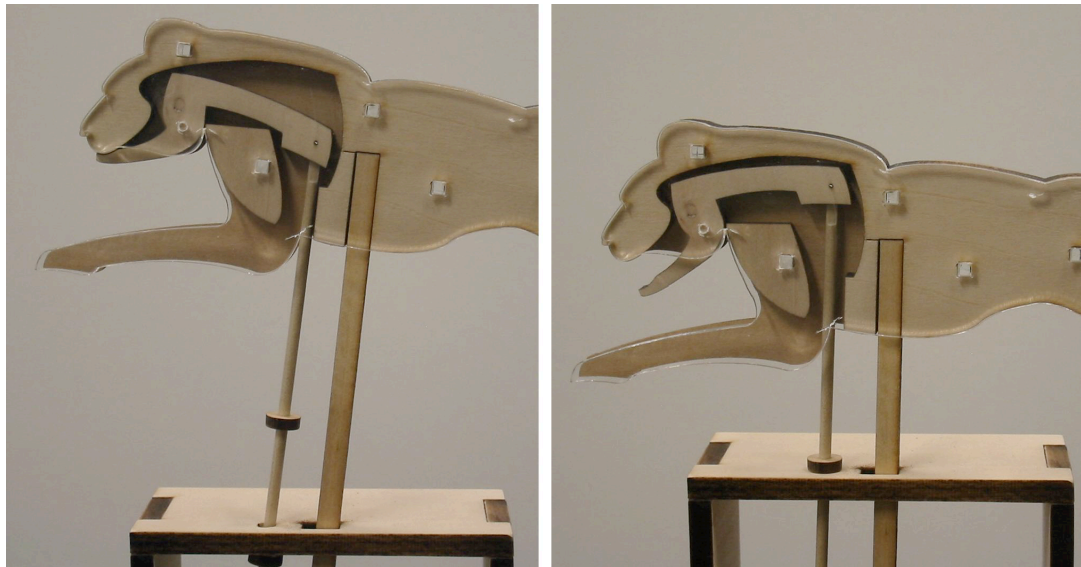


Figure B.9: The lion's jaw is a lever of the first order with its fulcrum near the lion's shoulder. As the lion is raised by the crank-slider, the lower stop on the pushrod contacts the underside of the top of the framework, pulling down on the rear of the lever which closes the jaw. As the lion is lowered by the crank-slider, the upper pushrod stop contacts the upper surface of the framework's top, pushing the rear of the lever upward which opens the jaw. This automaton was made from Dylan's original files and has the front side of the lion's body cut from clear acrylic to show the motion of the jaw.

The problem then became to utilize that aspect of the leaping motion without letting the front to back component interfere. He finally settled on a clever solution in which the jaw is moved by a rod attached to the end of the lever opposite the jaw. This rod passes through a hole in the top of the support framework that is long enough to allow it to rock back and forth as the lion moves front to back. The rod has two discs attached to it that act as stops to restrict its up and down motion; one below the framework top and one above it. As the lion moves up, the rod also moves up until the lower stop contacts the framework which occurs before the lion reaches the top of its motion. The additional upward motion of the lion causes the rod to pull down on

the lever and this closes the jaw. As the lion moves downward, the opposite happens, and the upper stop causes the rod to open the jaw.

The motion of the lion is similar to that of Ralphie the flying bison (Section D.1) but the action of the jaw is unlike anything Dylan had seen before starting. The body, crank-slider and ratchet components are laser cut from basswood. The grass attached to the framework is laser cut from craft foam. The tail is a bundle of kite twine twisted at one end and inserted into a spring from a ballpoint pen.

B.4 Dylan - Busy Beehive

Dylan's second automaton was a considerable departure from the lion. Begun in the spring of the year it was inspired by the bees that he was seeing flying around the flowers that were blooming in his yard. His idea was to have two bees engaged in the maintenance of the hive. One bee would fly from the hive to collect pollen and then return it. The second bee would shuttle back and forth, moving the collected pollen from one place to another. Dylan originally feared that this would be too hard to construct.

Dylan was able to design mechanisms that would provide the two motions he wanted and that could be driven from the same input. As it turned out, the input from the crank turned by the user is transferred to one mechanism which in turn transfers it to the second. The circular motion of the flying bee is driven directly from the input crank by a pair of pinwheel gears. This allows the shaft to which the crank is attached to be placed horizontally in the mechanism while turning an output shaft that is rotated 90 degrees to the input. This permitted Dylan to put the crank on the side of the support framework and to have the bee fly in circles that are parallel to the shaft. Because he wanted the two bees to move at different rates, the gears chosen for the flying bee have a two to one ratio; the bee flies one complete circle for each two turns of the input crank.

