AC 2011-792: THIRTY YEARS OF RUBE GOLDBERG PROJECTS: A STUDENT-DRIVEN LEARNING LABORATORY FOR INNOVATION

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Thirty Years of Rube Goldberg* Projects:
a Student-Driven Learning Laboratory for Innovation

Abstract

One of the authors runs an annual "Rube Goldberg*" design project as the culminating student demonstration of a junior level electrical laboratory class. Over the past 30 years attendance has grown from a few students the first year to now include city-wide attendance and television coverage from multiple stations. The term "Rube Goldberg" originates from Reuben Lucius Goldberg's cartoons portraying complex solutions to simple problems, and engineers sometimes use the term as a derogatory description for an unnecessarily complex system.

The "Rube Goldberg" student project assignment includes: "*This is a project, proposed, designed, and built by yourself, to demonstrate your creativity. Use of conversion from electronic signals to physical motion is encouraged. An electric motor should be used somewhere in the project. A good example of what is being sought is the 'Mousetrap Game.'*"

Many students see this preparation and demonstration as the epitome of their engineering education. They catch an excitement far out of proportion to the slight grade they get as a reward, and are motivated instead in proportion to the large amount of learning they accomplish. Camaraderie is generated, and the night before the public presentation a large number of students spend all night in the lab adding last-minute details, drinking energy beverages, and eating pizza. The comment "if Professor Graff doesn't teach Lab 3 [with Rube Goldberg] anymore, there's no reason to come to [this] University" has been overheard on campus.

The open-ended Rube Goldberg design project has six very intentional learning goals. These goals include providing students with hands-on experience with: (1) teamwork, (2) public presentation, (3) creativity & innovation, (4) systems thinking, (5) energy transfer and conversions, (6) Murphy's Law (if anything can go wrong, it probably will), and (7) learning from failures. The effect on student learning has been phenomenal, demonstrated in part by qualitative assessments such as conversations with alumni. Many teaching principles have been gleaned, such as "Learning by Failure", "Last-Minute-Engineering", "The Stupidity of Not Planning Ahead", "The Importance of Duct Tape", and "How to Explain Technical Principles to a Diverse Audience." Each successive year the University has seen fit to ban more energy transitions, for safety's sake, so that the students find it necessary to find innovative ways to produce shock and awe in future presentations.

1 Introduction and Background

Ruben Lucius Goldberg (1883-1970) was educated as an engineer at the University of California –Berkeley and worked for the Water and Sewer Department of the city of San Francisco before beginning a career as a newspaper cartoonist, editorial cartoonist, and sculptor. Goldberg developed a number of cartoons, including "Mike and Ike (They Look Alike)," "Foolish Questions," "Lala Palooza," and "Boob McNutt."

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* Although the projects here are not associated, please note that Rube Goldberg is the ® and © of Rube Goldberg, Inc.

“It was in 1914 that Goldberg created the series that brought him **lasting** fame — a series that was inspired by his academic studies. Recalling the so-called "Barodik", an incredibly complex contraption for determining the mass of our planet, cooked up by Goldberg's analytical mechanics instructor, Professor Frederick Slate, Goldberg drew a convoluted and highly improbable "Automatic Weight-Reducing Machine" for the *Evening Mail.”*[1]

In 1929 he created the comic strip for which his name is famous. “The Inventions of Professor Lucifer Gorgonzola Butts” established the “Rube Goldberg” mechanism, a complex and humorous set of interactions that accomplish a simple objective at the end. “Rube Goldberg” appears in some dictionaries as a descriptor for a complicated apparatus that accomplishes little.

“Best known for his ‘inventions,’ Rube’s early years as an engineer informed his most acclaimed work. A Rube Goldberg contraption – an elaborate set of arms, wheels, gears, handles, cups, and rods, put in motion by balls, canary cages, pails, boots, bathtubs, paddles, and live animals – takes a simple task and makes it extraordinarily complicated. He had solutions for How To Get The Cotton Out Of An Aspirin Bottle, imagined a Self-Operating Napkin, and created a Simple Alarm Clock – to name just a few of his hilariously depicted drawings.”[2]

Figure 1 shows a sample Rube Goldberg Cartoon, described as follows: “As you sit on pneumatic cushion (A), you force air through a tube (B) which starts ice boat (C), causing lighted cigar butt (D) to explode balloon (E). Dictator (F), hearing loud report, thinks he's been shot and falls over backward on bulb (G), snapping picture!”[3]

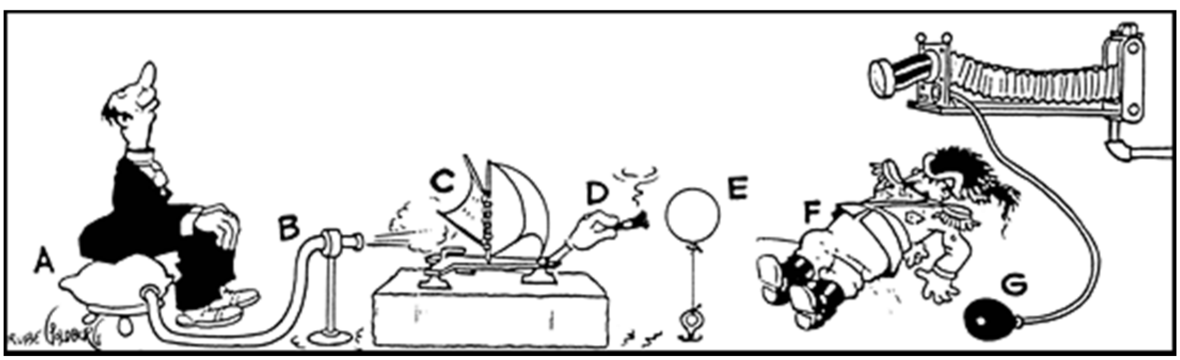


Figure 1: Sample Rube Goldberg Cartoon – Picture Snapping Machine[4]
(Used with permission. Rube Goldberg is the ® and © of Rube Goldberg, Inc.)

Rube Goldberg-style machines maintain the fascination of the public as evidenced by the £6 million[5] Honda advertisement “The Cog.” The CGI-free 2 minute chain reaction made entirely from Accord parts boasts 1.2 million viewings on one YouTube Posting[6] and is followed with a “making of” video, numerous spoofs, and even a video illustration of how they (legitimately) made the wheels roll uphill.

Two Purdue engineering fraternities popularized a Rube Goldberg contest in the 1940s and 1950s, and it was revived 1983. Now Purdue University hosts an annual national Rube Goldberg Machine Contest for college students, and promotes one for high school students, with winners appearing on numerous television shows.[7]

Although the annual Rube Goldberg competition at LeTourneau University has no connection with “official” competitions, it taps into the same universal fascination for such machines shared by both engineers and the larger public. The project is conducted as an extra-large lab activity within a junior level electronic lab class requiring teams of two (usually), at least 10 energy conversions, a non-binding proposal with sketch (examples in Appendix A), and a written report.

As an example, the objective of the “Turmoil in the Toolroom (1992)” sketch (the first in Appendix A) is to drop bandages for a carpenter who has cut himself, spurting fake “blood” from a glove onto the toilet tissue which weakens and breaks, thus beginning the chain reaction. A sample Rube Goldberg project is shown in Figure 2, with numerous other pictures in Appendix B and summaries of highlights over the years in Appendix G. An example assignment and grading rubric are included in Appendix C and Appendix D.

Figure 2: Sample Rube Goldberg Project from 2009

2 Teaching Goals Accomplished

The use of computer modeling has generally reduced students’ proficiency such that increasing numbers of students are unfamiliar with basic “hands-on” concepts such as common grounds in the physical lab. This course (Electronics Design Lab or “Lab 3”) is used as a review of all the electrical courses students have had to date, with a few extra topics they have never seen before, such as an in-depth study of real transformers, microwaves, antennas, and lasers. The Rube Goldberg event is designed to be the crescendo of the course. Students often dread its approach but brag about their experience when it is over. Thus, it has become a sort of “rite of passage”. Many say it was the hardest thing they have ever done. They usually misjudge the amount of time it will take to implement their ideas, and therefore stay up all night previous to their presentation.

The Rube Goldberg project facilitates numerous teaching goals, including: (1) teamwork, (2) public presentation, (3) creativity & innovation, (4) systems thinking, (5) energy transfer and conversions, (6) Murphy 's Law (if anything can go wrong, it probably will), and (7) learning from failures. The projects are also a fun highlight of the junior year for many students.

2.1 Teamwork

Students work in teams of two, because experience has taught that when three people are on a team, one is usually left out; however, by the end of the semester, when I have become familiar with the student's capabilities, more may be allowed on a team.

This is not a competition, but a demonstration; as the time for the presentation draws near, panic ensues, and the various teams typically help one another. I have seen this situation happen on the eve of most of the presentations, usually around 2:00 AM. One student told me, after it was all over, that the experience was the highlight of his student career at (university). He said the cooperation among teams, sharing ideas for fixing problems and helping one another, bonded them together.

