Introduction to Kinetic Sculpture: A One-Week Course for Middle School Students

by

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ABSTRACT

A one-week course in kinetic sculpture was designed to introduce middle school students to the marriage of art and engineering. Because art can appeal to different sensibilities than engineering alone, it can serve as a means to broaden perspectives of students with different motivations. In light of increasing emphasis on the development of programs in STEM (Science, Technology, Engineering, and Math) in U.S. education, this project fills a need for more opportunities in STEAM (Science, Technology, Engineering, *Arts*, and Math). Even though the availability and popularity of STEAM programs for children is growing, these opportunities for young children are still limited. Therefore, there is a market for a course that incorporates art and the engineering design process like this one.

Daily activities in an introductory week-long kinetic sculpture course are defined. Each day's lessons are provided along with resources for further study. The structure of the course is based on sound pedagogical practice. The strength of the course is its ability to incorporate science and art in a fun way that will be appealing to students. Future work would consist of the expansion of the lessons with more detail for teachers and the addition of more alternate activities.

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1. Introduction

The role of art in contemporary education practices is a critical one. As the demand for skilled workers in science, technology, engineering, and math (STEM) has led to the proliferation of extracurricular activities in these fields, many students are now enrolled in summer technology camps. For many of these students this is their first exposure to engineering principles, whereas others have more experience. The integration of art into these technology camps is vital for both groups of students. This thesis provides a curriculum for a short, introductory course in kinetic art for middle school students.

This program in kinetic art, the art of both real and apparent motion, is practical for both the less technologically inclined student and the more technologically savvy one. For the less initiated, art can be a gateway into engineering. Students who were previously intimidated by or uninterested in engineering may discover new passions. To see how engineering can be applied in traditionally non-scientific fields can be eye-opening.

For more engineering-centered students, the integration of art into engineering exposes them to new ideas and helps them to develop new ways of thinking about problems. Many students may not have previously taken much interest in art because of preconceived notions about classical art, static painting and sculpture. By learning about contemporary, kinetic sculptures, these students will be able to see how engineering principles can have aesthetic as well as functional applications.

This thesis was primarily inspired by the kinetic sculptures of Arthur Ganson (Ganson, n.d.). His exhibits at the MIT museum display the offbeat and novel work he has done in the contemporary art world. Ganson's use of humble objects such as miniature chairs and bicycle chains engender thoughts and feelings in different ways than many static sculptures. *Corey's Yellow Chair* (1997) and *Machine with Roller Chain* (1996) are prime examples.

This thesis is comprised of four main sections: Background, Program Design, Conclusion, and Appendix. The Background section provides further motivation and relevance of this project. The Program Design section contains five sub-sections: Goals, Education Standards, Lesson Schedules, Rationale, and Budget Estimate. The Goals sub-section specifies the learning goals of this course. The Education Standards sub-section outlines the education standards that are met by the course. The Lesson Schedules sub-section provides a suggested daily schedule of activities to be completed. The Rationale sub-section discusses the pedagogical rationale for the course's content and structure. The Budget Estimate sub-section provides the estimated cost of materials for this program. The Conclusion section summarizes the successes and shortcomings in this project and makes suggestions for future work. The Appendix contains detailed lesson plans for each day as described in the Program Design section and a bill of materials.

2. Background

Twenty-first century K-12 education practices have increasingly utilized STEM (Science, Technology, Engineering, and Mathematics) learning opportunities, and curricula based on these four disciplines have been implemented in the U.S. in order to address perceived shortcomings of our educational system (Dugger, 2010). In spite of this, only 16 percent of American high school seniors are proficient in mathematics and interested in a STEM career (U.S. Department of Education, 2013). With the growing demand for professionals in STEM-related fields, there has been increasing demand for improvements in STEM teaching and learning.

An offshoot of the STEM movement integrates art and design into these subjects. In 2006, Georgette Yakman introduced the concept of STEAM (Science, Technology, Engineering, Arts, and Mathematics) (Steam Education, n.d.). Even though there is some debate about the role and importance of art in STEM fields of study, the STEAM-approach is gaining support because of its emphasis on integrating creativity across content areas (Jolly, 2014). However, because STEM/STEAM projects take a backseat to Common Core requirements, after-school and summer activities often fill the void in these areas.

The author's experience in teaching at science summer camps showed him that the adoption of STEAM principles has been slow. Starting in 1998, the author has taught in five different summer camps and taught over nine different courses, including different levels of computer science, rocketry, robotics, wearable technology, digital game design, and engineering prosthetic devices. In those years, the courses evolved from a more narrow focus to broader ones that incorporate multiple branches of science and engineering. However, it has been only recently that more art has seeped into the curriculum. Therefore, I have sought to find programs that fill the need for more art integration. Research reveals very little in the field of kinetic art or art in engineering. There are many resources that detail individual activities in this area, such as PBS's Design Squad Nation (www.pbskids.org/designsquad), The Royal Institution's Experimental (rigb.org/experimental), the Museum of Science, Boston's Engineering is Elementary (www.eie.org), and sci-experiments.com, but there are almost no coherent compilations of courseware that develop meaningful learning in this arena. One exception is the MIT course STS.035 Exhibiting Science, a project-based class in which students develop exhibits for the MIT Museum, which has been offered annually in the spring since 2004 as part of the MIT Program in Science, Technology, and Society (STS).

In order to correct the apparent lack of enrichment programs including art in engineering, a summer camp course was designed to address the demand for STEM/STEAM opportunities. To that end, I have developed a one-week course in designing and building kinetic sculptures for middle-school students. The course was inspired by artists such as Arthur Ganson and Theo Jansen.

3. Program Design

3.1 Goals

This course is designed to introduce middle school students to the engineering design process and its applications in the art world. The goal is to enable students to improve their attitudes about their own artistic and engineering abilities.

Assumptions:

- Students learn best when they engage in activities that are fun and challenging.
- Students must have some autonomy to determine their own goals and the pathways to reach those goals.
- Students learn better when they have the opportunity to communicate and collaborate with others.

By participating in this course, students will learn: that they can use the engineering design process to solve problems, that art and science can be intertwined, and that they have talent and potential in art and engineering.

They will also build their skills in problem solving, teamwork, and creative thinking. Specific disciplines explored will include physics, math, mechanical engineering, and art.

Specific goals for the week progress as follows:

- Students will be introduced to engineering and the engineering design process as they tackle an initial challenge of learning how to balance objects on their centers of mass. (Day 1)
- They will learn about contemporary kinetic art and sculptors such as Arthur Ganson and Theo Jansen. They will then reconstruct a miniature model of one of Jansen's works. (Day 1)
- The next day they will consider means of movement such as gravity, wind, or other applied forces. They will learn about Alexander Calder, and then make a mobile and a pinwheel. They'll make the connection between pinwheels and wind turbines. (Day 2)
- On the third day, students will learn about the automata style of kinetic sculpture. Cams, gears, cranks, followers, and linkages will be introduced. Students will create a kinetic sculpture incorporating some of these. They will also start designing their final project. (Day 3)
- On the fourth and fifth days, students will design and construct their final projects, either in groups or individually. They will be prepared to present what they learned during the week and share their creations. (Days 4 and 5)

3.2 Educational Standards

This course meets many of the Next Generation Science Standards (NGSS Lead States, 2013).

Table 3-1: Next Generation Science Standards

	Day 1	Day 2	Day 3	Day 4	Day 5
MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.	X	X	X	X	X
MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.	X	X	X	X	X
MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.		X	X	X	
MS-ETS1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.			X	X	

3.3 Lesson Schedules

The course is organized according to a schedule of five six-hour days. However, the schedule is merely a suggestion. Teachers may compress or extend it and schedule the breaks as they see fit. Students may complete each activity individually or in groups, at the teacher's discretion. As discussed in Section 3.4, while the course was designed for the full middle school age range of 5^{th} – 8^{th} grade, the plans presented below are targeted toward the younger ages, because it is assumed it will be easier for teachers to enhance the lessons for older students than to determine what to remove for younger students.

Table 3-2: Day 1 Schedule

Activity	Description	Time (min)
Ice breaker (5.1)	A chance to get to know fellow students.	15
Center of Mass, Part 1 (5.2)	An intro to the concept of engineering. Students learn about center of mass to build a balancing structure.	60
Break		15
Engineering Design Process (5.3)	Students learn about the engineering design process and discuss how they may or may not have applied it during the previous challenge.	
Center of Mass, Part 2 (5.4)	Students now apply the engineering design process to a challenge that builds on the previous one.	45
What is technology?	Define technology and engineering. Play technology quiz game.	15
Lunch and recess		90
Intro to kinetic art	Videos, slides, discussion.	15
Strandbeest kit	Students start assembling Strandbeest model kit.	45
Break		15
Strandbeest kit, continued	Students complete their kits. Review mechanisms that make the model move.	45

On Day 1, students first engage in an icebreaker activity. The activity in Section 5.1 is merely a suggestion. Teachers may choose any other brief activity that allows for discussion.

Students immediately tackle their first challenge, Center of Mass, Part 1 (see Section 5.2). While completing the challenge, they will learn about the concept of center of mass.

Center of Mass – The point in a body or system around which its mass is evenly distributed and balanced. It is often used interchangeably with center of gravity.

After completing Part 1, teachers will explain the Engineering Design Process (see Section 5.3). Teachers will go through each step and ask how it applied to the previous activity as follows:

Did we *identify* a problem? Yes. The task was to create a balancing sculpture.

Did we *investigate*? Yes. We discovered that the sculpture must balance and that we are limited to using certain materials.

Did we *imagine* solutions? Yes and No. Even though some students may have started to brainstorm their own ideas, a solution was already provided in this activity.

Did we *plan*? No. A predetermined plan was provided. In the future, students will be expected to create their own plans.

Did we *create*? Yes. All students built a sculpture.

Did we *improve*? Yes. If the sculptures did not balance properly at first, adjustments were made to the structures.

Did we *communicate*? Yes. We shared our findings and discussed how the concept of center of mass applied to this activity.

Then, in pairs, they create their own unique sculptures during Center of Mass, part 2 in Section 5.4. This time, they go through each step of the Engineering Design Process in order to design their own sculptures.

After completing this task, students will learn the definitions of technology and engineering.

Technology – Anything designed by humans to help solve a problem.
Engineering – The use of creativity and the knowledge of science and math to design technologies to solve problems.

They then will play a game such as technology hangman or Jeopardy. Teachers can find online resources for these educational games (www.gameclassroom.com). They may also develop their own games.

After lunch, teachers will introduce the concept of kinetic art. They will show the TED Talk video of Theo Jansen (Jansen, 2007) and then hold a class discussion about the video. Students should be encouraged to share their impressions of Jansen's work.