To get the back and forth motion of the other bee, Dylan added a third pinwheel gear that receives its input from the gear attached to the flying bee's shaft. Dylan wanted this bee to move faster than the flying bee so he chose a gear the same size as the one attached to the crank.

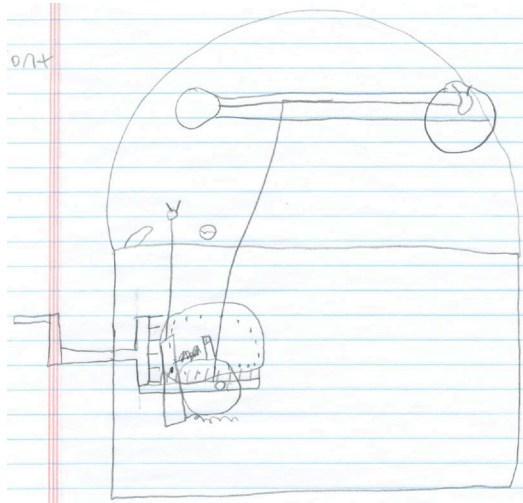


Figure B.10: Dylan's first sketch for the beehive. At the top, one of the bees flies in and out of holes cut in the hive while a second bee moves from side to side shuttling the pollen from one pile to another. This sketch was made after Dylan had decomposed the overall motion he wanted into several simpler motions. Note the difference between this sketch and the one he made for the lion with respect to the amount of detail in the mechanism.

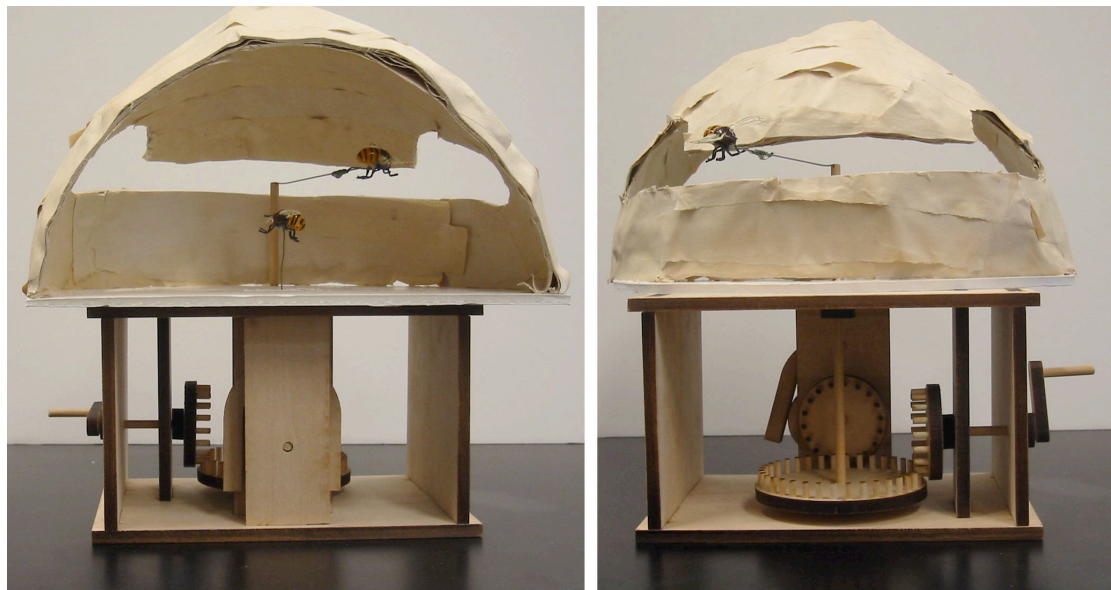


Figure B.11: Front (left) and back (right) of the completed beehive. The pinwheel gears can be clearly seen in the back view along with the Y-follower for the eccentric cam. The cam is hidden between the two vertical supports and just a small part of it can be seen touching the follower.

The ratio of these two gears is one to two and the effective ratio of this gear to the input gear is

one to one. This means that for each turn of the crank, the flying bee moves one half of its total path distance and the lower bee moves from one side to the other and back again. This gear is attached to an eccentric cam whose follower provides the even side to side motion of the lower bee. The follower is oriented vertically and cannot depend on gravity to hold it in contact with the cam. Dylan had originally planned on using a spring to hold the follower tight to the cam, but eventually decided to create a follower in the shape of an inverted capital “Y”. The forked part of the follower straddles the cam to provide positive contact and the bee is attached to the end of the vertical leg.