It almost always takes longer to implement a process than originally expected. This concept is made real to the students by the Rube Goldberg project.

Panic is a great generator of "action rather than planning." There is a subset of "technical types" who spend long periods of time calculating and never get around to actually doing something. As the time for presentation looms near, the ensuing panic drives them to **do** something, and duct tape facilitates a lot of the result. Duct tape is a classic "rapid prototyping" medium, famous for this purpose at least since the distressed Apollo 13 mission was saved in part by the use of a duct tape roll onboard the spacecraft[8,9].

2.2 Communication: Written and Public Presentation

Each student team must publicly demonstrate their device and explain the steps in the energy transfers. Even students who are reluctant to speak in class are required to speak to the audience about their project. Furthermore, they are not allowed to "snow" the audience, which consists of students, faculty, and local people from all walks of life. They must be able to communicate technical concepts to a nontechnical audience. Typically some students are interviewed by news media after the presentation (Figure 3).

Figure 3: Students are Often Interviewed by News Media

One student after viewing the presentation video advised, "If there is acting involved, script it and practice it. Ad-libbing is not something everyone can do well, and it's very easy to overact. Good acting/presenting definitely enhances a Rube Goldberg project. Consider having some outsider(s) critique the acting, and be willing to humbly receive their constructive criticism. Also, consider using a clever theme such as 'Automatic Breakfast Maker.'"

Each student writes a proposal before the event, and the teams work on the implementation. The proposal is not binding, because more ideas will be forthcoming during implementation. A final report is written after the presentation by each student (not "each team"). Each student has to explain part of the sequence to the audience. There can be no "silent partners".

2.3 Creativity and Innovation

The founder of LeTourneau Technical Institute (now University) was a self-educated engineer and businessman famous for his ingenuity and Christian faith. (Most sources attribute between 290-300 patents to his name, and a Google patent search turns up several hundred.) As a result of these qualities, the LeTourneau University motto is "Faith brings us together. Ingenuity sets us apart." Robert Gilmour LeTourneau was known as "Bob," but after becoming famous for his inventions his employees began to refer to him as R. G. "for Rube Goldberg"[10] (R.G. LeTourneau was a contemporary of Rube Goldberg the cartoonist.)

The authors believe there is a connection between the flamboyant abandon necessary to produce a Rube Goldberg system and Mr. LeTourneau's successes, and thus these exercises are intended to build these innovative qualities. Making the projects totally open-ended promotes creativity, and new ideas win more points. Students are encouraged to think "outside the box". A good example of this occurred when one team ran a physical chain-reaction sequence into a wall, and then the action became virtual; pictures of levers were projected on the wall, tossing a virtual ball onto another position at which the action resumed physically. A second example was a system in which the choreographed moves of six dancing students generated lights, music, and smoke in response to their changing pressure on dance pads. This predated the modern "Dance Dance Revolution" (DDR) video game by many years, which differs slightly in that DDR dancers follow scripted dance moves and music provided by the video game, whereas in this project, the dancers create the music through how they danced.

2.4 Systems Thinking

The numerous modules within a Rube Goldberg machine forces systems thinking, and the challenge of interfaces in particular, since each module must correctly interface with the next. If two working systems are interfaced, the pair will often not work together. An example of this in the electrical domain occurs when an output impedance is not matched to the input impedance of the next device.

2.5 Understanding Energy Transfer and Conversions

The existence of various energy transfers in a sequence helps the student to see that there are several ways to accomplish the same goal. This has a lot to do with the fact that the physical principles, and, therefore the mathematics behind the various operations, are the same (this idea is elaborated in a hydraulic circuits paper[11]). Energy can be stored in batteries, water towers, flywheels, pendulums, or chemicals, for example.

Since this is an electrical engineering course, electrical energy transfers are encouraged. Electrical energy transfers are typically fast, however, so the students are encouraged to intersperse electrochemical and electromechanical transfers, so that the action can be followed by the audience. One alumnus advised, “Keep it simple, but not too simple. On paper the final design had 11 stages (see Appendix A), but the video only looked like 4 or 5 because some of the smaller ones happened too quickly and were almost too small to be seen. I’ve seen that a lot with other students’ designs, too.”

A list of sample energy transitions used over the years is shown in Appendix F. Some of the most notable include: a tesla coil induces a fluorescent tube to glow which activates a photosensor, a speaker voice-dials one cell phone to call another which vibrates down a ramp, an iced switch is thawed by a hair dryer, a soft-pellet machine-gun cuts a paper in two which drops a weight, and a nail gun bursts a balloon.

2.6 Understanding Murphy’s Law

Whenever a student suggests that all he has to do is to “build the circuit and it should work the first time,” it is obvious that he has not built many circuits and has not done a Rube Goldberg. Most of the projects hang up at some point and require student intervention to realign or reset.

The professor in charge begins most public presentation sessions by explaining to the audience who Rube Goldberg was, and also the principle of “Murphy’s Law”[12,13]. He explains the statistical improbability that one of the student machines will work without intervention (which takes some pressure off the students.)

After 40 years of teaching the first author concluded:

> Many students today live in a “different reality” than I did. Their “reality” has been influenced by so much TV, video, and computer games that some actually think that these things represent real life. It’s as if they had grown up in “the Matrix”. They have been immersed in a world in which they have very little experience with reality as dictated by the laws of probability, physical principles, and Murphy’s Law. They have

> learned to expect “miraculous interventions”, superhuman strength, and magic. They have not experienced the laws of probability, because very improbable things have become commonplace to them. When I first saw “Mission Impossible”, having been trained as an engineer, I had to laugh out loud, as a complicated device, built without having been tested, functioned perfectly the first time! My sophomore students have to be retrained in the way they build projects, so that they test each part of the device individually before incorporating it in the overall project. This is now necessary in order to overcome their expectation that everything will work perfectly the first time they try it. In other words, they need to learn, by experience, “Murphy’s Law”. One of the projects I assign in lab is to build a Rube Goldberg machine, which is a long string of energy transfers, like the “Mousetrap Game”. The main purpose is to show them that in real life, something will probably go wrong, since real components follow Murphy’s Law. Simply explained, Murphy’s Law says that” if anything can go wrong, it probably will.”[14]

A Rube Goldberg device can usually be modeled as a chain of simple devices, each of which is triggered by the previous device. This is where Murphy’s Law comes into play. If there are ten devices in the chain, and the probability that each individual device will work is 0.8, then the probability that the whole machine will work is only 0.107. The probability of failure in this exercise is very great! This makes it ideal for the goal of “Teaching through Failure”.

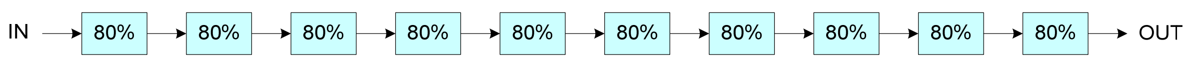


Figure 4: Probability of Achieving Output is Only 11%

An alumnus writes years after graduation, “Murphy’s Law works better than people expect most of the time. The more trial runs, the better. Yes, it adds to the development time, but can prevent more serious problems later. Students may not really appreciate it now, but this principle definitely transfers to real-world engineering. In business, more beta testing can save face – and lawsuits – if design flaws are found before a product has gone to market. Millions of Dilbert fans cannot be wrong!”

2.7 Learning through Failures

Motivation is everything. One strong motivation is fear of failing; another is the fear of being unprepared to present something before an audience (this is especially true for engineering students in general).

It has been observed that if a student has a project or speech to present in one course, work and homework in other classes are put on “hold” until after that presentation.

The “teaching through failure” method is to push students toward failure in a task for which the penalty for failure is low, so that they are motivated to learn, and therefore succeed, in more important tasks.

For example, when teaching a class in circuits, the students are tested in the second period on basic principles (usually memorized formulas). The quiz is a 5 minute quiz, and most of the students fail it. This is graded, and the same quiz is given in the 3rd period. The students soon realize that there will be a quiz at the start of every class period, and begin to study incrementally throughout the semester instead of in spurts before big tests. In the final analysis, the five-minute quizzes each count as only 0.126% of the final grade, so that their weight is practically inconsequential. This principle is a consequence of two previous articles[15,16].

3 How Did This All Begin?

At the end of a spring 1978 laboratory course, called "Electrical Lab 3", students had been designing transistor amplifiers and other electronic systems, and it was proposed that the students build a Rube Goldberg machine. There were 11 students in the class, and the presentations were done in small groups. This produced great enthusiasm. News spread around campus, so it became a regular part of the course.