Each student then receives a Mini Strandbeest Assembly Kit, as sold at Theo Jansen's website for $35.00 each (www.strandbeest.com/shop/index_usa.php). The kit is recommended for ages 8 and up and will take approximately 90 minutes to assemble (Jansen, n.d.) .No other materials or tools are needed. After completing construction, students will be able to see how the Strandbeest can move via wind power, which is provided by either a small fan or simply blowing.

Details of the lesson plans as well as a list of materials for Day 1 are found in Sections 5.1-5.4. The cost of consumable materials for Day 1 is approximately $420 (including the Strandbeest kit) for a class of ten students.

Table 3-3: Day 2 Schedule

Activity	Description	Time (min)
Intro to wind, gravity, and other forces	Videos and discussion about the forces that can animate objects.	30
Calder Mobiles (5.5)	Students learn about Alexander Calder's work,	45

Activity	Description	Time (min)
	continue to explore the concept of center of mass by building mobiles.	
Break		15
Waves in art	Students learn about Reuben Margolin's work.	15
Candy Wave Machine (5.6)	Entire class constructs candy wave machine	45
Lunch and recess		90
Milk Carton Turbine (5.7)	Students learn about turbines then build a simple one from a milk carton.	20
Pinwheels (5.8)	Students design and build pinwheels.	40
Break		15
Pinwheels, continued	Students share their creations. Review, critique, improve.	20
Introduction to Ganson	Videos, discussion of Arthur Ganson's work. Students brainstorm some ideas for final project.	25

On Day 2, teachers begin by talking about the forces that can animate objects. Topics covered should include, but not be limited to, gravity, wind, electricity, human interaction, linear motion, and torque. Teachers can find background information at http://hyperphysics.phy-astr.gsu.edu/hbase/force.html.

Teachers then show a short video on Alexander Calder and his work (For Bingham's Students, 2010). Using this as inspiration the students then work individually to build their own mobiles (see Section 5.5).

Students then learn about Reuben Margolin's artwork by watching his TED Talk (Margolin, 2012). As an entire class, they build a large scale candy wave machine (see Section 5.6). They will observe the propagation of waves in the machine. They will also modify the placements of candy and observe how the waves change. The teacher will explain and demonstrate concepts such as amplitude, frequency, and wavelength, defined as:

Amplitude – The distance between the mid-line of a wave and its crest or trough. It can also be measured as the maximum disturbance of a wave from its undisturbed position. It corresponds to the energy of the wave.

Frequency – The number of waves that pass a certain point per second. Measured in hertz (Hz).

Wavelength – The distance between a point on one wave and the same point on the next wave. Often measured from crest to crest or trough to trough.

After lunch, students will quickly build a turbine from a milk carton (see Section 5.7). Most importantly, they will watch the water make the carton spin. The teacher will explain Newton's Third Law of Motion and the concept of action/reaction force pairs. Resources for this physics lesson can be found at http://hyperphysics.phy-astr.gsu.edu/hbase/newt.html.

Each student will then design and build his or her own pinwheel, as outlined in Section 5.7.

At the end of the day, students will watch a video about Arthur Ganson and his work (Ganson, 2004). This will introduce them to more complex mechanical concepts. In a large group, students discuss the pieces of art that are interesting to them. They also start brainstorming ideas for their final project. The teacher asks the students about what knowledge and tools they might need in order to build some of these ideas.

Details of the lesson plans as well as a list of materials for Day 2 are found in Sections 5.5-5.8. The cost of consumable materials for Day 2 is approximately $50 for a class of ten students.

Table 3-4: Day 3 Schedule

Activity	Description	Time (min)
Gears 101	Introduction to the concept of gears.	15
Making Gears (5.9)	Students create simple gears from cardboard.	30
Cams 101	Introduction to cams and followers.	15
Agreeable Sheep (5.10)	Students create a nodding sheep from a model kit.	30
Break		15
Linkages 101	Introduction to four-bar linkages.	15
Linkages (5.11)	Students play with linkages and trace their paths.	30
Lunch and recess		90
Automata (5.12)	Students design and construct automata sculptures using cams, cranks, and followers.	45
Break		15
Automata, continued	Students complete their sculptures.	45
Automata, completed	Students present their creations to class.	15

Students begin with a lesson in gears. The following points should be made in "Gears 101":

1. Gears are the toothed wheels used in many machines.
2. Explain how gears work in a bicycle.
3. Consequence of riding in lower gears vs higher gears
4. Transmission of torque

Teachers can refer to http://www.technologystudent.com/gears1/geardex1.htm for more material. In groups of two or three, students then build their own gears from cardboard (see Section 5.9).

The next lesson covers cams and followers. Students will not have much prior knowledge of these, so teachers should show examples in machines like sewing machines and cars. Teachers must explain how a cam converts a simple motion into a more complex one, often rotary into linear. It is important that students understand how the shapes of the contacting surfaces determine the prescribed motion. Pear, eccentric, oval, snail, and irregular cams should be explained. Teachers can refer to http://www.technologystudent.com/cams/camdex.htm for details about cams and the next lesson about linkages

Individually, each student is then given the Agreeable Sheep patterns printed onto thin card stock (see Section 5.10). After building the kit, students are instructed to modify the shape of the cam and observe and discuss any differences in movement of the sheep's head.

The next topic is linkages. The teacher will show real-world applications of linkages, such as in bike suspensions, vice grips, and front loading vehicles. Students will revisit the Strandbeest and how its linkages work. They will then construct simple three and four bar linkages from cardboard (see Section 5.11).

Students spend the latter part of the day making a more complex version of the Agreeable Sheep. Instead of working from ready-made patterns, they must design their own automata sculpture, with at least two cams and followers. Students are provided with the Googly Monster (Leftbraincraftbrain, 2015) project template to help facilitate their projects (see Section 5.12).

Details of the lesson plans as well as a list of materials for Day 3 are found in Sections 5.9-5.12. The cost of consumable materials for Day 3 is approximately $100 for a class of ten students.

Table 3-5: Day 4 Schedule

Activity	Description	Time (min)
Final Project (5.13)	Students again brainstorm ideas for final project.	15
	Students start designing.	60
	Break	15
Final Project	Students share and critique their designs.	20
	Students revise design, may start building.	40
Lunch and recess		90
Final Project	Students build final project.	60
Break		15

Final Project	Students continue building.	60

On Day 4, students begin their final project. They may work as individuals or in groups of two or three. Teachers should encourage students to entertain many different ideas. Students should freely share these ideas with each other.

Details of the lesson plans are found in Section 5.13. The cost of materials for Day 4 is built into the previous costs of Days 1-3.

Table 3-6: Day 5 Schedule

Activity	Description	Time (min)
Final Project (5.13)	Students share and critique their projects.	20
	Students continue working on project.	55
Break		15
Final Project	Students continue working on project.	60
Lunch and recess		90
Final Project	Students do final testing and improving.	60
	Students do final touch-ups on project.	30
Showcase	Students present their creations to parents and other students.	60

Day 5 is spent building and improving final sculptures. At the end of the day, parents are invited to see what their children have done and students will present their work.

Details of the lesson plans are found in Section 5.13. The cost of materials for Day 4 is built into the previous costs of Days 1-3.

3.4 Rationale

The course is structured to follow methods espoused by cognitive developmental theorists such as Jean Piaget (Piaget & Inhelder, 1966), Lev Vygotsky (Vygotsky, 1962), and Jerome Bruner (Bruner, 1977). Even though they have differing opinions, they share some common views. For example, they all believed that children learn best when they are active learners. To that end, this program emphasizes active participation as much as possible and minimizes lecture and video time.

The lessons are also developmentally appropriate. That is, they are appropriate for the stage of cognitive development that is most common in 5th-8th grade students – the formal operational stage. This is the stage when children are able to grasp abstract concepts and start thinking in more systematic ways (Piaget & Inhelder, 1966). Because middle school covers a large span in the course of development, the lesson plans have been skewed to the younger students. This is not detrimental because there is still enough freedom for the older students to make more complex sculptures and participate in deeper collaborations with classmates.

Vygotsky believed that learners develop higher-order cognitive functions such as problem solving in a social learning environment (Vygotsky, 1962). In this course, students work in small and large groups in order to foster this type of environment.

The activities outlined here begin with simple ones and grow in complexity, building upon and revisiting the previous lessons. This embodies Jerome Bruner's principle of instructional scaffolding – a process in which the teacher helps students gain deeper levels of understanding (Bruner, 1977).

Furthermore, all theorists believed that children construct their own knowledge. These lessons tried to incorporate that constructivism by allowing students the freedom to design their own sculptures. It also allows a degree of self-regulation. Because there are blocks of time with little structure during each day, students must plan their own strategies for how they are going to complete their tasks. This is important because there is a link between effective self-regulation and gains in students' achievement (Zimmerman, 2001).

During this time in a child's development, it is also important that metacognitive strategies are integrated into learning and that they have access to emotionally meaningful curriculum (Armstrong, 2006). To that end, a kinetic art class lends itself nicely to both. It evokes emotion while also requiring students to examine themselves and their own goals.

Finally, this program embraces the notion of the teacher as a learner. The teacher is encouraged to make as many discoveries as the students. Even though the teacher must serve as a guide, he or she can also be a student. All of the lessons are structured such that the teacher can build his or her own sculptures while also helping the students.

3.5 Budget Estimate

Bill of materials and cost is detailed in Section 5.14. The total cost of this course, for a class of ten students is approximately $737. The breakdown is as follows:

Items that are reusable throughout the week are considered a fixed cost. The fixed cost for ten students is approximately $167.

Items that are consumable have the following costs:

Day 1 – $410

Day 2 – $50

Day 3 – $100

Day 4 – $0

Day 5 – $0

There are no additional costs on Days 4 and 5 because the final project is constructed using leftover materials from previous days.

The average cost of materials per student for the entire course is $73.70.

4. Conclusions

A one-week course for middle-school students was designed to introduce the engineering design process and how it relates to the field of kinetic art. The curriculum consists of five, six-hour days containing a variety of lessons in engineering and art. The strengths of the program include educational value, simplicity, flexibility, and fun.

The program teaches students complex concepts in an uncomplicated manner. Physics topics such as center of mass, Newtonian mechanics, and wave mechanics are illustrated in visual, concrete ways. Mechanical engineering topics like gears, cams, and linkages are similarly brought to life. Throughout the week, students are encouraged to learn and practice sound engineering design process.

The program's flexibility lies in the freedom it allows teachers to choose which activities are most appropriate for their students. Furthermore, each activity can be made more or less complex for students of different abilities.

Finally, all the activities incorporate the notion of creative play. Because this is a course designed for a summer camp setting or other extracurricular environment, it was important for students to have the freedom to express themselves through art and engineering.

While the open-endedness of some of the lessons can be liberating for teachers and students, it is also a weakness of this project. More detail in the teaching points would help teachers construct more comprehensive lessons and minimize their work-load.

Another area of improvement would be to minimize the amount of time students watch video. It would be preferable to carve out time during the week in which students could visit a museum to see some of these kinetic sculptures in person. However, only those classes that are within close proximity to such museums can make these field trips. One solution would be to create videos of virtual museum tours.