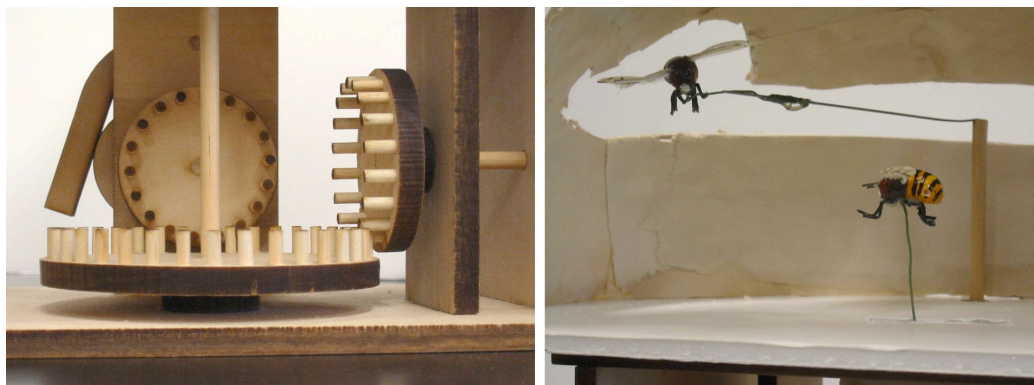


Figure B.12: On the left is a close-up view of the beehive mechanism. The pinwheel gear on the right is attached to the crank by the shaft seen here and supplies the input motion to turn the large horizontal pinwheel gear. This gear's shaft is attached to the flying bee and moves it along its circular flying path. The third pinwheel gear is driven by the horizontal gear and turns the eccentric cam just visible to the left of the vertical support. The motion of this cam rocks the Y-follower which in turn provides the back and forth motion of the lower bee. On the right is a close-up view of the two bees.

The framework and mechanical components were cut from basswood on the laser cutter. The shafts and teeth for the pinwheel gears were cut from birch dowels. The bottom of the beehive was cut from foamcore board and the beehive itself is papier mâché, formed over an inflated balloon. The bees were purchased from a craft store and are used in making artificial flower arrangements. Each bee has an attached wire that is used to secure it to the automaton. The lower bee's wire was inserted into a hole drilled in the end of the follower and glued. The

flying bee had its wire wrapped around and glued to a piece of music wire that was bent 90 degrees at one end and glued into a hole drilled in the pinwheel gear shaft.

B.5 Frank - Evil Cat

Frank was 12 years and 1 month old and in the sixth grade when he began this project. The idea came from two sources. First, Frank's family were cat owners and he was familiar with the ways in which cats often play with their prey. This gave him the idea of building an automaton of a cat juggling a mouse. Second, his parents had been renting DVDs of Felix the Cat cartoons and the black and white coloring of Felix made its way into his design. Initially, Frank wanted the cat to simply toss the mouse from one paw to the other and then back again. During the prototyping he decided that the eyes should also move and track the mouse as it flies through the air.

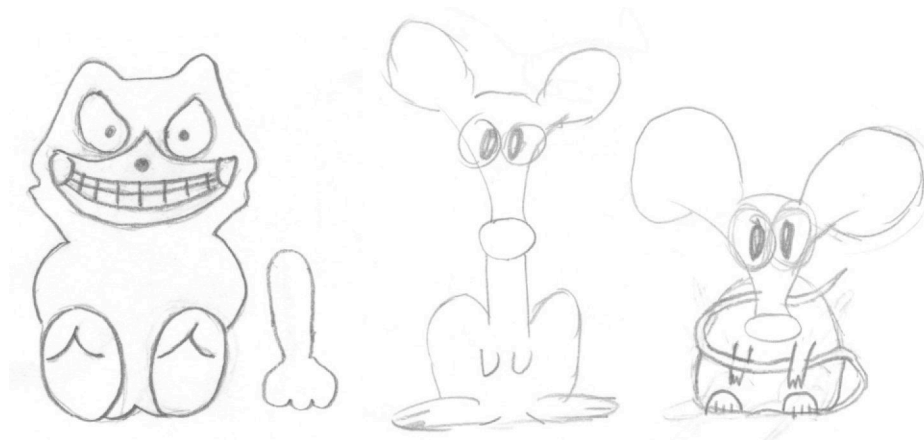


Figure B.13: Frank's first sketches for the evil juggling cat. On the left is his design for the cat and one of its paws. On the right are two possible mice that the cat could juggle. The rightmost mouse became the final design.

