# The Rube Goldberg Three-Minute Timer: A Design Based Learning Tool For Engineering Freshman

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## Introduction

Rube Goldberg: a man whose name has become synonymous with using convoluted, complicated machines to perform simple tasks. Engineer: among other things, one who designs machines and systems to make difficult, complicated tasks simple. Although the goal of Rube Goldberg's machines and the goal of the engineer's machines may seem quite at odds, the two fit quite well together as a design project in an introduction to engineering class. In fact, freshman engineering students at Youngstown State University are given their first exposure to the design process via a four-week Rube Goldberg project. The project requires the students to design a machine, Rube Goldberg style, which will time three minutes as close as possible without going over. The original intent of this Rube Goldberg machine was to time the hard-boiling of an egg.

The idea of design in freshman engineering classes certainly is not new. For that matter the use of Rube Goldberg type designs in engineering education is not either. However, in this project, for the entire four weeks, the project was used as a springboard for the lecture topics. This allowed for all aspects of the design process to be addressed, from the first brainstorming session to a prototype machine to the final technical design report. Through the process, the students discover first hand how the application of math and science principals fits into engineering design as well as how to systematically complete a design at a level fitting of an engineer. The project, as will be explained in detail, culminates with two main components: the actual building and timing of the machine and the final design report.

## Course Information

This project is part of a first semester freshman engineering course at Youngstown State University. The three semester hour course is comprised of two lecture hours and three laboratory hours per week. The project is presented, explained, and discussed in the lecture setting. However, questions that arise because of the project are addressed in the laboratory or the lecture. Prior to the project, the students have received instruction and completed exercises on web searches, web page construction, and word processing with equation editor. Concurrent with the project, students receive instruction on MS EXCEL in the lab. The completed project draws from the skills taught in both the lecture and the lab setting. In addition to this course, the typical student is taking pre-calculus or calculus I along with other first year basic courses. However, the large majority of students have not yet taken college physics.

Project Stage One – Introduction to Team Projects

The project begins with a brief introduction in class using a standard project assignment sheet. The students are informed of the guidelines of the project, of the grading parameters, and of the project timetable. Two mandatory web searches, one on Rube Goldberg and one on the history of timers, are assigned. The students had already been given instruction on performing effective web searches in the course's accompanying computer lab class. Class time is taken to discuss the importance of preliminary background research when starting a new design/research project. Therefore, not only does this assignment reinforce a previously learned skill, but also it shows the students how to get a foundation upon which to start their project.

The project is a group venture with teams consisting of four members each. The students are allowed to form their own teams. However, since it is introduced the second week of class, many students need assistance forming full teams. This causes the vast majority of teams to consist of members who have no prior interaction with each other. To add to this, Youngstown State is predominately a commuter university, making it difficult to form teams in which the students have similar schedules outside of class. Therefore, class time is taken to discuss team dynamics using the Tuckman Model[1]. This is done with the intention that by being exposed to the pros and cons of teamwork and to the evolution that teamwork follows, unproductive team dynamics will be minimized.

With this basis, each week, the teams are required to complete a Tuckman-based questionnaire[2] to help them assess at which stage of teamwork their group currently lies. The goal of this is to give a tool to the groups to help them quickly identify, address, and correct teamwork problems. Instructor intervention is available when their abilities to cooperate are exhausted.

The third portion of stage one is the introduction of the design process. A brief introduction is given on the entire process as broken into six steps: 1) Problem Identification 2) Preliminary Ideas 3) Refinement 4) Analysis 5) Decision 6) Implementation. This is done with the intention of relating to the students that there is a methodical approach to design and problem solving that doesn't rule out creativity. The first two steps are then discussed in detail. Time is also given in class for the teams to conduct an initial brain storming session. The rest of the steps are discussed in detail when the time is appropriate.

Project Stage Two – Introduction of Mathematical Modeling

Although the final design of the timers is up to each individual group, the teams are required to include one of three events into their machine. They could include a lever, a funnel, or a ball rolling down an incline. The requirement is a springboard for the students to then be instructed in the analysis portion of machine design. It also shows them how engineers use mathematical formulas to model physical occurrences and to predict certain outcomes. This proves to be very powerful as the students grasp this portion of engineering at a very early stage in their education.

If a group chooses to include a lever in their machine, they must theoretically determine to what height a cup must be filled with the material of their choosing to cause the lever to shift. First, the students are shown how, by using principles and equations of levers, to theoretically determine the weight needed on the high end of the lever to cause it to tip. From this, they are shown how to determine the volume of material, based on its density, needed to accomplish the lever shift. The groups using the lever are required to experimentally determine the actual volume needed and to investigate and discuss any discrepancies.

If a group chooses to use a funnel in their machine, they are required to find the time it takes to fill a cup to a certain height. The students are instructed in the application of Bernoulli's equation to find the velocity of the fluid exiting the funnel. From this they are shown how to use the velocity and the exit diameter to find the flow rate. Knowing the desired height, the students are instructed in the relationship between volume, flow rate and time so that ultimately the time can be predicted. Just as with the lever, the groups using the funnel are required to experimentally determine the actual time required and investigate and discuss any discrepancies.