Two other areas that can be augmented are the building materials used throughout this course and the addition of alternate activities. Common items were selected to make it easier for teachers, but more exotic items could enhance the course and foster more excitement in students. For example, batteries, wires, and metal gears could be used to animate sculptures. Lego or TETRIX robotics could also be incorporated.

Overall, the program is designed to be a viable and useful one that could serve as a solid foundation for further development.

5. Appendix

5.1 Icebreaker – Super Powers

<u>Materials</u>
Construction paper
Colored markers

<u>Procedure</u>
1. Each student folds a piece of construction paper in half.
2. On one half, they write their names.
3. On the other half they draw themselves with any super power they wish they could possess.
4. Students share their drawings, discuss their powers, and share at least one more detail about themselves.

5.2 Center of Mass, Part 1

This activity is adapted from Alfrey (n.d.) and introduces the physics concept, center of mass. Students will construct simple, symmetrical sculptures that balance on their ends, seemingly defying gravity.

<u>Materials</u>
Play-doh or other sculpting clay
Wooden dowel rods, 3/32" diameter x 2 5/8" long. Three dowels per student
Stiff paper, such as card stock, 1/2" x 3/4" piece per student
Hot glue guns and glue sticks
Diagonal cutters
Scissors
Masking tape
(Optional) Sandpaper for smoothing the dowel ends

<u>Steps</u>
1. Cut out the paper rectangle (1/2" x 3/4"), if not pre-cut.
2. Fold paper rectangle in half

3. Use hot glue to attach dowels to paper rectangle and fold over the top of the paper, as shown in Figure 5-1.

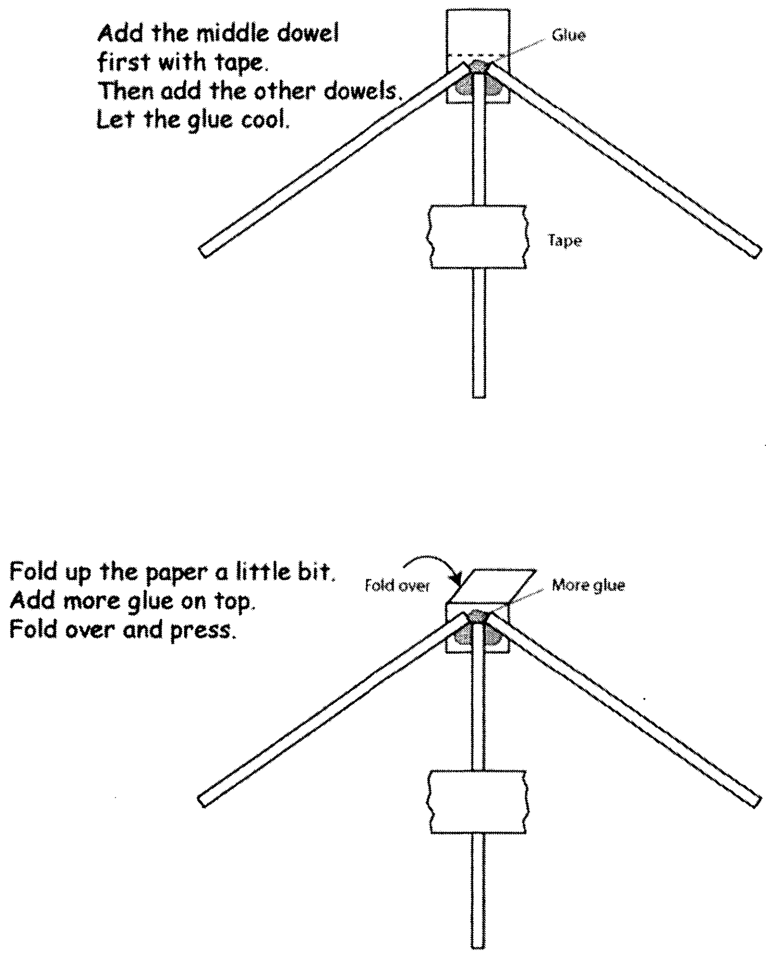

Figure 5-1 – Diagram of balancing sculpture assembly made of paper and wooden dowels. Photo credit: Alfrey (n.d.).

4. Roll two 1/2" cubes of clay into smooth balls and push them onto the ends of the outer dowels. Use pencil to mark the middle dowel along the same axis as the center of the two balls, as shown.

5. Use the diagonal cutters to cut the middle dowel just above the pencil mark.
6. Test the balance by trying to balance the sculpture on a finger. If it falls, cut a little more off the middle dowel until it balances.

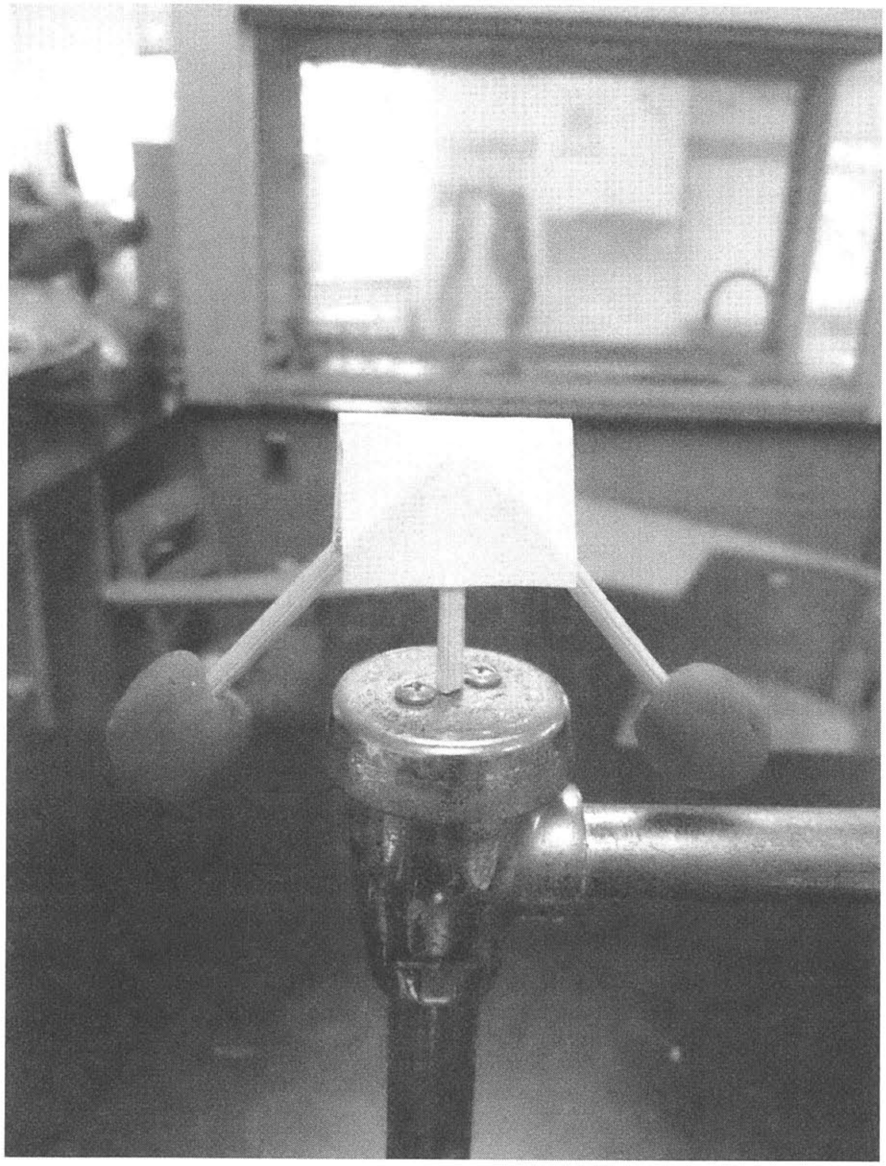

Figure 5-2 – Balancing structure made of dowels, paper, and clay

5.3 Engineering Design Process

This rubric is adapted from the Boston Museum of Science's "Engineering is Elementary" program (The Engineering Design Process, n.d.).

1. Identify - What problem are you trying to solve?
2. Investigate – What are the criteria and constraints? What are some solutions others have discovered in the past?

3. Imagine – Brainstorm solutions. Evaluate the pros and cons of each idea. Then choose one idea.
4. Plan – Sketch/draw details of the chosen solution. Discuss how it will work.
5. Create –.Carry out the plan. Record any changes to the plan.
6. Improve – Test and redesign as necessary.
7. Communicate – Share the strengths and weaknesses of your solution. Ask for feedback.

Teachers explain that the engineering design process is a series of steps that you repeat to develop or improve a product, process or system. You can start anywhere in the process and return to any step at any time.

5.4 Center of Mass, Part 2

This activity, adapted from Royal Institution (2014), expands on the previous one. Students will now create asymmetrical sculptures with more than two elements, while locating new centers of mass and trying to maintain balance. They will work in pairs.

Materials
Play-doh, plasticine, or other sculpting clay of various colors
Wooden dowel rods, 3/32" dia x 8" long. At least 10 dowels per student
Carrots, marshmallows, gum-drops, balloons, or any other small items that can be attached to ends of dowels
16 oz water bottles, one for each student
Diagonal cutters

Steps
1. Cut a piece of carrot about 1.25" long and push a 1.5" long dowel into one end of the carrot.
2. Replicate the sculpture from Activity 1. Use two dowels of equal length extending downward 45 degrees from each side of the carrot and push marshmallows on each end. Now balance the sculpture on a finger or on top of the water bottle.
3. Slide the marshmallows along the dowels and notice what happens.
4. Push more dowels of varying lengths into the carrot and attach other items (gum-drops, balloons, etc.). Adjust their positions so that the sculpture remains balanced.

5.5 Calder Mobiles

This activity is adapted from Jessica (2008). Students will create mobiles from sticks, yarn, and paper.

Materials
Construction paper or felt
Scissors

Yarn
One-hole punch
Sticks
Diagonal cutters
Hot glue guns
20 gauge floral wire (optional)

Procedure

1. Students gather sticks from outdoors or the teacher may provide them. Lengths should vary, but they should all have slim diameters.
2. Cut shapes from the construction paper or felt and punch a hole at the top of each one.
3. Lay out sticks how you would like to tie them to each other. Students should have at least four sticks (i.e. their mobiles will have at least four levels). See Figure 5-3.