In the fall of 1979, the author reported on this project in the ASEE ERM magazine[17], as follows:

> "An effort is made in Lab 3 to wean the students from the instructor's direction and on to creative thinking. Assignments are made for which several different paths lead to a solution, and the students have been introduced, by this time, to several elements which may be used as building blocks through the use of "mini-labs" [1] (short, 1-2 hour experiments using only one device which can be bread-boarded at home and demonstrated to the instructor briefly in lab).
>
> By the middle of the semester, the students have been primed to begin the "Rube Goldberg Design Project." The statement of the problem is as follows:
>
> "This is to be a project, proposed, designed and built by you to demonstrate your creativity. Use of conversion from electronic signals to physical motion is encouraged. A good mechanical example of what is being sought is the 'Mousetrap Game'."
>
> The students have two to three lab periods to perform the task, and the grade is very subjective, depending heavily upon how creative the instructor deems the project. The students may either choose to work alone, or in teams of two. They write a short project proposal, to be turned in at the end of the first week, but are not held rigorously to it (I'd hate to quench a brainstorm).
>
> Previous to this assignment, the labs have been open-ended on one end; that is, the objective was specified, and could have been reached in any way the student desired; this one, however, is open-ended at both ends: not only the method of solution, but the problem itself, is a variable.
>
> … the general idea [is] much ado about nothing … A few of the other successful projects have been: a model rocket launching system (with provision for recording the initial take-off velocity); automatic marshmallow toaster (which caught on fire); automatic electronic spider catcher; automatic robot exterminator; and remote calculator activator. These employed all kinds of chips and some home-built devices, electromagnets, SCRs, pulsing circuits, home-built VCO's, amplifiers, transmitter-receiver systems, active and inactive filters, and power supplies.

Overall, the experiment served to stimulate thinking and educate the interfacing of devices.

In subsequent years, the Rube Goldberg project became more elaborate, and news of it spread to the whole campus; non-technical students began coming to the presentations, and eventually there was not enough room in the electrical labs to contain them. The laboratory building consisted of several rooms without ceilings, and the presentations began to spread from one room to another. One presentation involved a live popcorn machine was moving across a large open space between rooms while popping popcorn which showered on the audience as Christmas music played "Chestnuts Roasting on an Open Fire". However, as students climbed on tables and leaned over walls, it was feared that something might collapse (Figure 5). So, in the spring of 1989, the Rube Goldberg presentations were moved to the campus assembly building. This required more preparation, because the student body assembled there daily for chapel services and lectures, so that permission had to be obtained far in advance, and seats had to be moved out and replaced after the event. Students were required to do most of the preparation and cleanup, and the local media began to take notice in the ensuing years. This further motivated the students to excel, not only technically, but in their presentations. One memorable presentation consisted of a sequence which would have obviously caused the bloody execution of a hamster, when, at the last moment, Superhamster (complete with cape) slid along a wire across the room to ultimately save him. The audience cheered!

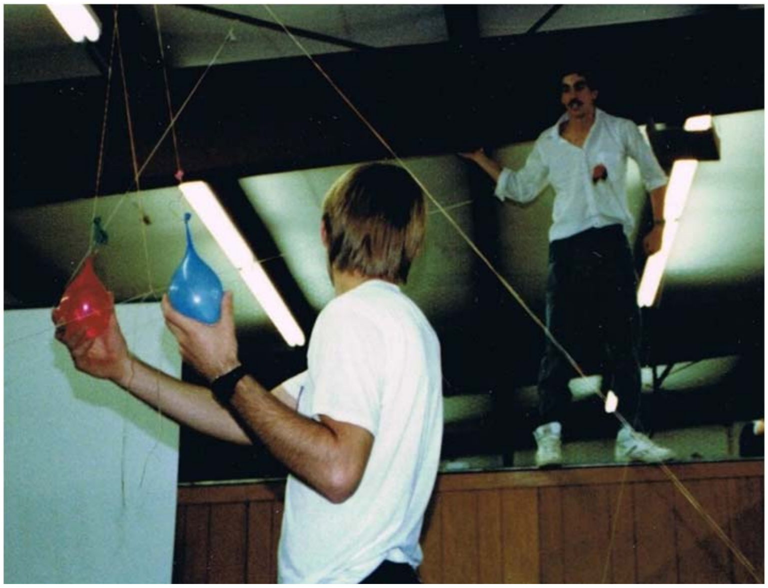


Figure 5: Students Standing on Walls – Ultimately Causing the Move to a Larger Space

Since one of the objects of this exercise is to encourage innovation, the students were told that the exercise could be expanded to include Robot Wars. Thus, in the spring of 1991, two groups built robots, each of which carried hooks on pulleys and were propelled by electric motors remotely. The robots were about 2 – 3 feet long and weighed over 50 pounds each. They fought in an arena until one disabled the other. The audience sat in a circle around the arena in which they fought. This was so successful that the next year, in 1992, one of the presentations done by a team of 5 students was billed as "Robot Hockey". They designed and built a pair of robots which were remotely controlled and were able to catch and shoot a hockey puck. These two robots played against each other in a game of hockey, amidst the cheers and groans of hundreds in the audience. Incidentally, three of the five members of that team went on to earn their Ph.D.'s at three different universities.

The following year, spring 1993, the entire class of 8 students wanted to do "Robot Wars". This was permitted so as not to quench their enthusiasm, but it seems that their enthusiasm exceeded their abilities. Five students built one robot, and the other three built another. One worked, but the other had a critical malfunction and was totally disabled. Since there could be no contest, the students who had built the non-working robot had to explain to the audience why it didn't work.

Appendix G summarizes additional memorable events over the years, many of which shaped the competition into the present form.

4 Explosions and Rules Changes over the Decades

In 1995 "The Meteor Shower Defense System" finished in a huge explosion. A loud alarm system had warned of the supposed meteor and a simultaneous "clear the area" signal preceded the launching of a rocket into a plastic bag hanging from a tree that contained oxygen and acetylene. This resulted in a new rule that *no oxygen was to be put into acetylene balloons* in future Rube Goldbergs. The students, one now an engineering professor, were gratified to find their presentations lauded in the city newspaper the next day. By this time, the news media was becoming a regular occurrence at Rube Goldberg presentations.

In 2000 "The Nothing Machine" was supposed to remove a cat from a tree. The final step was the ignition of a combination of *hydrogen and oxygen* in a plastic milk jug, obtained by electrolysis of water. The jug was set in an outdoor tree, and when the explosion occurred, the head of security happened to be close by. He stormed into the assembly building and loudly asked who was in charge of this event. I was strongly rebuked, and deserved it, since I had not made sure the students had alerted the authorities that there was to be an explosion that day. No more explosions are allowed in future Rube Goldbergs. The student who had engineered that explosion graduated and became a rocket scientist, putting up satellites, and now builds submarine drones.

During the 30 years since we began this project, we have had to change the rules. We can no longer allow the use of rockets, fireworks, fire, explosions, or toasters hanging from the ceiling; and we can no longer use tables as dominoes. However, as restrictions are added (usually due to unfortunate happenings and nearly groundless fears), the students are simply driven to try new methods of producing shock and awe for their audience (Figure 6).

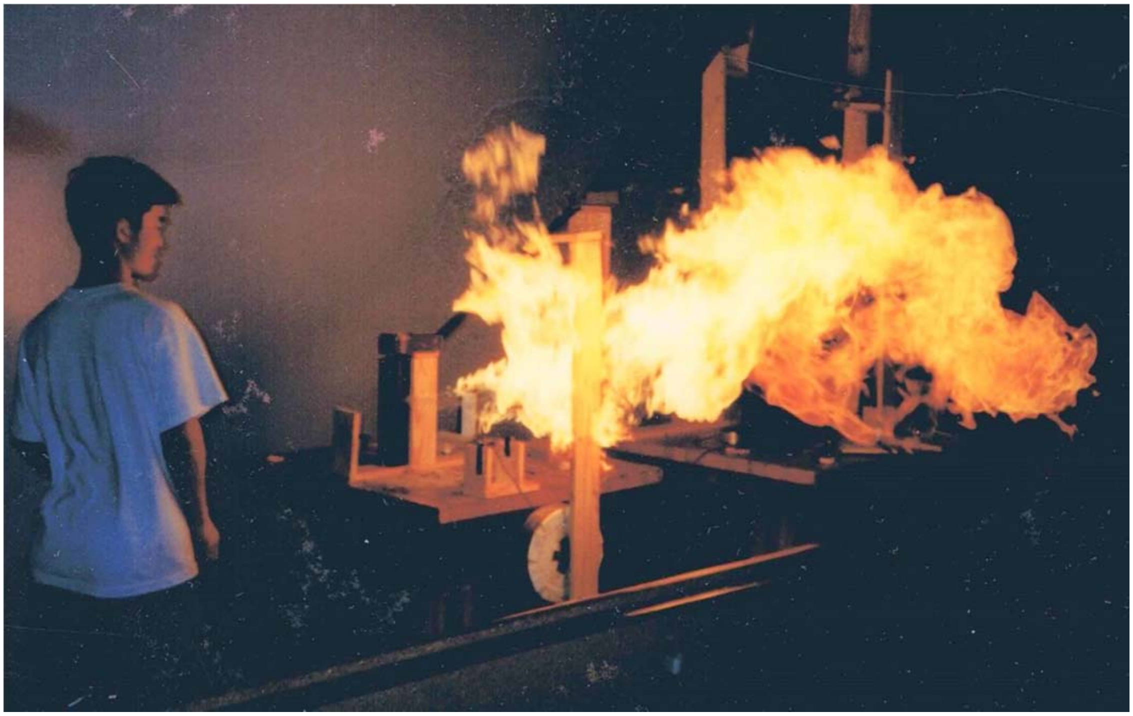


Figure 6: Each Year Additional Items are Banned (Hairspray Shown Here), Thus Driving Students to Find New Methods

5 Conclusions

The open-ended Rube Goldberg design project has very intentional learning goals, and the effect on student learning has been phenomenal. The progression of the projects over the years is illustrated with numerous examples in part so that anyone else wishing to undertake such projects can benefit from the mistakes and discoveries reported here.