The initial requirements for the motion of the automaton seemed simple, but it soon became apparent that getting the timing to work out correctly for all three motions would be challenging. While the eyes have an obvious linear reciprocating motion, the movement of the mouse and the paws could also be seen a reciprocating along a curved, rather than a straight path. These three motions were all of different physical lengths but all had to occur in the same amount of

time; one rotation of the crank. Because this mechanism was the most complex of any built during the user testing, a significantly longer time was spent working with cardboard prototypes to insure that the mechanism was correct before fabricating components from more durable materials.



Figure B.14: Front views of the juggling cat showing the extreme positions of the mouse and how the paws and eyes move to match. Franks drawings of the cat and mouse were scanned and converted to files that were then used to fabricate the pieces with the laser cutter.

The first motion to be designed was the rocking motion of the paws. Attaching the paws to the ends of a first order lever was the obvious solution, but a method was needed to convert the rotation of the crank into the rocking of the lever. An eccentric cam, offset to one side of the levers fulcrum was considered but discarded early on when having the cam in that location made working with the other motions more difficult. Frank settled on a disc with an offset pin as used in the crank-slider but looked for a way to move the lever without resorting to a slider rod. He managed this by making the lever T-shaped. The paws were supported on the ends of the crossbar of the T and a slot was cut into the leg of the T that was longer than the total vertical travel of

the pin as it rotated. In this way, the horizontal position of the pin controlled the motion of the lever and the vertical position of the pin was ignored. The length of the crossbar was determined by the location of the paws with respect to the body and the length of the leg of the T and the distance from the disc to the lever's pivot were changed iteratively until an acceptable motion was obtained.



Figure B.15: The mechanism of the cat. The clear acrylic framework pieces can be seen on the left, as can the dowels that protrude through the body of the cat and attach to the paws. The rear view on the right shows the intricate nature of the mechanism. The disc near the bottom is attached to the crank and supplies input for all of the motions through its offset pin. The three-bar linkage at the left of the mechanism moves the third order lever that the mouse is attached to. The paws are attached via short dowels to the cross arms of the cross shaped first order lever. The top of the lever provides input to the second order lever that moves the eyes back and forth.

Frank then turned his attention to how the mouse would move. While the paws travelled only a short distance as they moved, the mouse would need to travel through an arc of nearly 180 degrees and would have to do it twice for each turn of the crank. Attaching the mouse to another

lever would sweep it through that arc, but directly attaching the lever to the disc (as was done with the paws) would not work. To convert the relatively short motion of the pin into the much longer motion of the mouse involved attaching the mouse to a lever of the third order and moving that lever with a linkage made from three other levers. Again, a significant amount of experimentation went into determining the the correct size and placement of the linkage pieces before the mouse moved as Frank wanted.

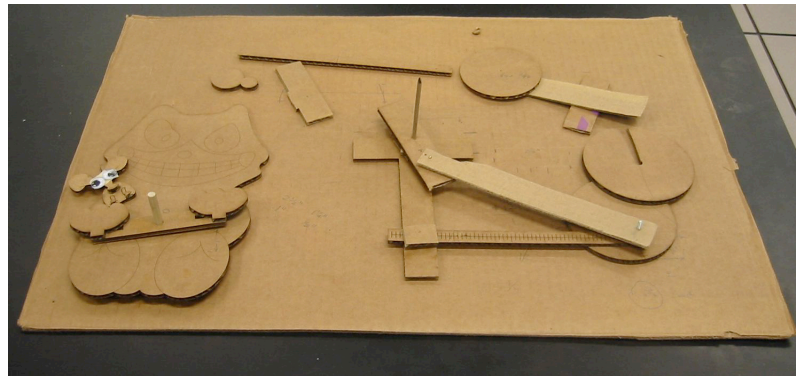


Figure B.16: Shown here are some of the cardboard pieces created during the prototyping phase of the cat's design. Because of the complex and intricate nature of the mechanism, considerable time was spent refining and perfecting the prototype.