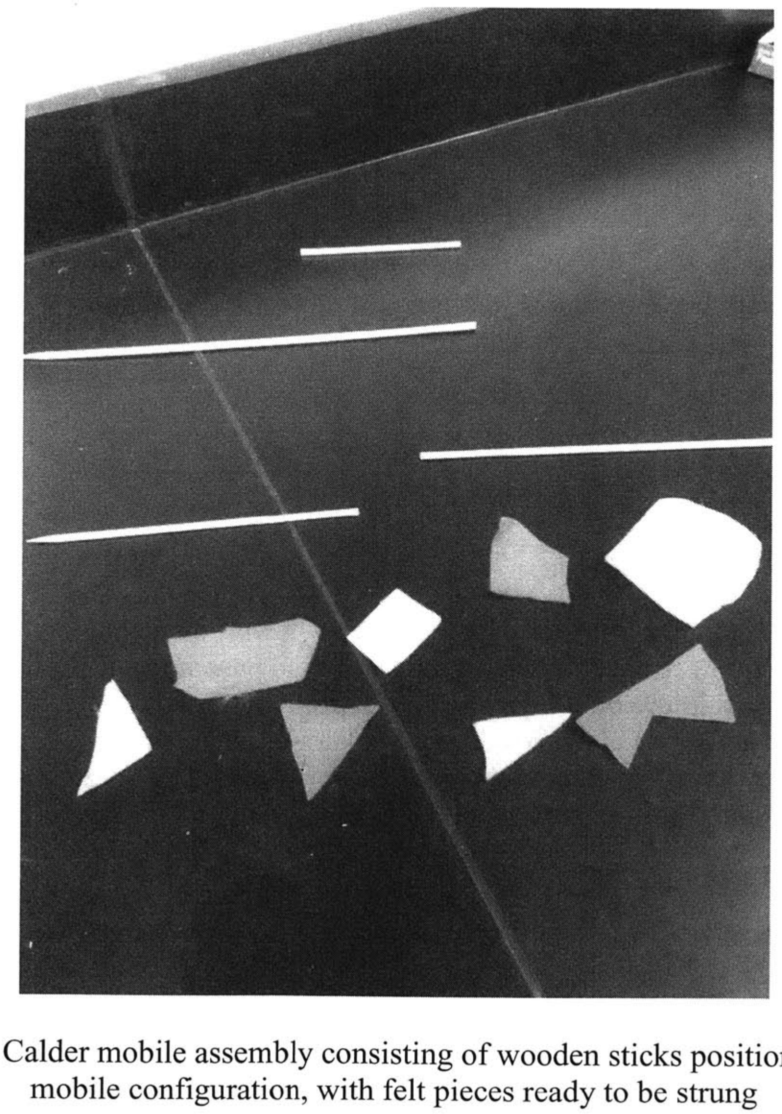

Figure 5-3 – Calder mobile assembly consisting of wooden sticks positioned in desired mobile configuration, with felt pieces ready to be strung

4. Tie sticks together with thread and tie the paper shapes to the sticks.
5. Hang the mobile from the ceiling or other high location.

6. Starting at the top stick level, move the thread back and forth until it balances. When it does, glue the thread in that spot.
7. Repeat for each subsequent level until all the sticks hang horizontally.
8. Students can add different objects, instead of just paper, to their mobile. The challenge is to keep it balanced.
9. Instead of sticks and yarn, students may use the floral wire by bending it and cutting with diagonal cutters.

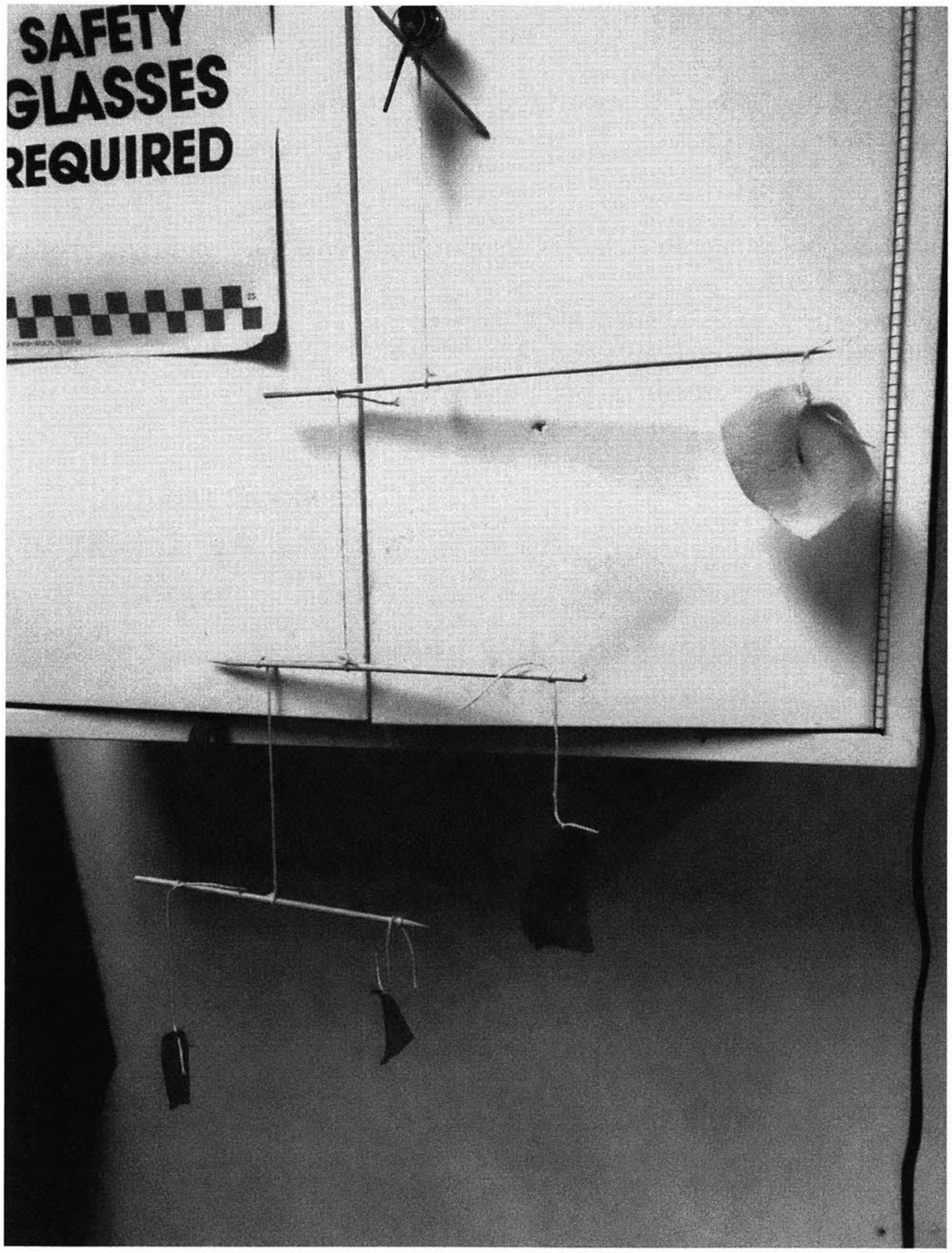

Figure 5-4 – Completed Calder mobile made of sticks, felt, and yarn

5.6 Candy Wave

This exercise is adapted from a demonstration by National STEM Centre (2014). The class will construct a candy wave machine that will demonstrate wave properties when an impetus is applied.

Materials

Three boxes of Dots candies (or Jelly Babies, etc.) – about 150 pieces.
75 wooden skewers
Duct tape
4 table clamps, 4 ring stands, 4 support rods, and 2 crossbars
Permanent marker

Procedure

1. Assemble anchors using table clamps, support rods, crossbars, and right angle clamps as shown in figure 6.2.
2. Stretch duct tape across the table, sticky side up.
3. Mark the tape at even intervals (2" or 3").
4. Attach ends of tape to crossbars. See Figure 5-2.

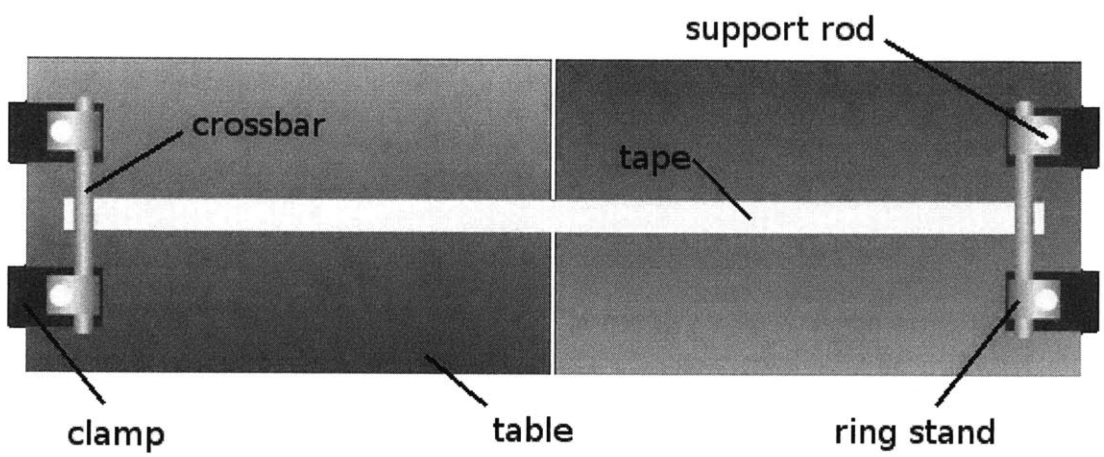

Figure 5-5 – Diagram of table set-up for candy wave machine

5. Push one Dot onto each end of every skewer. Find the balance point on each skewer and mark it.
6. Attach the skewers (with Dots attached) to the duct tape, centering them. See Figure 5-6.