Based on experiences over the years such as reported in this paper, it is recommended that faculty wishing to begin a similar event start small, perhaps constrained to a session or two in a laboratory course with students presenting to classmates. Details concerning grading possibilities are contained in the appendices. The emphasis on innovation rather than technical expertise calls for generous grading. The purpose of the exercise is to push students to "think outside the box". The students themselves will advertise and the event is likely to grow year by year.

References

[1] "Rube Goldberg," *Donald Markstein's Toonopedia, http://www.toonopedia.com/, accessed Jan 18, 2011*

[2] "Rube Goldberg," www.rubegoldberg.com, *accessed Jan 18, 2011*

[3] "Picture Snapping Machine," http://www.rubegoldberg.com/gallery_05.php, *accessed Jan 18, 2011*

[4] "Picture Snapping Machine," http://www.rubegoldberg.com/gallery_05.php, *accessed Jan 18, 2011*

[5] COG (Advertisement), http://en.wikipedia.org/wiki/Cog_(advertisement), *accessed Jan 18, 2011*

[6] "Honda –The Cog," http://www.youtube.com/watch?v=_ve4M4UsJQo&feature=related, *accessed Jan 18, 2011*

[7] "Rube Goldberg Contest at Purdue," http://www.purdue.edu/newsroom/rubegoldberg/index.html, *accessed Jan 18, 2011*

[8] "Duct Tape," http://en.wikipedia.org/wiki/Duct_tape, *accessed Jan 18, 2011*

[9] "The Frustrations of Fra Mauro," http://www.hq.nasa.gov/alsj/a13/a13.summary.html, *accessed Jan 18, 2011*

[10] LeTourneau, R.G. Mover of Men and Mountains, Autobiography (Prentice-Hall 1960, 1967; Reprint Moody Press 1967, 1972), ISBN 0-8024-3818-0, p. 202.

[11] Graff, Leiffer, Neimi, Vaughan, A HYDRAULIC CIRCUITS LABORATORY – TO IMPROVE STUDENT UNDERSTANDING OF BASIC ELECTRICITY, Annual Conference of the American Society for Engineering Education, 2007, AC 2007-452

[12] "Murphy's Law," http://en.wikipedia.org/wiki/Murphy's_law, *accessed Jan 18, 2011*

[13] The Contributions of Edsel Murphy to the Understanding of the Behaviour of Inanimate Objects. http://www.frontiernet.net/~wmooney1/Fixed_files/murphy.pdf, *accessed Jan 18, 2011*

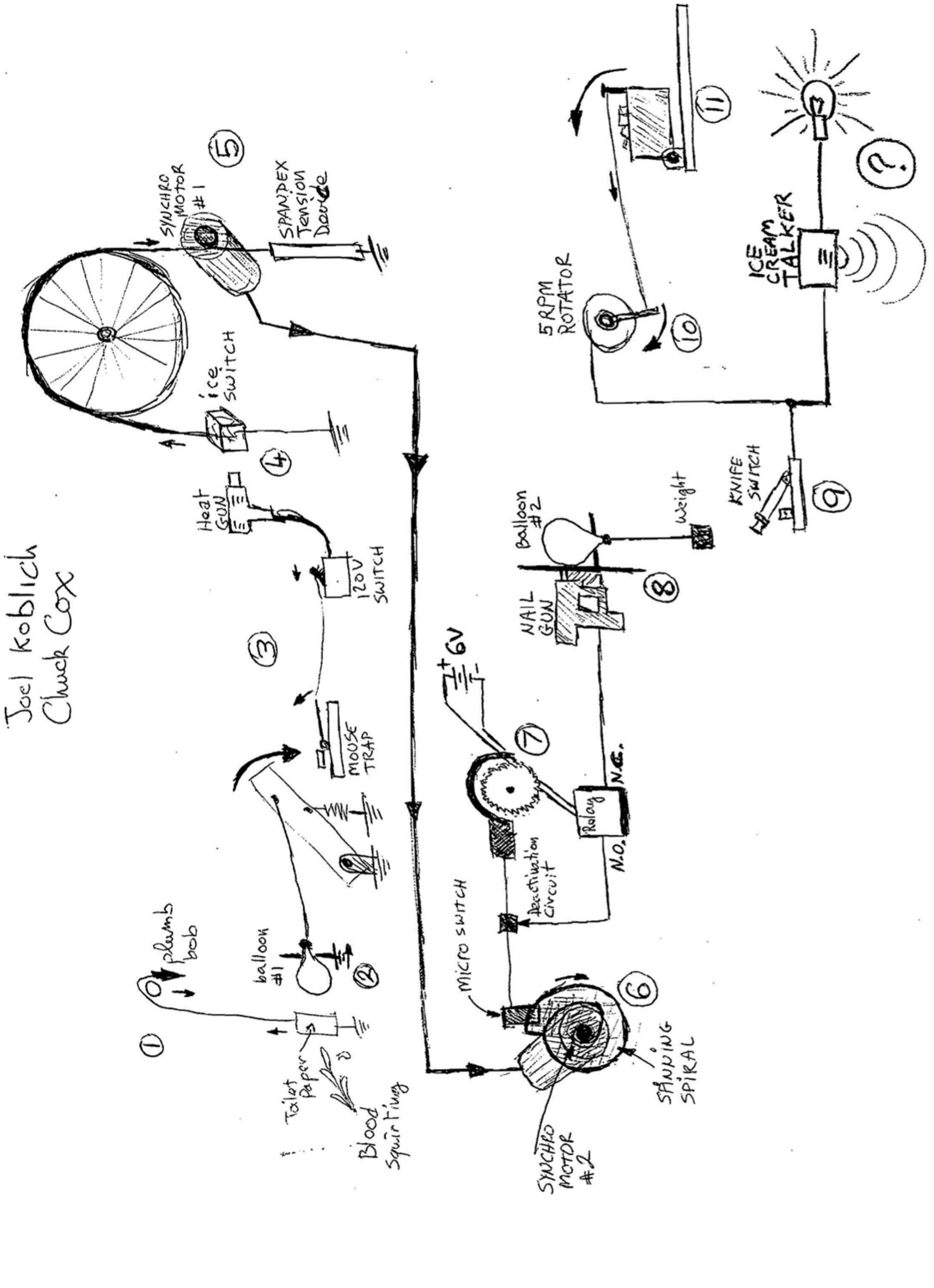
[14] Graff, R.W., Leiffer P.L., Batts, M., Leiffer M., WHAT FUZZIES MIGHT LEARN FROM TECHIES, Annual Conference of the American Society for Engineering Education, 2010, AC 2010-911