It was at this time that Frank decided that the cat's eyes should follow the mouse as it moved. Once more, the problem of getting a useful motion from the crank became the immediate problem. The solution came while looking at example automata on the Web. By adding another leg to the T-shaped lever, and making it a cross, the movement of the disc could be transmitted to the eyes. In doing this, however, the direction of movement was reversed as the lever ends moved in opposite directions. This would mean that the cat would look away from the paw where the mouse would be. The solution was to add yet another lever, this one of the second order, that would be driven by the cross-shaped lever and would move the eyes.

Because this was such a fascinating mechanism to watch in action, the support framework was made from clear acrylic plastic to allow all of the mechanical components to be visible. The components themselves as well as the body parts for the cat and mouse were cut from basswood

with the laser cutter. Frank painted the figures before final assembly, as well as a rectangular piece of wood that covers the lower part of the framework below the cat's body and represents a box on which the cat is sitting. Birch dowels attach the paws to the lever and the crank and main shaft to the disc are also made from clear acrylic. The mouse attaches to its lever with music wire and its eyes were purchased at a craft store.

B.6 Iris - Globe Trotter

Iris was 10 years and 11 months old and in the fifth grade when she began this project. The idea for this automaton came from watching a friend spin a globe in their classroom at school. Initially, the only motion Iris was thinking of was the spinning of the globe, but as she worked on it, she decided to have the figure move his arm as if causing the globe to spin and to move his head from side to side as if looking for a location on the globe.

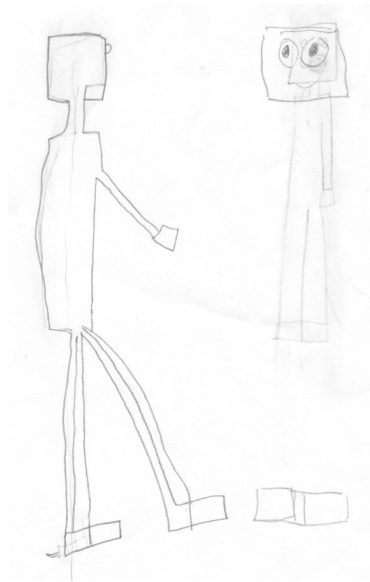


Figure B.17: Iris' initial sketch for the figure on her automaton. Note the curved legs and large eyes that made it to the final design.

During the design of her automaton, Iris was drawn to the mechanism in Celia the sea lion (Section D.3). The method used in Celia to spin the ball on her nose became the obvious choice

of how to spin the globe. Iris was insistent that the shaft that supported the globe should not be vertical as it was in the sea lion, but should be tilted as it would be with a real globe. By tipping the shaft, the contact area between the driving and driven discs became very small and because of the weight of the globe, it would not spin reliably. To overcome this, the driving disc (attached to the mechanism's main shaft) was tapered to allow more contact area between the discs.

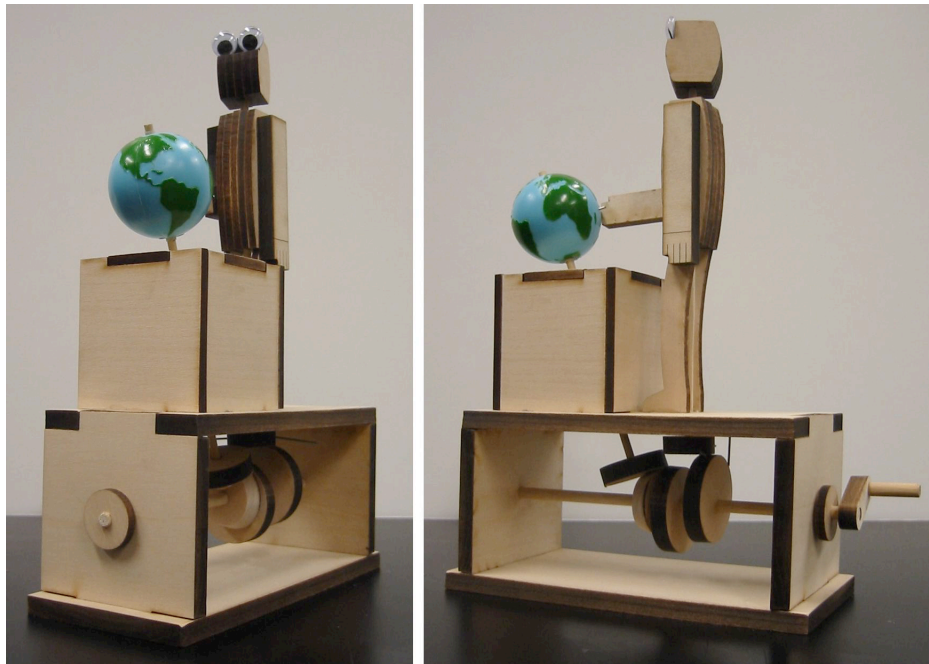


Figure B.18: Two views of the Globe Trotter showing the general arrangement of the tableau and mechanism. Note the detail of the figure's left hand that was etched into the wood by using a higher speed and lower power setting on the laser cutter.