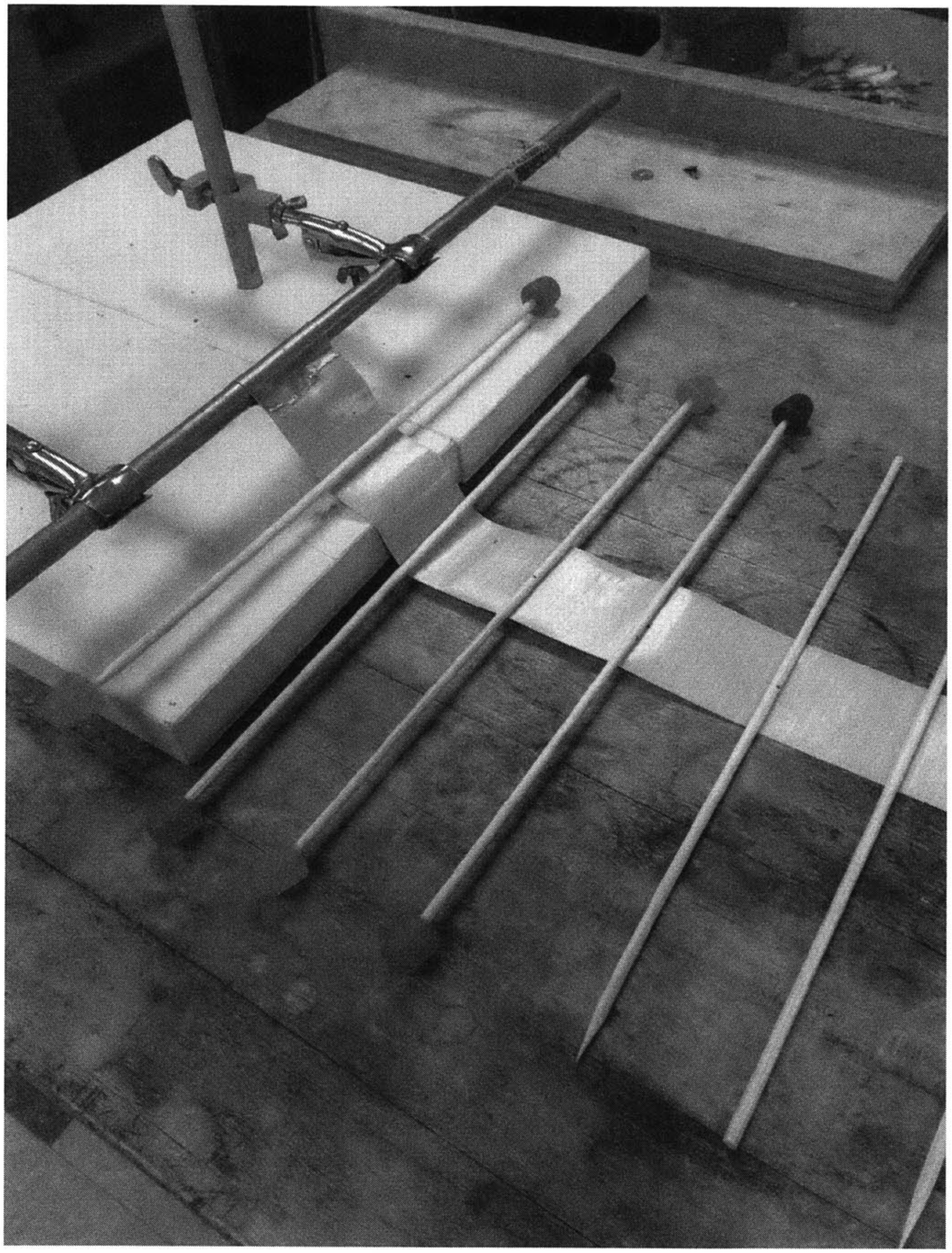

Figure 5-6 – Candy wave machine assembly consisting of wooden skewers and candy on duct tape attached to supports

7. Raise the loaded tape and crossbars and make sure the tape is taught.
8. Adjust Dots as needed to balance. See Figure 5-7.

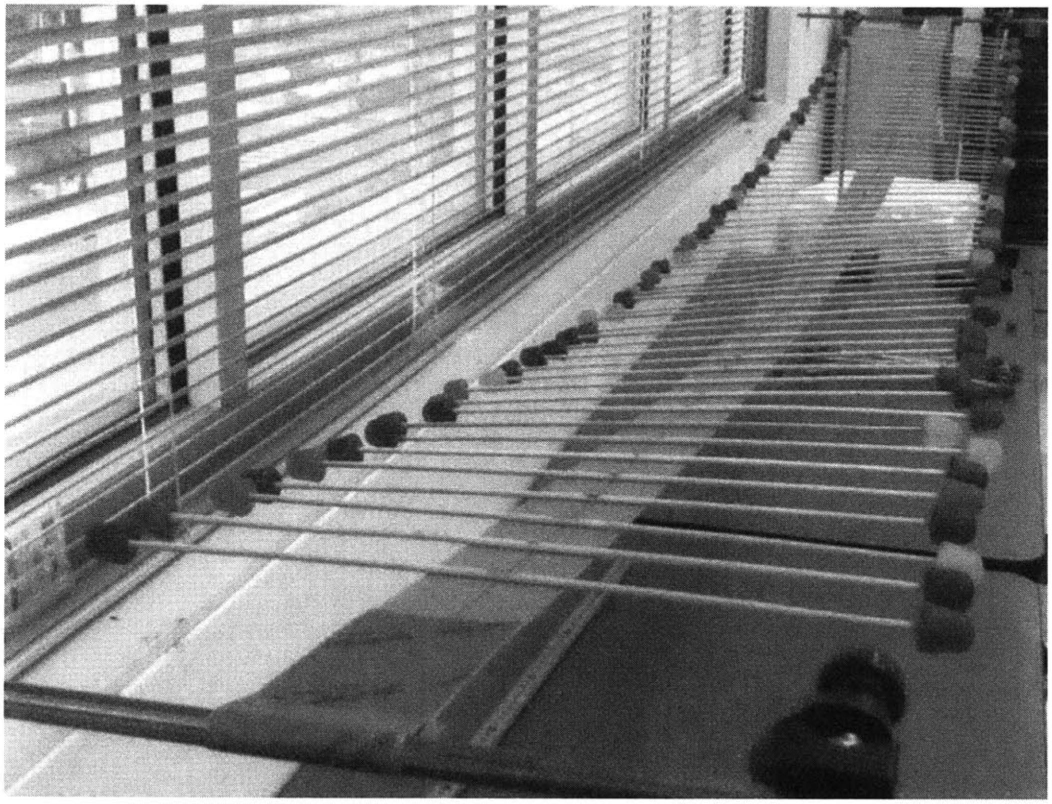

Figure 5-7 – Completed candy wave machine
Photo taken from Instructables (n.d.).

9. Send a wave down the machine by pushing down on one end of a skewer.
10. Observe the wave patterns.
11. How does the wave change based on force applied and position of candies?

5.7 Milk Carton Turbine

Students will make a turbine from a milk carton that hangs from a tree. This activity is adapted from Energy Quest (2006). This activity requires outdoor testing.

Materials
Empty quart or half-gallon milk carton
Masking tape
Nail
Yarn
Pitcher of water

Procedure
1. Use the nail to punch a hole in the bottom right corner of each side of the milk carton.
2. Punch another hole in the center of the top ridge of the carton.
3. Run yarn through the top hole and tie it. The carton will hang from this yarn.

4. Put masking tape on each of the bottom holes.
5. Hang the carton from a low tree branch.
6. Fill the carton with water from the pitcher.
7. Pull the tape of one corner. Observe what happens.
8. Pull the tape of two opposite corners. Observe what happens.
9. Pull all the tape off the corners. Again observe.

Figure 5-8 – Drawing of completed milk carton turbine hanging from tree
Photo credit: Publications International, Ltd. (2007)

Explain how Newton's Third Law of Motion applies here. For every action there is an equal and opposite reaction. When water pours out of one hole it pushes the carton in the opposite direction, causing it to turn. The more holes, the faster it turns.

Explain that some turbines push water or steam through small holes to turn a shaft, which connects to an electric generator.

5.8 Pinwheels

This activity is adapted from "Make a pinwheel" (Tryon, n.d.).

Materials
Square paper
Pencil
Scissors
Push pins
Dowel rods
Wooden or plastic beads

Procedure

1. Fold square paper corner to corner, twice.
2. Make pencil mark about 1/3 of the way from the center on each of the folds.
3. Cut along the folds, stopping at the pencil marks. See Figure 5-9.

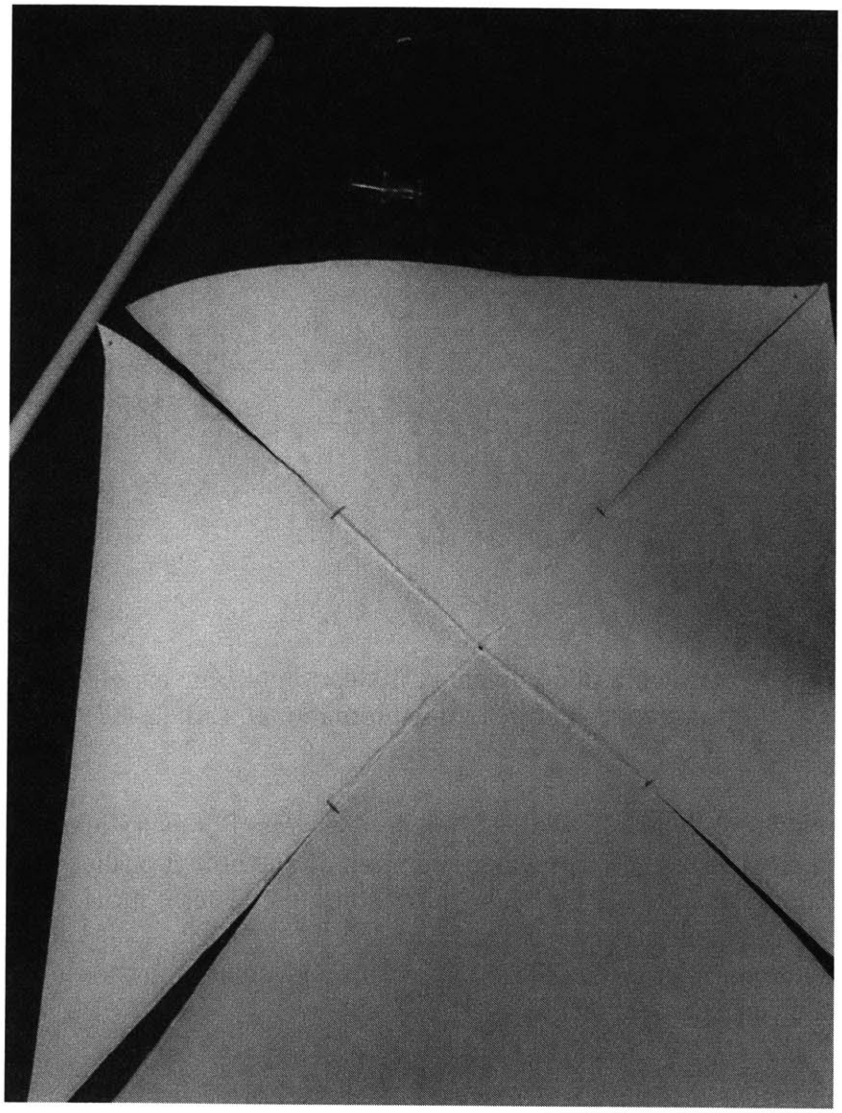

Figure 5-9 – Pinwheel assembly consisting of square paper, folded corner-to-corner with cuts along folds, one-third of the distance away from center

4. Bring every other corner to the center and stick a pin through the four points.
5. Make sure the pin pokes through the center of the wheel because this is the hub around which it will spin.
6. Stick the pin into a thin dowel, using two or three beads as spacers.
7. Students should experiment with different wheel configurations and can decorate their pinwheels with a variety of craft items.