[15] Graff, R. W., "The Three Levels of Learning," ERM, Vol. 3, #4, June 1971

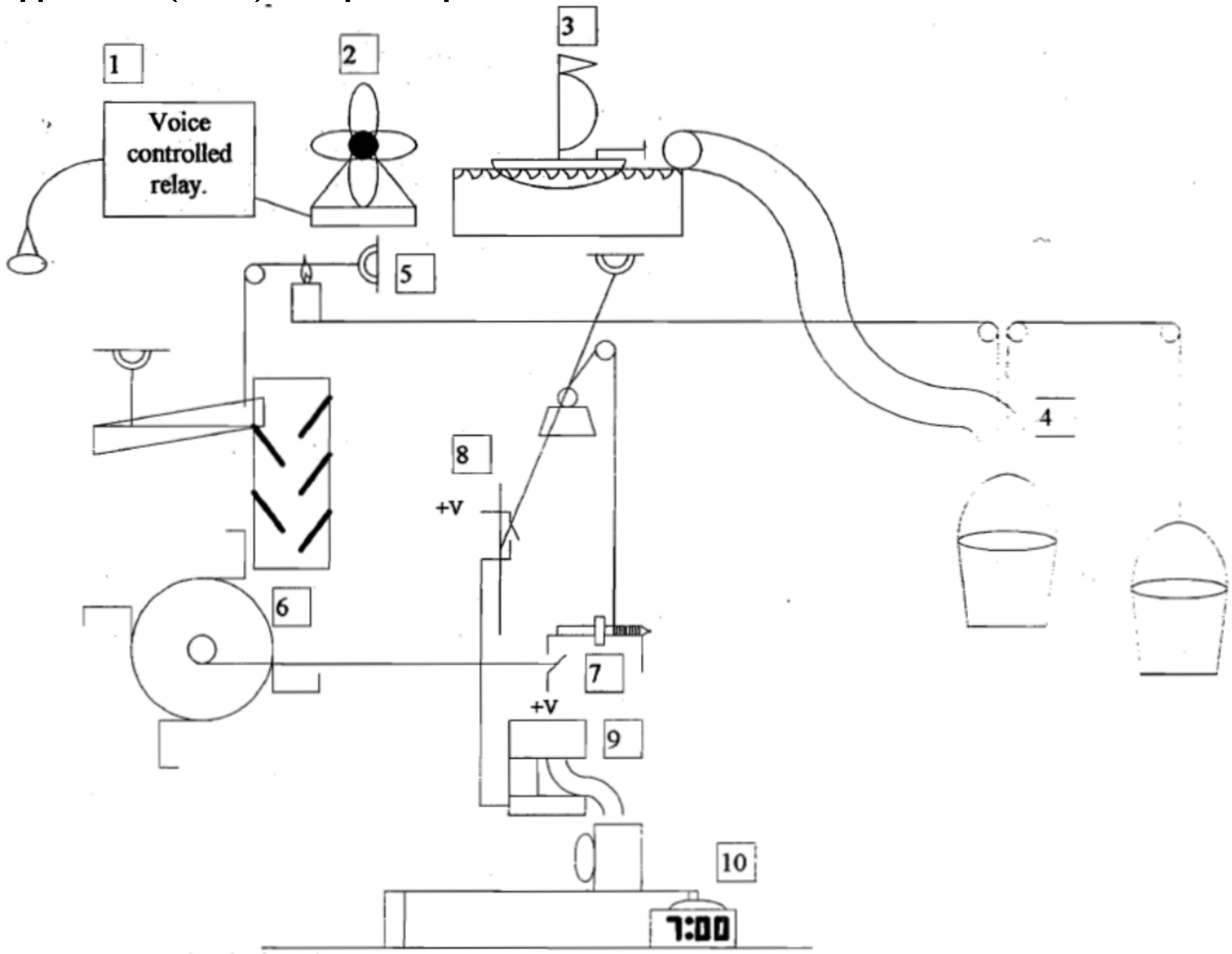
[16] Graff, R. W., "Optimal Learning," ERM Vol. 4, #2, March 1972

[17] Graff, R. W., "The Rube Goldberg Design Project," ERM Magazine of the Educational Research and Methods Division of the American Society for Engineering Education, Spring 1980

Appendix A: Rube Goldberg Student Proposal Sketch #1: "Turmoil in the Toolroom"