The Markey oscillator used to move the tail in the sea lion was chosen to move the head of the figure. The sea lion's tail is limited to moving back and forth because it contacts the body at the limits of its motion. The figure in Iris' automaton had no such limiting features, and as first designed, the head would often end up rotating rather than looking left and then right. To prevent this, two small pieces of music wire were glued into the edge of the disc attached to the shaft that moved the head, and another two pieces of wire were glued into the underside of the framework's top.



Figure B.19: A side view of the Globe Trotter showing the mechanism. The main shaft is rotated by the crank at left and in turn rotates the two eccentric cams that move the head and the tapered disc that spins the globe. Wires in the disc attached to the head contact wires in the underside of the top of the framework and limit the amount of movement the head can make. A small wire inserted into the globe moves the right arm when the globe spins and the spring used at the elbow allows the arm to return to its original position.

Iris had wanted to have the figure's hand move as if that were the force behind the globe's motion, but as the head and arm were both attached to the body, there was insufficient room in the mechanism for additional components to move the arm. As the project neared its end, Iris happened to see another of the automata that used springs removed from ballpoint pens. By placing a spring at the elbow joint of the arm and having a small piece of wire protrude from the surface of the globe, the arm is moved as the wire strikes it and the spring allows that motion and moves it back into place to move again.

The framework and components for Iris' automaton were cut from basswood with the laser cutter. The main shaft and the those for the head and globe are cut from birch dowels. The base of the disc attached to the globe's shaft has sandpaper glued to it to increase the friction between the discs, thereby reducing the chances that the globe will slip when the crank is turned. The box

on which the globe rests and the pieces used in the figure are all laser cut basswood. The globe was purchased at a toy store, and the eyes for the figure came from a craft store.

B.7 Sam - Soccer Player

Sam was 11 years and 5 months old and in the sixth grade when he began these projects. The automata that he built and his experiences in the testing are related in greater detail in Chapter 7, but are reprised here for completeness.

The idea for the soccer player came one afternoon when he was attending soccer practice. Sam's initial idea for the automaton was simple; have the player kick the ball into the net. From his early encounters with the sample automata and mechanisms, Sam wanted the motion of the ball to be directly accomplished by the mechanism. After a number of discussions, he decided that the mechanism could be much simpler, and the entertainment value of the automaton much higher, if he built it so that the player actually kicked the ball.

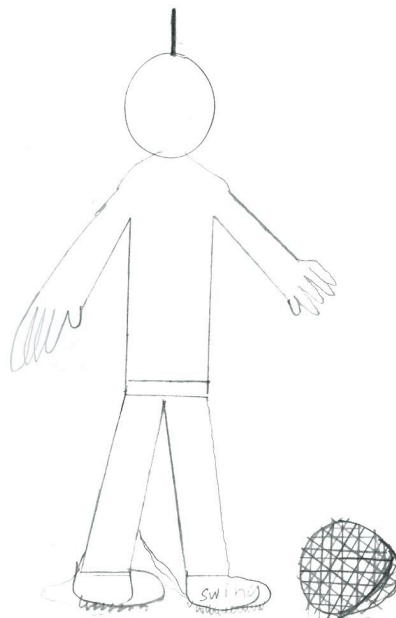


Figure B.20: Sam's first drawing for the soccer player included no indication of what mechanism might be needed nor what other parts of the tableau, such as the goal, would look like.

While simplifying the mechanism, this introduced two issues. First, the automaton would

need some way to insure that the ball returned to the proper location so that it could be kicked again. Second, the speed with which the leg moved needed to slow enough as it moved back to allow the ball sufficient time to return and quick enough on the forward stroke to propel the ball all the way to the goal. The first of these was addressed by two methods. A small slope was introduced into the kicking surface with the player's location lower than that of the goal. Then a second layer was added to the kicking surface that had a V-shaped section removed from it. With the wide end of the V at the goal, and the narrow end in front of the kicking foot, the ball not only returned to the proper kicking spot consistently, but the likelihood that any given kick would stay on the surface of the automaton was significantly increased.