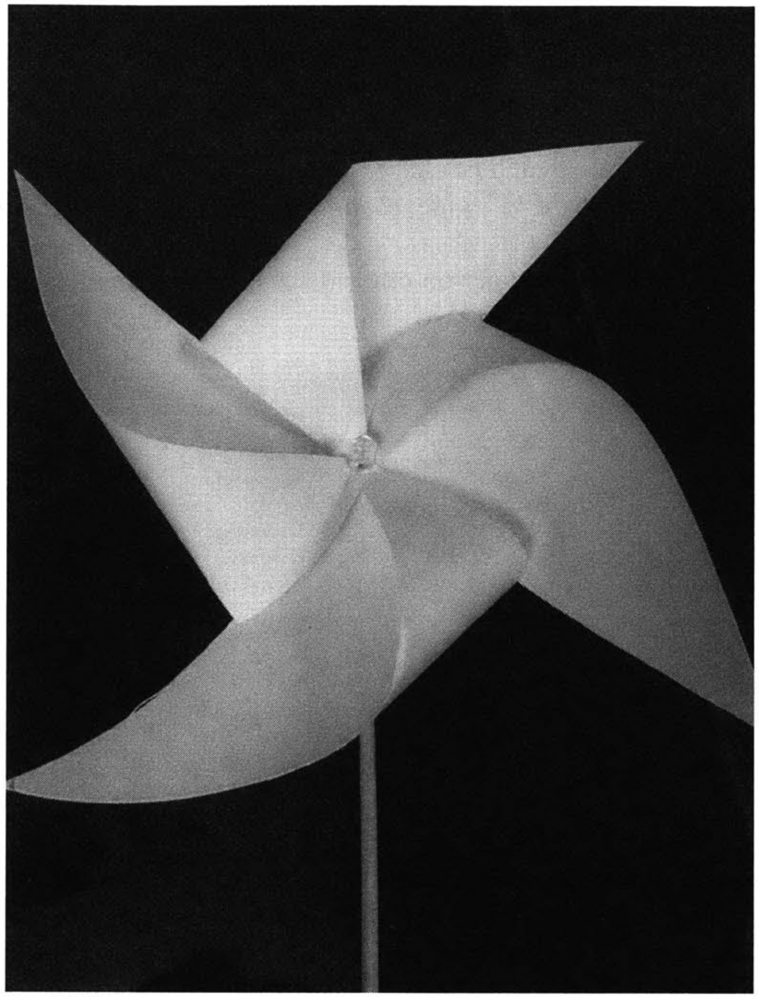

Figure 5-10 – Completed pinwheel made from paper, dowel rod, and push pin

5.9 Making Gears

This activity was adapted from a blog post on www.education.com (Touchette, 2013).

Materials
Corrugated cardboard
Ruler
Pencil
Compass
Scissors or hobby knife
Glue
Push pins
Permanent Marker

Procedure

1. Cut out a piece of cardboard that is at least 8“x8”. This will be your base.
2. On another piece of cardboard, use the compass to trace out at least four circles with 1 inch, 1.5 inch, 2 inch, and 3 inch diameters.
3. Cut out circles with scissors or hobby knife.
4. Calculate circumference of each circle.
5. Cut a long strip of cardboard ¼” wide, along the corrugation. This will be the teeth of the gears.
6. Carefully remove the brown paper on one side of the corrugated cardboard. This will leave the bumps. See Figure 5-11.

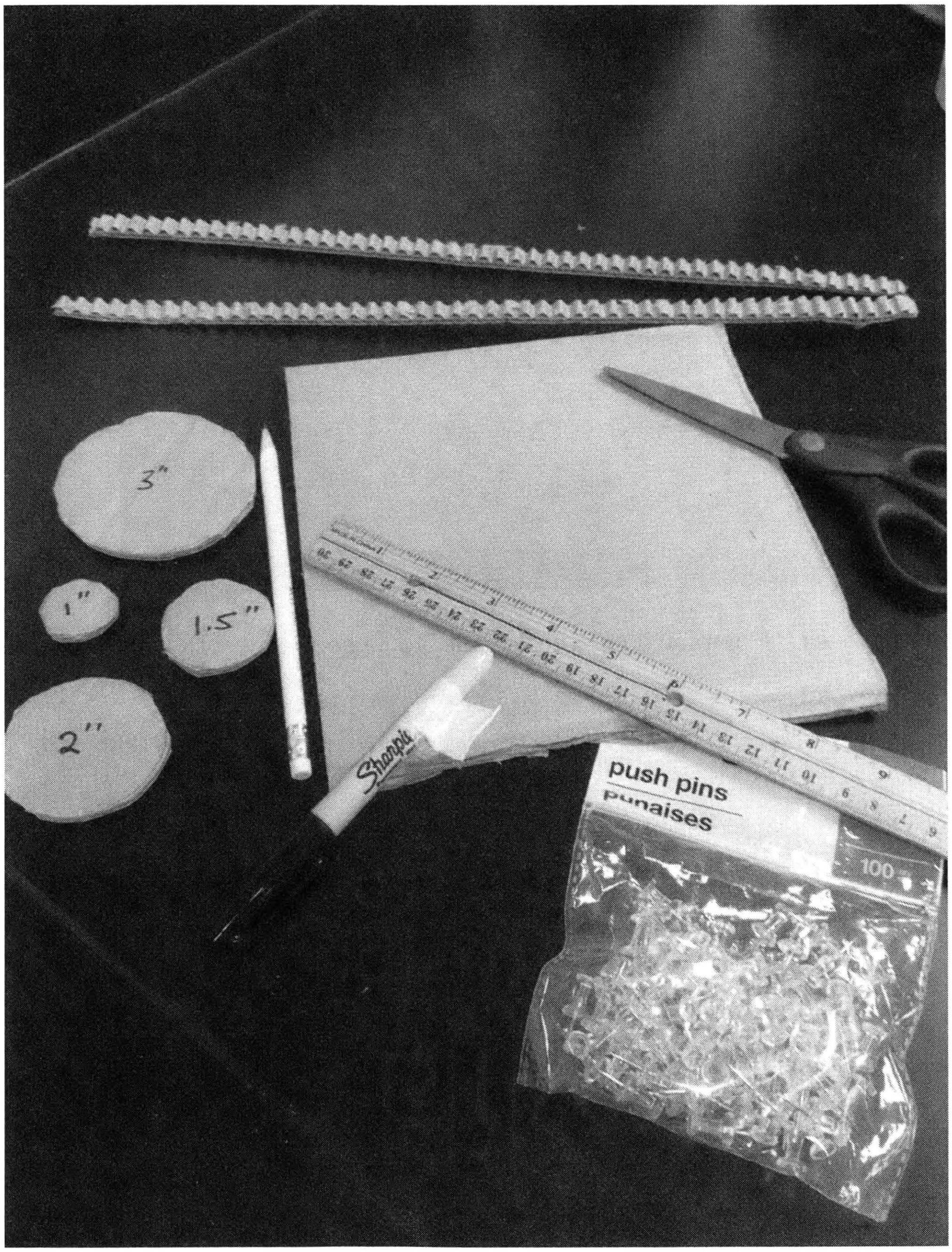

Figure 5-11 – Materials and assembly of cardboard gears, consisting of cardboard circles of various diameters, corrugated cardboard for the gears, push pins, scissors, ruler, pencil, and marker

7. Using the circumferences that you calculated, cut out a piece of stripped corrugated cardboard for each circle.
8. Glue the correctly measured piece of corrugated cardboard around each circle, making sure the bumps are on the outside.
9. Secure the stripped corrugated cardboard with pins.
10. Use a permanent marker to make a mark on one tooth of each of your gears, in order to track when it has made a full rotation.
11. Attach the 3-inch and 1 ½-inch gears to your board, using push pins at the center of each. Make sure that the gears' teeth interlock.
12. Rotate the 3-inch gear clockwise. Which way does the 1 ½-inch gear turn?
13. Using the marks to keep track, turn the 2-inch circle once. How many times does the 1 ½-inch gear turn?
14. Now, turn the 1 ½-inch gear once. How many times does the 3-inch gear turn?
15. Arrange other gears as desired.

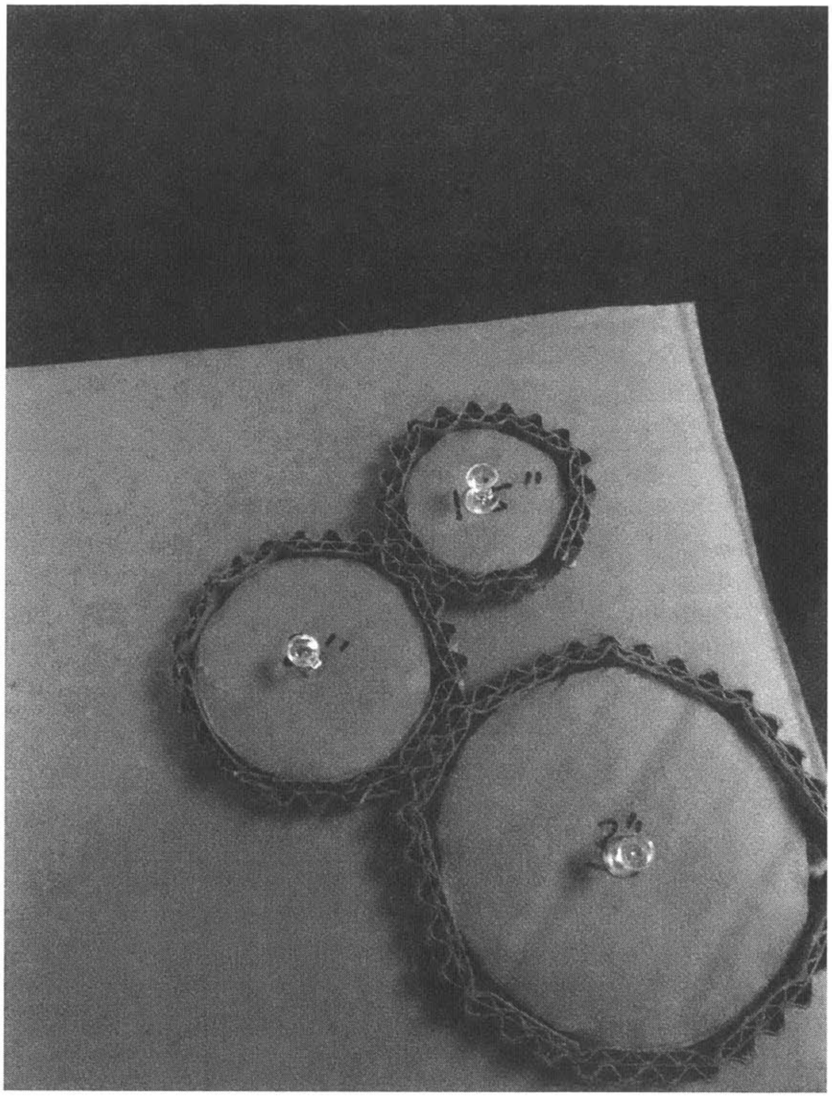

Figure 5-12 – Completed cardboard gears with diameters of 1.5", 2", and 3", affixed with push pins

5.10 Agreeable Sheep

This activity utilizes the Agreeable Sheep project from www.robives.com (Ives, 2010).