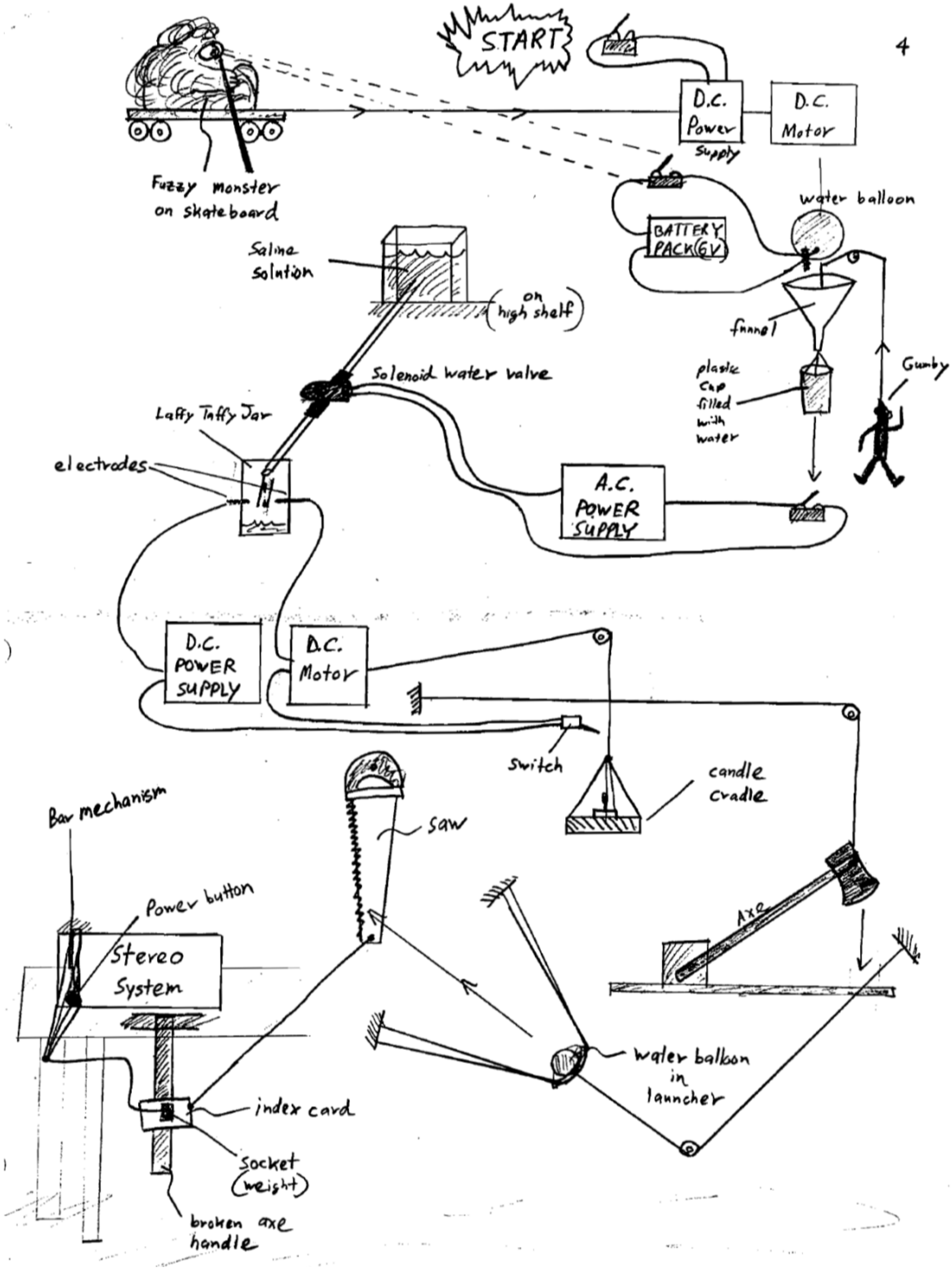


Appendix A (Cont.): Sample Proposal Sketch #2

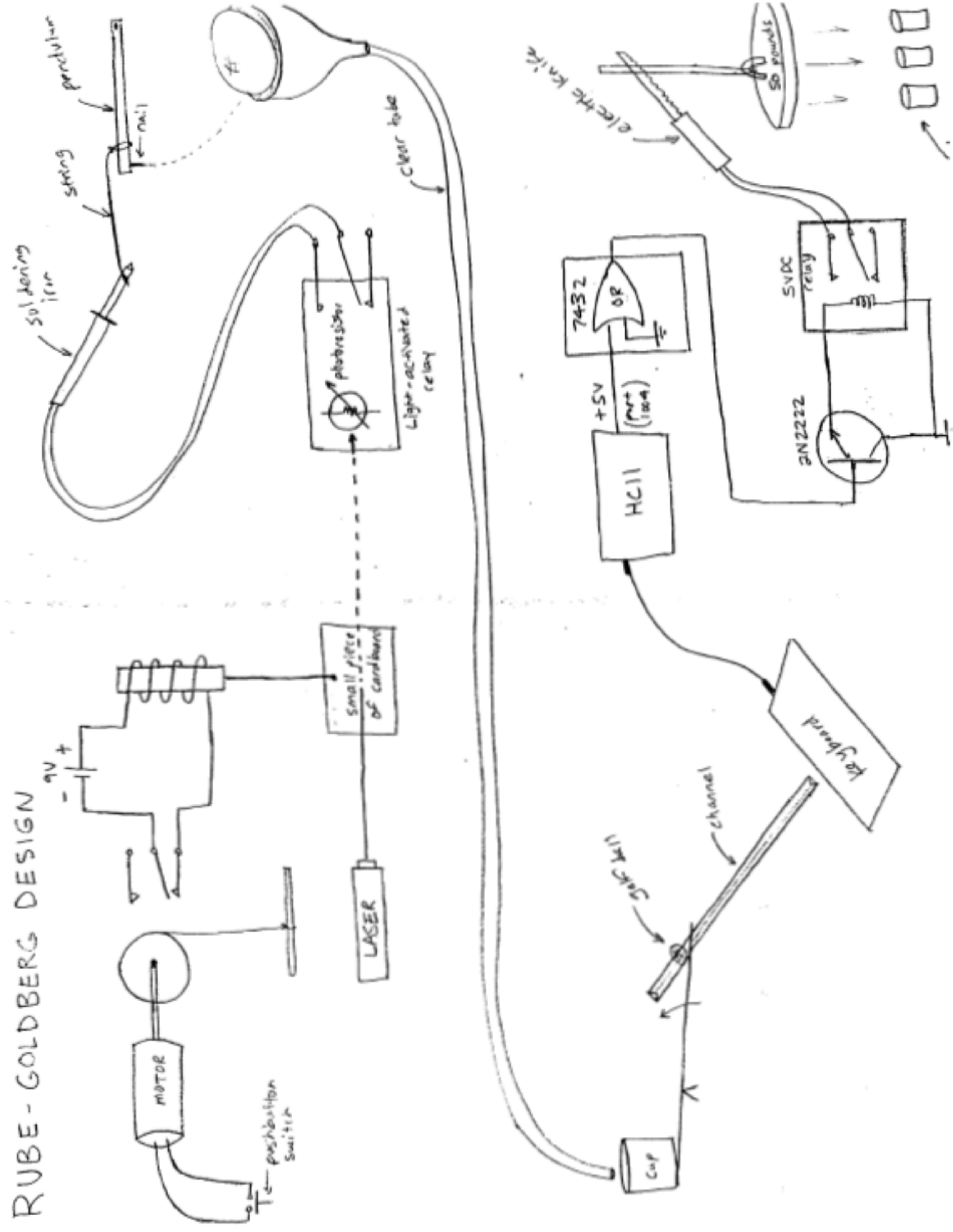


1. A loud noise directed into the microphone triggered the voice controlled relay.
2. The relay turned on a fan.
3. The fan blew a boat through a tub and bumped a ball into a tube.
4. The ball rolled through the tube and landed in a bucket.
5. The falling bucket pulled a candle under a string which held a container of water from spilling.
6. The container of water spilt down a water fall and turned a water wheel.
7. The water wheel wound up a string which closed a knife switch turning on a soldering gun.
8. The soldering gun burnt through a string which held a weight suspended from the ceiling, the weight fell on and closed a second knife edge switch.
9. The switch turned on a coffee maker which brewed and directed the "coffee" down a PVC pipe.
10. The "coffee" filled a cup which overcame the spring in the snooze button on the alarm clock thus shutting it off.

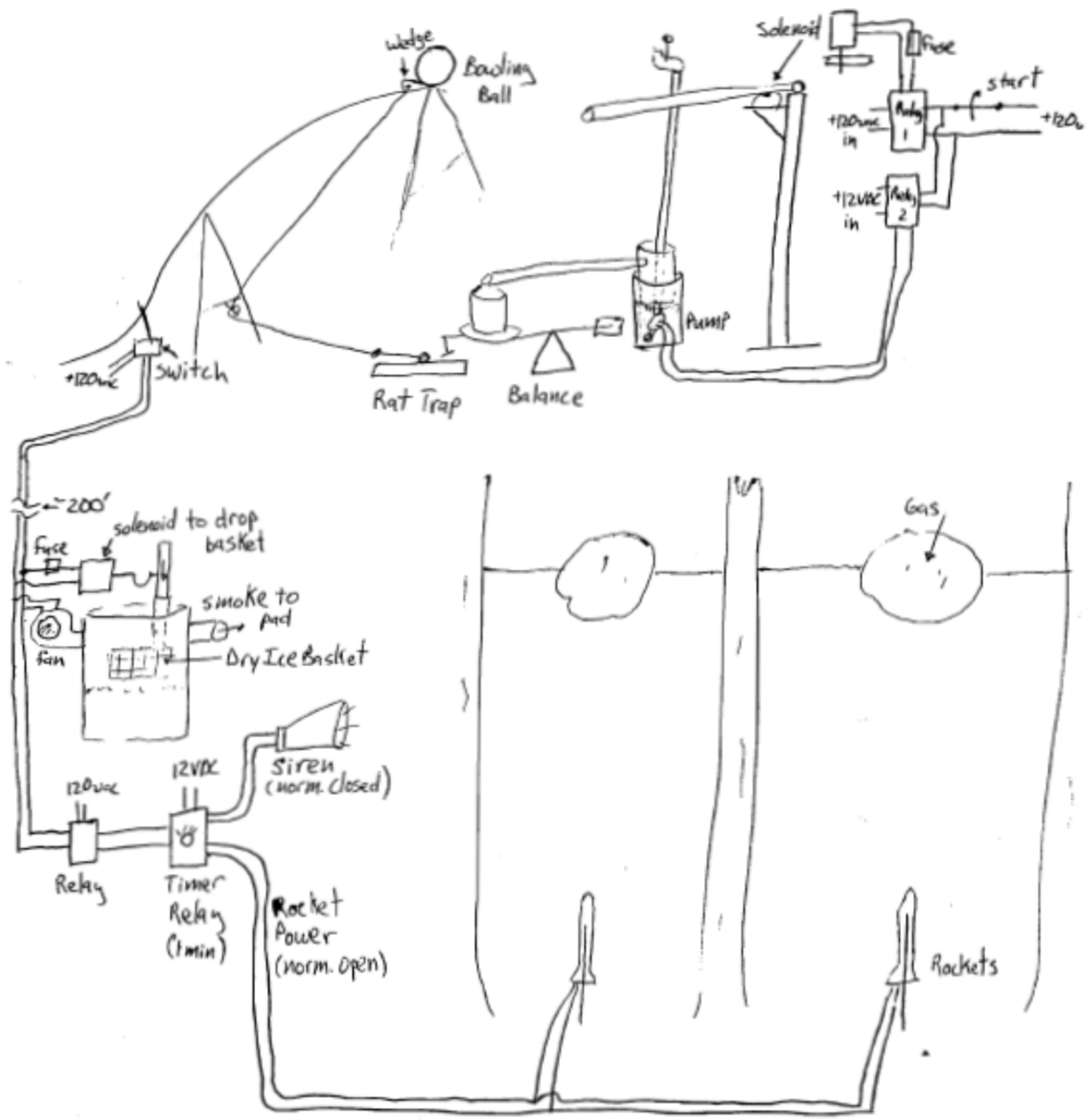
Appendix A (Cont.): Sample Proposal Sketch #3



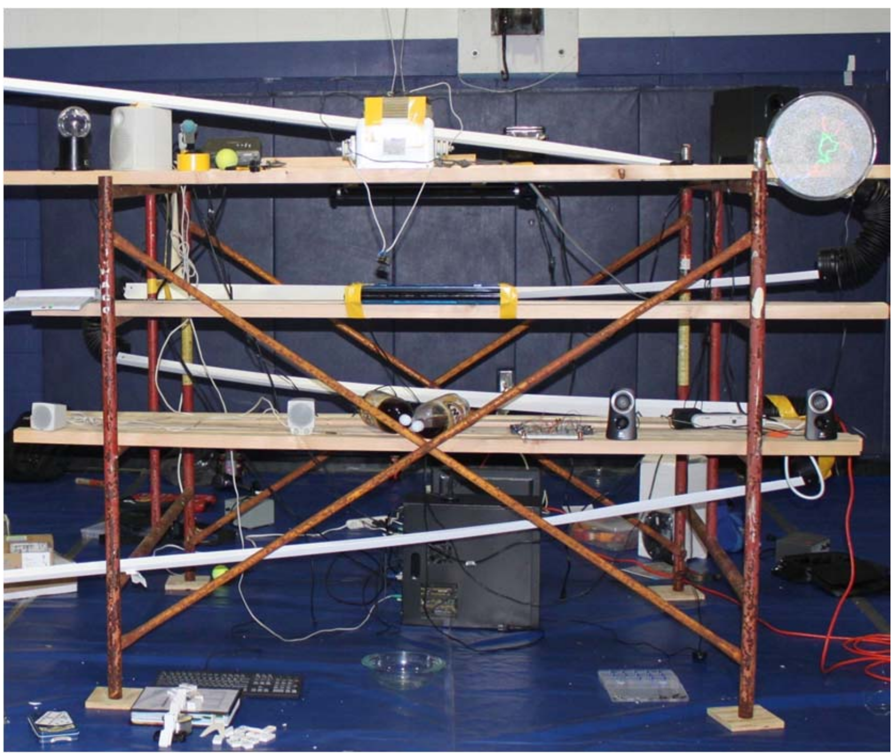
Appendix A (Cont.): Sample Proposal Sketch #4