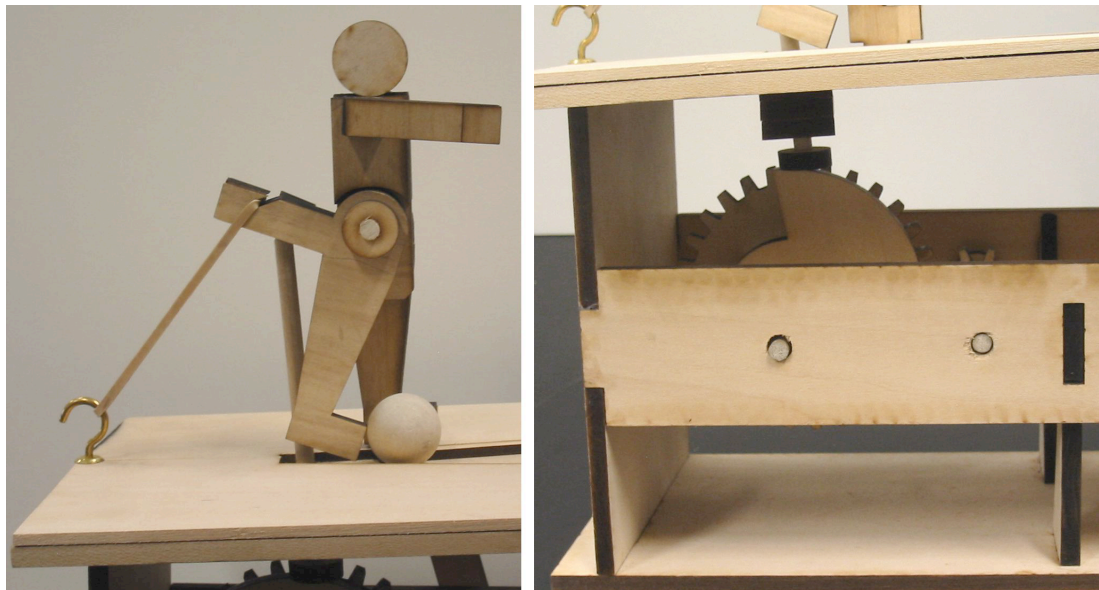


Figure B.21: Close-up views of the figure and mechanism. On the left, the player's leg is pushed back by the rising of the cam follower and this motion stretches the rubber band. When the follower drops, the leg is driven forward by the rubber band and this kicks the ball toward the goal. On the right can be seen the snail cam and follower that move the leg as well as the larger of the two spur gears that transmit the motion of the crank to the cam. The top of the smaller gear is just visible above the horizontal framework member. The shaft that carries this smaller gear is also attached to the crank.

The speed that the kicking foot traveled was controlled by the mechanism that Sam selected. To move the foot slowly to the rear, he used a pair of spur gears with a three to one ratio.

The smaller gear was attached to the crank's shaft and the larger gear was attached to the cam's shaft. Because of this, the cam rotates only once for every three turns of the crank. If the crank is not turned too vigorously, the ball will usually be in contact with the foot before the leg has finished moving. By using a snail cam to move the leg, the sharp drop off the lobe allows the rubber band to snap the foot forward with sufficient force to get the ball to the goal. Interestingly, because the ball is free to move in three dimensions, there are times when it doesn't get to the goal, times when it becomes entangled in the net, and times when it leaves the automaton altogether.



Figure B.22: On the left is another view of the mechanism that shows both gears and the cam. Note the tall cam lobe that was necessary to get the leg to move enough to propel the ball all the way to the net. On the right is the poster Sam made for the science fair explaining both the mechanical domain and his automaton.

During this project, Sam decided that he would use the automaton to illustrate some of the mechanical principles of the domain for his school's science fair. To supplement his automaton, he made a poster with both explanatory text and sample components that were laser cut from foamcore board and cardboard. His poster can be seen in Figure B.22.

For the soccer player, the mechanical components, support framework, player, and kicking

surface were all cut from basswood with the laser cutter. The shafts and followers are birch dowels. The ball is a decorative wooden item purchased at a craft store. A metal cup hook attaches the rubber band to the kicking surface and the net material came from an onion bag.

B.8 Sam - The Carousel

Sam's second automaton was a carousel. This project was much more ambitious than the soccer player, but Sam had acquired a good deal of skill, knowledge, and confidence while building the soccer player and his initial design was substantially complete and very similar in all important respects to the finished automaton. Sam wanted the carousel to have four animals, but only to have two of them move up and down.