Materials
Light 8 1/2" x 11" card stock
Glue
Scissors
Penny

Procedure

1. Download Agreeable Sheep patterns from www.robives.com/blog/agreeable_sheep_come_and_get_it.
2. Print (double-sided) patterns onto light card stock.
3. Cut along the solid lines.
4. Make hill folds along the dashed lines.
5. Make valley folds along the dotted lines.
6. Glue along the grey areas.
7. Continue to follow directions printed on patterns, folding and gluing as indicated.
8. Complete inner body, outer body, neck, and head. Glue these together as indicated.
9. Assemble box as indicated.
10. Assemble cam follower and glue penny into coin holder.
11. Glue cam follower into box.
12. Assemble push-rod and glue it into head of sheep and to cam follower.
13. Assemble cam shaft and glue it to cam.
14. Thread the cam shaft into the box and glue two washers onto shaft.
15. Assemble handle and glue into place.
16. After model is completed and working, cut the cam into a different shape.
17. Write down how the movement of the sheep has changed.
18. Try different cam shapes.
19. See Figure 5-13 for example of completed model.

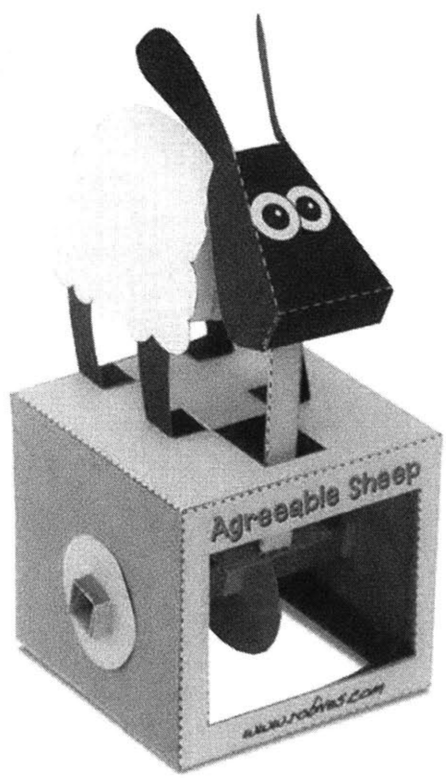

Figure 5-13 – Completed Agreeable Sheep automata sculpture
Photo credit: Ives (2010)

5.11 Linkages

Materials
Cardboard
Paper fasteners
Scissors or hobby knife
Poster board

Procedure
1. Cut out 0.5" wide strips of cardboard of varying lengths. These are the bars.
2. Cut out cardboard rectangles, triangles, and other shapes of various sizes.
3. Push paper fasteners through the ends of the cardboard strips
4. Use one large poster board as the base.
5. Use paper fasteners to attach one bar to the base, on both ends. This is the fixed link or frame.
6. Connect three more bars with fasteners to form a linkage.
7. Choose links to be the driver, follower, and connector.
8. Rotate the driver bar and trace the path of the follower with the pencil.
9. Change the lengths of the bars and/or use the other shapes as couplers or the frame.
10. Notice how the path of the follower changes.

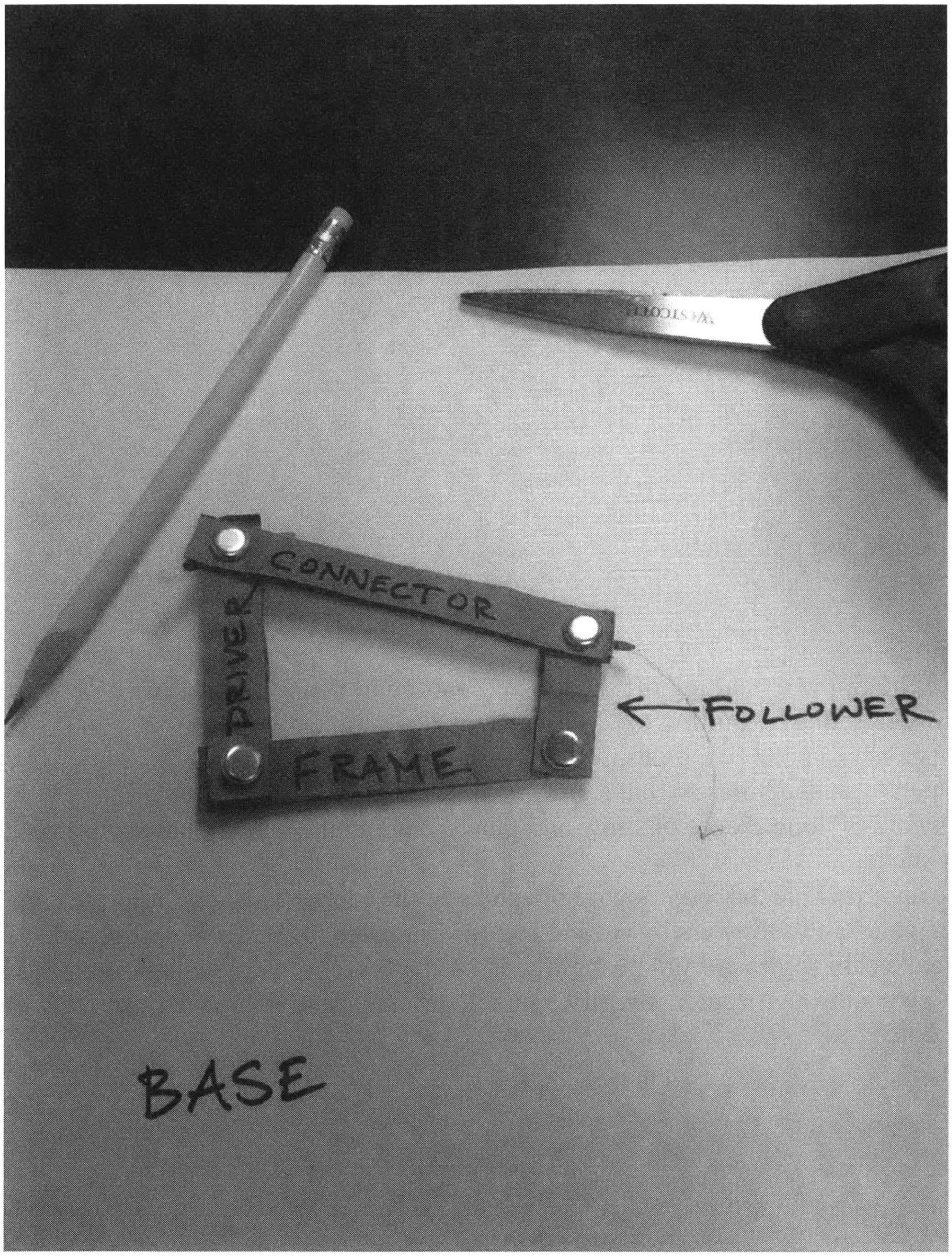

Figure 5-14 – Completed assembly of 4-bar linkage made of cardboard and metal paper fasteners. Path of follower traced by pencil

5.12 Automata

Students will design and build their own automata sculpture. They will have the following Googly Monster (Leftbraincraftbrain, 2015) instructions to provide them some guidance; however students are encouraged to develop their own ideas.

<u>Materials</u>
Small cardboard box
Extra cardboard
Wooden skewers
Straws
Scissors
Compass to draw circles
Masking tape
Pen
Hot glue gun and glue sticks
Felt

Procedure
1. Make the frame by cutting off the top and bottom of the cardboard box.
2. Reinforce frame by putting masking tape on sides and corners.
3. Use skewer to poke two holes into the top of the box, 2-4" apart.
4. Use pen to widen holes so that a straw can fit snugly in the holes.
5. Cut two 2-3" long pieces of straw and glue them into the holes. These will hold the puppet sticks.
6. Poke another hole halfway down both sides of the frame. This will hold the cam shaft.
7. Make cams and followers by cutting four 2" diameter circles from cardboard.
8. To make cam followers and push rods, mark the center of two cardboard circles and push skewers through center, slightly. Glue them in place to complete push rods. See Figure 5-15.

Figure 5-15 – Automata cardboard box assembly with cam shaft made of wooden skewer. Pushrod assembly consisting of two cardboard circles attached to two wooden skewers

9. To make cam shaft, poke skewer through center of one cardboard circle and off-center in the last circle. Make sure circles are approximately the same distance apart as two holes on top of frame. Keep circles aside after holes are made. See Figure 5-16.

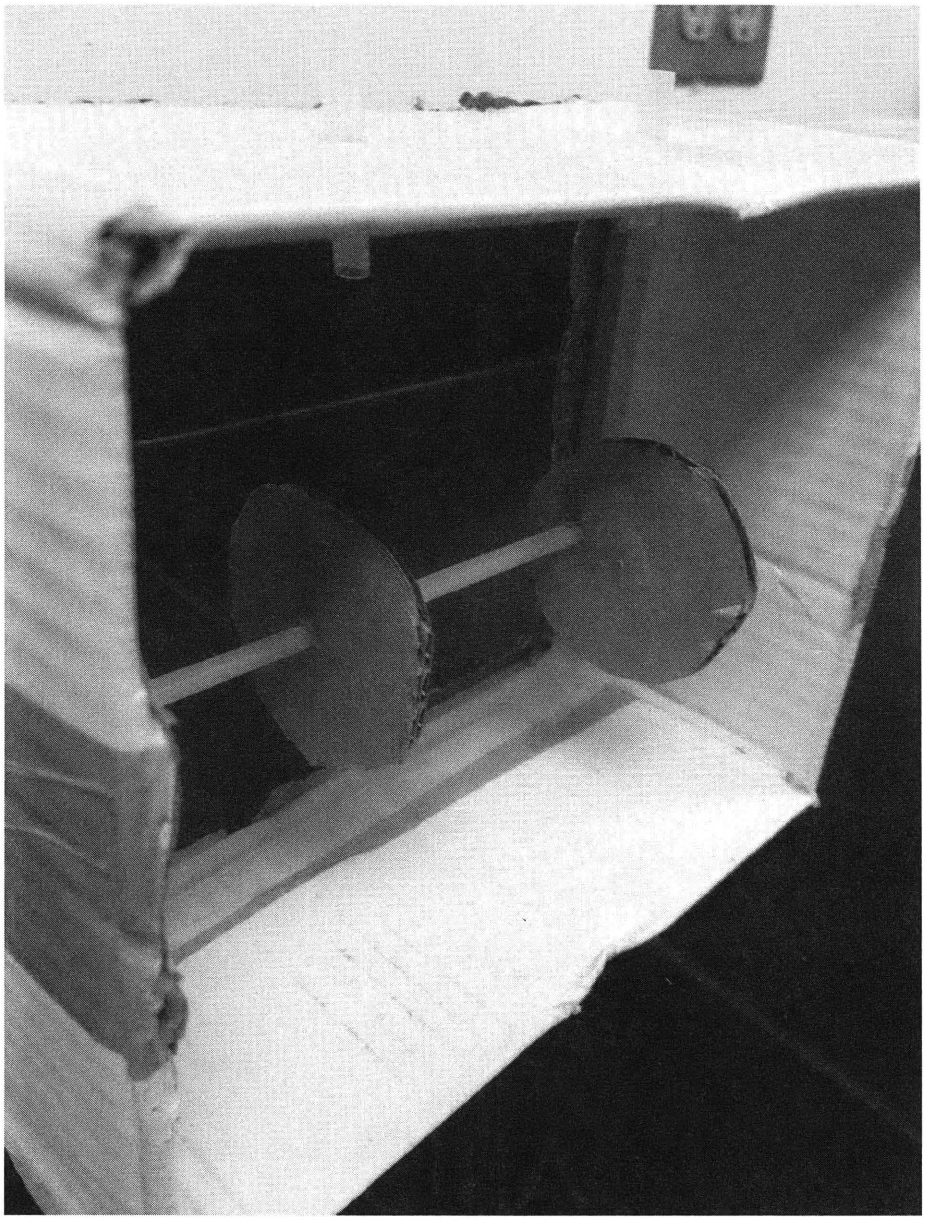

Figure 5-16 – Automata cardboard box assembly with cam shaft made of wooden skewer. Two circular cardboard cams mounted on cam shaft

10. Make figures from cardboard or finger puppets from felt.
11. Feed one skewer through side hole and add cams, then feed through other side hole. This is the cam shaft.
12. Feed each push-rod (with cam follower on bottom) through the straw holes on top of the frame. See Figure 5-17.