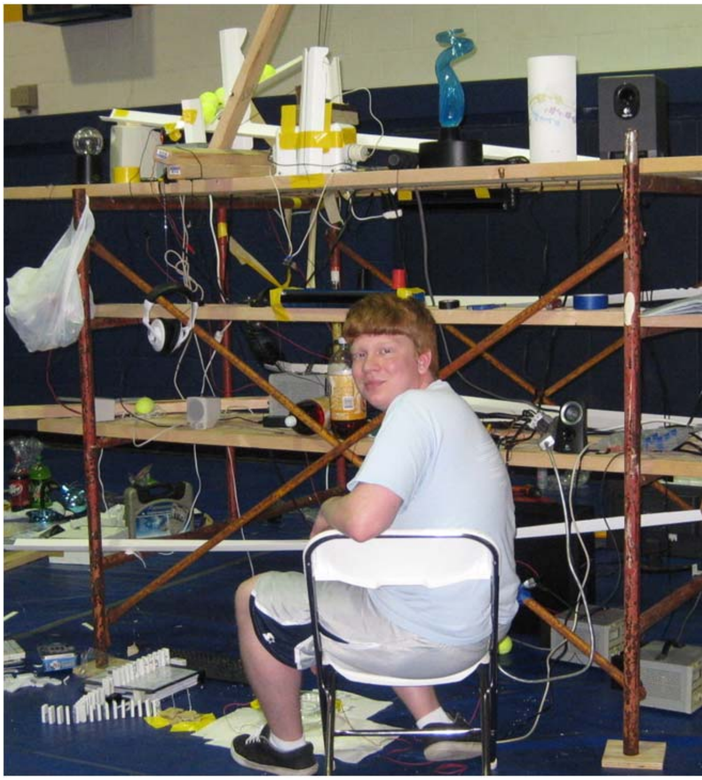


Appendix A (Cont.): Sample Proposal Sketch #5: Meteor Defense System



Appendix B: Sample Rube Goldberg Project Photos





Appendix C: Sample Rube Goldberg Project Assignment

1. **The Proposal:** should be at least 1 page, double spaced, typed, with another page for a diagram. Give an account of the steps to be used. Use proper English. Each person gives a separate proposal.

2. **The Final Report Shall Include:**
(a) a description, step-by-step, of the process
(b) a diagram of the setup
(c) a description of what it actually did in the presentation (explain any interventions)

3. **There are 3 parts to the grade of the Goldberg:**
(a) The Proposal - worth 10 points
(b) The Presentation - worth 10 points

    - You will be responsible for crowd control. You may want to arrange chairs around your location, or use ropes or ribbons, to set a boundary so that people don't encroach on your space.

    - Make a place for the cameraman - make sure the video camera can "see" the action of your Goldberg. You will be able to get a copy of the video later from A.V. if you want.

    - You need to clean up your spot when you're done. Part of your grade depends on how well and quickly you clean up. Please don't stuff things into the waste cans in the assembly building - take the big stuff to the dumpster outside.

    - <u>**Both**</u> members of the team should be involved in presenting the project to the audience.

    - We have 8 minutes between presentations. The actual time for your project to proceed from start to finish (from the push of the button to the cheer of the crowd) should be about <u>3 minutes</u>. If you take a few minutes to explain it beforehand, that should leave enough time for the crowd to re-assemble at the next presentation.

    - Be aware of your audience. Part of this is showmanship, and "hamming-it-up" is encouraged. Keep it exciting for the audience; for instance, avoid long waits for a soldering iron to heat up and melt something.

    - Use a lot of <u>electrical</u> things such as motors, light or sound detectors, or switches. If it is all <u>mechanical</u>, it is not too good. You can use this as an opportunity to build modules, for which you can get points later. I am on the lookout for <u>new</u> things. This is supposed to exercise your <u>creativity</u> muscles.

   (c) The Final Report - worth 10 points

4. **Assorted other ideas:**

   - We might consider putting a mock-up Goldberg on video so the audience could follow all the action at close range such as in the beginning of "Back to the Future" or the middle of "The Great Mouse Detective".

Appendix D: Sample Rube Goldberg Project Grading Rubric

Grading criteria include: Creativity, Complexity, Explanation of individual units, and Difficulty.

The Rube Goldberg project is 30 points (9.5% of the final course grade.)

(1) 10 pts Machine Proposal
(2) 10 pts Final Report
(3) 10 pts Public Machine Demonstration with Presentation

Item #3 "Public Machine Demonstration with Presentation" is sub-divided as follows:

Complication
Innovation
Works? (Minus ¼ point for each human intervention.)
(**U**) Clean up – slackers who leave a mess or don't exhibit teamwork lose points.

BONUS: Extra "artistic panache" gains up to 20%.

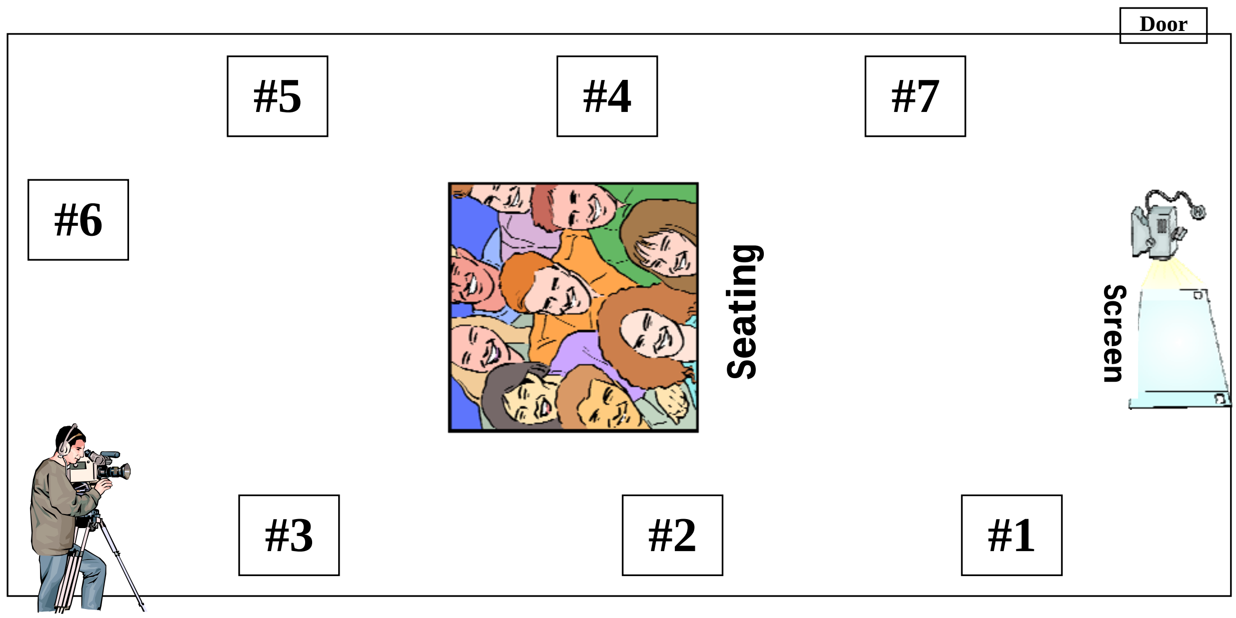
ELECTRICAL REQUIREMENT: Up to 30% is subtracted for omitting a motor, or not using very many electrical transitions (since this is supposed to be an electrical engineering course.)

Appendix E: Sample Rube Goldberg Publicity Flyer

LeTourneau University

2010 RUBE GOLDBERG

Thursday, April 1, 4:00 p.m. – Belcher Gymnasium/Solheim Center



4:00 p.m.	#1	*"Paperwad Disposal"* – James Frank, Tom Kelley, Paul Manley
4:10 p.m.	#2	*"Coffee for Two"* – John Khoury, Matthew Libby
4:20 p.m.	#3	*"Not Yet"* – Anna Bouchard, Jeffrey Lubin, Taylor Schwarting
4:30 p.m.	#4	*"Driver's License"* – Zach Jones, Joshua Veague
4:40 p.m.	#5	*"Murphy's Fist"* – Craig (Grey) Hawthorne, David Bevan
4:50 p.m.	#6	*"Disco"* – Rusty Goldsmith, Micah Martin
5:00 p.m.	#7	*"Clueless"* – Jim Brewer, Jonathan Campbell

We ask that all who are not participants in the show to be seated in the center section of the auditorium. **Please do not stand**, as that obstructs the view of others in the audience.

The action will be followed by a video camera and projected on the screens as the show progresses. As soon as one presentation is finished, the next one will begin. Each will probably take about 5 to 10 minutes.

The presentations will begin as soon after 4:00 as possible. Presentation times are only estimates.

Appendix F: Some Common (and Uncommon) Energy Transitions Over the Years

- Dominoes
- Rolling balls
- Programmed robots
- Tesla coil- causes fluorescent tube to glow- turns on photosensor
- Salt into water to produce a conduction path
- Jacob’s ladder cuts a string
- Rocket –used to burn string or carry action to next step (no longer allowed)
- Electric train
- Knife swings to cut string
- Cell phone calls another phone
- Automatic baseball pitcher throws baseballs at cart to push it to new position
- Marbles run down a track
- Electric motor pulls string
- Magnetic cannon or slow rail gun moves action to next point
- Hair spray and fire to cut string (no longer allowed)
- Sound detector to close switch
- Mousetrap used as switch
- Sound detector to close switch
- Switch frozen in ice, activated by hair dryer
- Microwave link activated by draining water from container between horns
- Tables used as dominoes (no longer allowed)
- Overheated resistor used to break string
- Electronic switches
- Solenoid switches
- Electrically operated soft-pellet machine gun used to cut paper in two, dropping a weight
- Pneumatic tennis ball cannon
- Artificial blood pumped from glove/fake hand soaking tissue paper such that it weakened and dropped a weight.
- Plumb bob dropped onto balloon to burst it.
- Spandex tension device (underwear elastic) pulled on string.
- Circular saw cut through copper wire, opening a circuit.
- Carpenter’s nail gun shot a nail into a balloon.
- Sledge hammer smashes window
- Bowling ball on rope smashes a television screen
- Potato gun knocks over automobile hood, which closes switch

Appendix G: Memorable Rube Goldberg Events over the Decades, Continued

Turmoil in the Toolroom (1992): The objective was to drop bandages for a carpenter who has cut himself with a saber saw, spurting blood onto the toilet tissue which weakened and broke thus beginning the chain reaction. A sketch is provided in Appendix A.