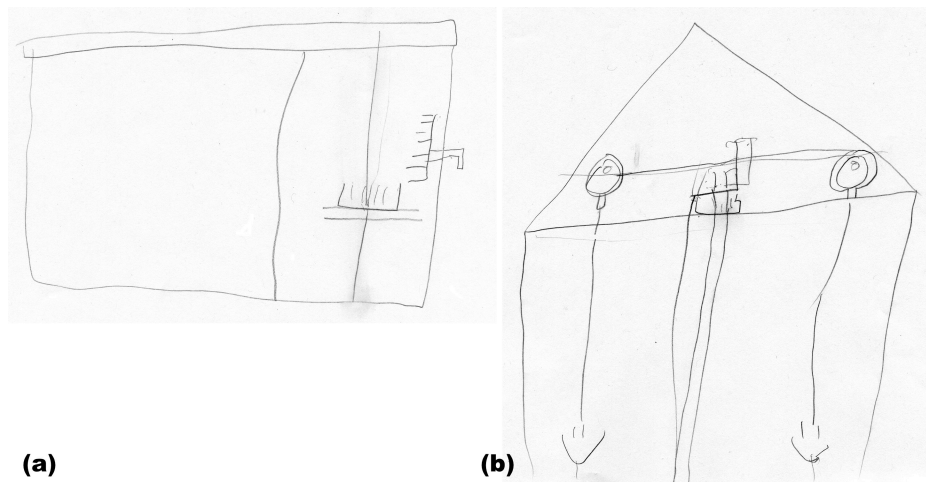


Figure B.23: (a) Sam's sketch for the base of the carousel showing the two pinwheel gears that will convert the rotation of the crank into rotation of the carousel. (b) Sam's sketch for the mechanism to move the animals. His idea is to use eccentric cams with ring followers (which can work in any orientation) to move the animals up and down and to drive the cams with a set of pinwheel gears that receive their power from the base. Compare these drawings to his drawing of the soccer player in Figure B.20 where the figure of the player is central and no hint of mechanism or structure is shown. In these drawings the structure and mechanism are key and the animals only represented by smiling faces.

Sam was able to decompose the mechanism into two fundamental parts: the part that would rotate the carousel and the part that would move the animals. To rotate the carousel, he

designed a spur gear train with a two to one ratio to allow the carousel to turn slower than the crank. He built this part of the mechanism into a box-like framework and put four rollers at the corners of the framework top to support the carousel in much the same way that rollers are used to support a rotating tray in a microwave oven. A large pinwheel gear was glued to the top and the shaft to connect the drive mechanism to the carousel passes through the center of the upper gear without touching it.



Figure B.24: The completed carousel. Sam had originally intended to drape cloth over the top to conceal the space between the two upper pieces but eventually decided against it.

The carousel itself sits between two structural sections that are necessary for the proper operation of the automaton. The two upper discs provide a space in which the lift rods for the animals can move without protruding from the top. The lower section contains the mechanical components that move the animals. To provide the up and down motion, each of the moving animals (the lion and the moose) is attached to a cam follower that is raised and lowered by an eccentric cam situated below the floor of the carousel. Each follower terminates in a crescent

shaped piece that provides constant contact with the cam and makes the mechanism more reliable.



Figure B.25: The carousel contains two separate mechanisms working in unison. In the base, the spur gears turn the shaft that passes through the upper horizontal pinwheel gear (which is rigidly fixed to the top of the base assembly) and engages the bottom of the carousel proper. As the carousel rotates, the smaller pinwheel gears are forced to rotate as they mesh with the large gear. This causes the two eccentric cams to rotate which causes the moose and the lion to move up and down.

Each eccentric cam is driven by a shaft attached to a small pinwheel gear located on the inside of this part of the carousel. The teeth of these gears engage the teeth of the large stationary gear attached to the base. As the carousel rotates, these small gears rotate in the same way an automobile tire rotates as the car rolls along a road. The teeth provide a positive link between the gears which provides a guarantee that the animals will move properly. To finish the carousel off, four pieces of mirrored acrylic plastic were cut and glued to a framework in the middle of the carousel, much like the mirrors on a real carousel.

The majority of this automaton was cut from basswood with the laser cutter. Shafts are

made from birch dowels and the mirrors are acrylic. The animals were purchased at a discount store and in some cases bear the marks of previous ownership.