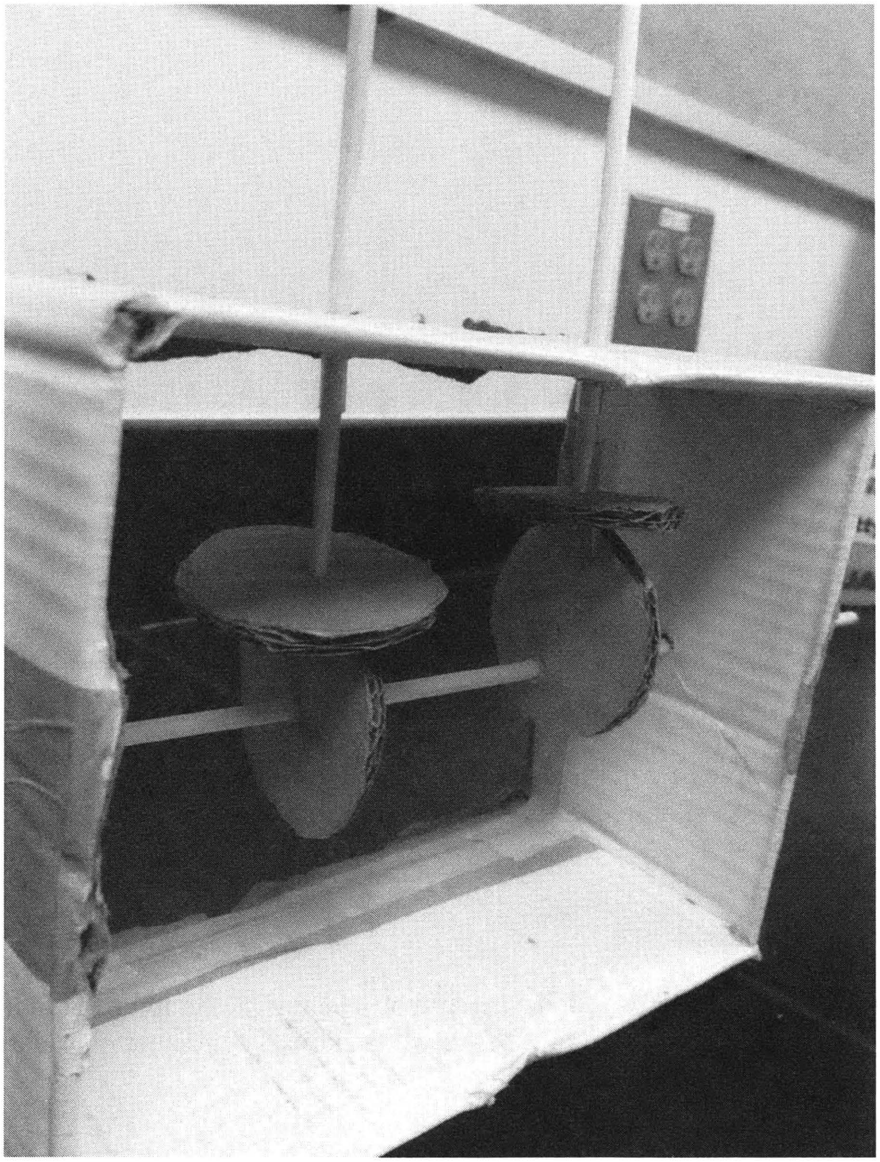

Figure 5-17 – Automata assembly consisting of push-rods and cam shaft made of wooden skewers, and circular cams made of cardboard

13. Attach figures or puppets to the top of the pushrods.
14. Align the vertical cams on cam shaft with the cam followers so the puppets turn or rise up and down when the cam shaft is turned.
15. Glue the vertical cams in place.
16. See Figure 5-17 for example of finished sculpture.

Students should play with different numbers and styles of cams. They can also create figures other than puppets that move atop the sculpture.

Figure 5-18 – Example of completed automata sculpture with googly eye finger puppets
Photo credit: Leftbraincraftbrain (2015)

5.13 Final Project

For their final project, students will design and build a unique sculpture of their own. They may work individually or in groups of two or three. The project must satisfy the following criteria and constraints:

1. Students must sketch out their designs on paper before building.
2. The sculpture must incorporate at least two different technologies learned during the week.
3. The sculpture must display some movement. It can be animated on its own or via human interaction.
4. Any materials used during previous activities can be used. Students may also bring in outside materials.
5. The sculpture must be completed by the designated time on the final day of class.

At the conclusion of the week, students will present their sculptures to their parents and classmates.

5.14 Bill of Materials

Table 5-1 – Cost of reusable materials for a class of 10 students

Activity	**Item**	**Assumptions**	**Total cost for all activities ($)**
5.2, 5.5	Mini hot glue gun	1 per student	54.90
5.2, 5.5	Diagonal cutters	1 per student	20.00
5.2, 5.5	Scissors	1 per student	20.00
All activities	Paper		
All activities	Pens	Box of 64	4.64
All activities	Permanent marker (color)	24 count	12.04
All activities	Pencils	1 per student	
All activities	Ruler	1 per student	5.00
5.9 and 5.12	Compass	1 per student	20.00
5.5	One-hole punch	1 per student	10.00
5.6	Table clamps	4 for all students	6.00
5.6	Ring stands	4 for all students	6.00
5.6	Support rods	4 for all students	4.00
5.6	Crossbars	4 for all students	4.00
5.7	Pitcher	3 for all students	0.45
	Total		167.00

Notes: Pricing was obtained using websites such as amazon.com and Google shopping.

Table 5-2 – Cost of consumable materials for a class of 10 students

Activity	Item	Assumptions	Cost per activity per student	Total Cost per activity ($)
5.1	Construction paper	200 sheets for two activities 5.1 and 5.5); divided equally	0.25	2.48
5.2	Play-doh or other sculpting clay	1 can per student	0.80	7.99
5.2	Wooden dowels	3 dowells per student	0.45	4.50
5.2	Masking tape	3 rolls	0.93	9.29
5.2	Sandpaper	2 sheets	0.53	5.33
5.2	Card stock	100 sheets for two activities (5.2 and 5.10), divided equally	0.59	5.88
5.2	Glue sticks	1 per student	0.19	1.90
5.3	No materials		0.00	0.00
5.4	Play-doh or other sculpting clay	1 can per student	0.80	7.99
5.4	Wooden dowels	10 dowels per student	0.45	4.50
5.4	Carrots	1 carrot per student	0.50	5.00
5.4	Marshmallows	1 large bag per activity	0.20	2.00
5.4	Gum drops	1 large bag per activity	0.20	2.00
5.4	Balloons	2 per student	0.26	2.60
5.4	16-oz disposable water bottles	1 per student	0.23	2.28
5.5	Construction paper	200 sheets for two activities 5.1 and 5.5); divided equally	0.25	2.48
5.5	Yarn	100 yards for two activities 5.5 and 5.7	0.19	1.87
5.5	Sticks	Students will collect sticks; otherwise, use leftover dowels	0.00	0.00
5.5	Glue sticks	1 per student	0.19	1.90
5.6	Dots candies	3 7.5 ounce boxes	0.48	4.77

Activity	Item	Assumptions	Cost per activity per student	Total Cost per activity ($)
5.6	Wooden skewers	1 100 count box (divided equally between 5.6 and 5.12	0.50	1.00
5.6	Duct tape	3 rolls	1.87	18.74
5.7	Empty quart- or half-gallon milk carton	1 per student		
5.7	Masking tape	3 rolls	0.93	9.29
5.7	Nails	2 per student		
5.7	Yarn	100 yards for two activities 5.5 and 5.7	0.19	1.87
5.8	Push pins	1 100-count box (divided equally between 5.8 and 5.9)	0.05	0.50
5.8	Wooden dowels	1 dowels per student	0.15	1.50
5.8	Plastic beads	1,000 color beads	0.20	1.99
5.9	Corrugated cardboard	5 pack of 20" x 24" sheets	0.60	6.00
5.9	Glue sticks	1 per student	0.19	1.90
5.9	Push pins	100-count box (divided equally between 5.8 and 5.9)	0.05	0.50
5.10	Glue sticks	1 per student	0.19	1.90
5.10	Card stock	100 sheets for two activities (5.2 and 5.10), divided equally	0.59	5.88
5.11	Cardboard	2 12x12 inch sheets per student	2.00	20.00
5.11	Paper fasteners	Box of 100	0.30	3.00
5.11	Poster board	1.5 per student	0.75	7.50
5.12	Small cardboard box	1.5 per student	2.25	22.50
5.12	Cardboard	1 12x12 inch sheets per student	1.00	10.00

Activity	Item	Assumptions	Cost per activity per student	Total Cost per activity ($)
5.12	Wooden skewers	100 count box (divided equally between 5.6 and 5.12)	0.50	1.00
5.12	Straws	1 box of 100 count	0.15	1.50
5.12	Masking tape	3 rolls	0.93	9.29
5.12	Glue sticks	1 per student	0.19	1.90
5.12	Felt	Pack of 12	0.40	4.00
	Strandbeest Kit		35.00	350.00
	Total			556.50

Notes: for some items that are usually sold in bulk (such as glue sticks), we used price per glue stick. We assumed a class of 10 when dividing cost of bulk items. Pricing was obtained using websites such as amazon.com and Google shopping.

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