Robot Wars (1992 & 93): Students may do this instead of a Rube Goldberg. One team built two remote controlled robots which could shoot a hockey puck; they then played each other in a game of hockey on the assembly room floor. Another team built larger robots, armed with hooks to be used to upset or disable their opponent robots, which fought to the finish before the audience.

1994: "Pad Pandemonium", was a presentation with lights, music, and smoke which was generated by two people (one of which happened to be the first author's daughter) dancing on dance pads - this received front-page coverage in the local newspaper. The music and lights were actually generated by the dance pads, so that the dancers produced the effects. This predated the modern "Dance Dance Revolution" (DDR) video game, which differs slightly in that DDR dancers follow scripted dance moves and music provided by the video game, whereas in this project, the dancers create the music through how they dance. The whole presentation required a team of six students. "Pad Pandemonium" was the last of six presentations, The others being entitled "Couch Potato Assist Device", "Snake Feeder", "Automated Pooch Grubber and Security System", "Surprise", and "Alarm Clock". Sixteen students presented.

1995: This year the Rube Goldberg presentation was put in the ATP building, because the assembly building was not available on the proposed presentation day. We were allowed to present it in a building which was being used for storage, designated ATP. This contained a lot of junk, some of which was available to use in the projects but most of which was simply in the way of observers, who moved around in crowds through the building as the various presentations occurred. There were nine groups presenting - two students in each. One of the presentations used a skeleton borrowed from the Biology lab. The climactic group, deemed "The Meteor Shower Defense System", finished in a huge explosion after a loud alarm system warning of the supposed meteor and simultaneous "clear the area" signal preceded the launching of a rocket into a suspended plastic bag hanging from a tree which contained oxygen and acetylene. A new rule was made that this mixture not be used in future Rube Goldbergs. One of the members of that team is now teaching engineering at another university. The students were gratified to find their presentations lauded in the city newspaper the next day. By this time, the news media was becoming a regular occurrence at Rube Goldberg presentations.

2000: This presentation was embarrassing for me. The next –to-last presentation, entitled "The Nothing Machine", was a device to supposedly remove a cat from a tree. The final step was the ignition of a combination of hydrogen and oxygen in a plastic milk jug, which had been obtained by electrolysis of water. The jug was set in a tree outside the assembly building, and when the explosion occurred, the head of security happened to be close by. He stormed into the assembly building and loudly asked who was in charge of this event – and that was me. I was strongly rebuked, and deserved it, since I had not made sure the students had alerted the authorities that there was to be an explosion that day. No more explosions are allowed in future Rube

Goldbergs. The student who had engineered that explosion graduated and became a rocket scientist, putting up satellites, and now builds submarine drones.

The campus newspaper reported that “despite the security department’s displeasure at this unauthorized explosion, the project was a success”.

2005: At this point in Rube Goldberg project history, a basic modification was made in the presentation format. In previous years, observers were allowed to roam around the assembly building and crowd around the groups giving the presentations. This time, seats were arranged in the center of the auditorium, and the campus audio-visual team was employed to tape the presentations as they proceeded, simultaneously showing them on two screens for the audience to view. This procedure was followed in all the future years.

2009: Due to the fact that the assembly building was being modified this year, we had to put the presentation in a building used by the Auto Society, a group of students who worked on their vehicles in a remote corner of campus. The area available was much smaller than in previous years, with a result that much of the action could not be seen by many of those attending. One of the results of this fiasco, however, was that we were allowed to use the gymnasium in the following year.

2010: The most recent year of Rube Goldberg included seven groups with 16 students, presenting their machines to one of the largest audiences in our history. This was fortuitous, since the gymnasium had the largest area we had ever had access to.

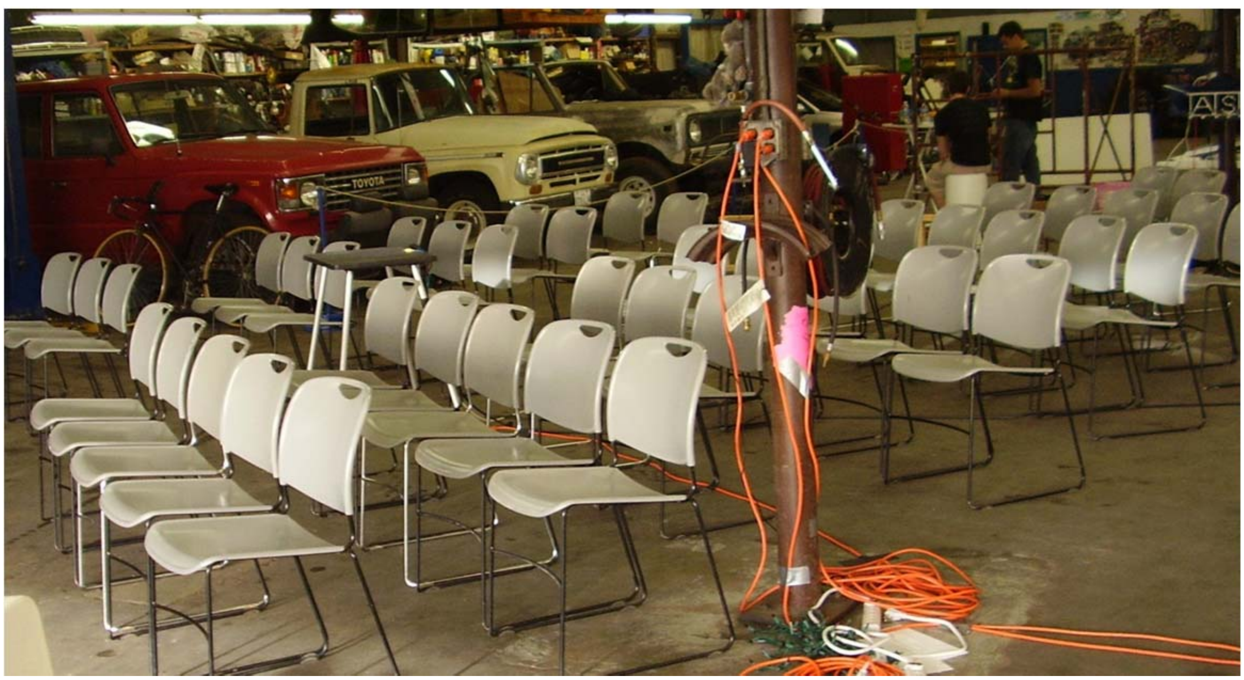


Figure 7: Due to Renovations the 2009 Demonstration was Cramped into the Auto Society Building

Sailing Simulator: Once initiated by a hand-clap, a sound-activated relay closes, starting an electric motor, which runs a generator, starting a second motor. This motor lifts a magnet up to a magnetic reed switch, energizing a relay which opens the circuit powering the first motor and simultaneously starting a tape recording of an appropriate song (“Sail On”) and starting a fan, which blows a toy sailboat into the path of a laser beam, activating a photocell – governed time delay circuit. After an appropriate delay, this activates a solid-state relay which turns on a second tape player with an appropriate concluding message. The whole chain of events takes about 30 seconds.

Candle Lighter: A pendulum is released and swings a magnet back and forth through a coil. The voltage produced is amplified and fed to a counter circuit, which counts a specified number of pulses and closes a relay. This turns on a light, activating a photocell, which lights a match. The match in turn lights a candle.

Figure 8 itemizes a sampling of size fluctuations over the years.

Year	# Teams	# Students	Location
1994	6	16	Assembly Bldg.
1995	9	18	ATP Bldg.
1996	13	26	Assembly Bldg.
1997	5	9	‘ ‘
1998	7	15	‘ ‘
1999	7	13	‘ ‘
2000	6	12	‘ ‘
2001	6	14	‘ ‘
2002	9	17	‘ ‘
2003	5	11	‘ ‘
2004	6	13	‘ ‘
2005	3	8	‘ ‘
2006	4	8	‘ ‘
2007	3	9	‘ ‘
2008	4	11	‘ ‘
2009	7	16	Auto Society Bldg.
2010	7	16	Gym

Figure 8: Sampling of Size Fluctuations over the Years