Lastly, the groups that choose to use an incline plane are required to predict the time in takes for the ball to reach the bottom of the incline. The students are presented the general equation for the Conservation of Energy, which virtually all are familiar with. They then are instructed in the appropriate formulas for the gravitational potential energy, the translational kinetic energy, and the rotational kinetic energy. They are shown how manipulating these formulas enables the determination of the velocity at the bottom of the incline. The students are then introduced to the equations of motion for constant acceleration so that they can see how to determine the time of travel of the ball. Once again, the group using the incline must determine this time experimentally and investigate and discuss any discrepancies.

This stage of the project proved to be the most difficult for the students. Originally, the equations were presented to the students in lecture form as they might see in a dynamics or fluids class. Much confusion ensued. Surprisingly, the vast majority of them had never applied even simple mathematical formulas to model physical phenomenon and very few are taking college physics. To make matters worse, the students, regardless of which event they chose to include in their machine, were responsible for understanding the application of all three events. To aid in understanding, a small experiment of each event is brought in, and the equations are re-presented and discussed as they occur in the experiment. For example, when explaining the application of Bernoulli's equation, two funnels were brought in, identical to each except for the diameter of the exit hole. After the equation was written on the board and water was added to one of the funnels, the students could then visually see why the pressure terms cancelled out and why the velocity of the liquid at the top of the funnel could be approximated as zero. They then could understand how to algebraically solve for the exit velocity of the liquid. The students realized, much to their surprise, that the velocity of the exiting liquid did not depend on the diameter of the exit hole. It was at this point that both funnels were filled to the same height so that the concept of flow rate and how it depended on the exit diameter could be discussed. This technique greatly improved the students understanding of the connection between the formulas and the actual events.

Student Handout
The following is the handout given to the students at the beginning of the project. The students are warned that the handout is not a comprehensive list of what is required in the project and report, but rather a guideline to help get them started.

Engineering 1550
Design Project #1
Rube Goldberg Timer

OBJECTIVE:
The objective of this project is to design a machine that will time three minutes as close as possible without going over. The original intent of this Rube Goldberg machine was to time the hard-boiling of an egg.

MATERIALS:
- Total material cost to build the machine is limited to $10.00
- Any material you find lying around the house, basement, etc. is considered free.
- No commercially available timers, i.e. sand hourglass, are allowed.
- No electricity or compressed air may be used.

DUE DATE:
Machines will be tested and timed on October 2nd and October 4th in the lecture. A stopwatch will be used that measures to a tenth of a second. Times will be rounded to the nearest second.

DESIGN CONDITIONS:
- The machine must have a defined start and finish that can be seen or heard (other than a team members voice) for timing purposes.
- The machine must be able to perform multiple trials. Replacement of consumed parts is permitted.
- The machine must perform at least four unique events during the course of the three minutes.

COMPETITION:
You must come to class with minimal set up time required, ready to time your machine. Each team will be given two trials to time three minutes without going over. The better of the two times will be used for the competition. The team closest to 3:00 without going over is the winner of the competition. In the event of a tie, the winning team will be determined by the best second time of the two teams. In the event that there is still a tie, the winning team will be the team with the most unique events. Competition Points will be awarded as follows:

| Time | Points |
|---|---|
| 2:56 to 3:00 | 100 |
| 2:51 to 2:55 | 95 |
| 2:46 to 2:50 | 90 |
| 2:41 to 2:45 | 85 |
| 2:36 to 2:40 | 80 |
| 2:31 to 2:35 | 75 |

etc, etc, etc

REPORT REQUIREMENTS:
A report must be submitted one week after your machine is timed. The report must be written in Microsoft Word and include, among other items, the following:

- Cover/title page with project title, group name, and group members
- Table of contents, list of figures, and appendix if appropriate
- Comprehensive introduction, body, and conclusion as discussed in class.
- EXCEL chart of a work time line
- Theoretical prediction and experimental result of a required event
- List of machine parts and their cost
- Written description of machine
- Sketch and picture of machine
- Time sheet from the competition

FINAL GRADE:
The final grade given to a team will apply to all team members.
Grading will be comprised of two parts:

1) Competition points
2) Report and professionalism grade

Each part will make up 50% of your final grade for design project #1. Your team can get up to 10 bonus points for tasks your machine performs over the required four. One point awarded for each additional, unique task.

QUESTIONS:
I will be happy to answer any questions in the lecture class. However, you can also email questions to me at hmpierson@eng.ysu.edu

Please don't wait till the last minute to do this, it isn't as easy as you might think.

GOOD LUCK !!!

Project Stage Three – Introduction of Technical Reports

Stage three of the project is dedicated to technical report writing. Past experience with using this project has show that the students are particularly ill prepared in generating a logical, structured technical report. Therefore, much structure is given as to what would be expected in the report while leaving it up to the individual teams as to how they would accomplish this. For example, an EXCEL chart showing the hours spent on various tasks of the project is required. Some teams used a pie chart, while others used bar charts, column charts, etc. Also, some teams showed their time on each task as a percentage of the total project time, while others presented the actual hours. Furthermore, some had a chart for each day they met; others compiled all days into one total. The following is the structure of what is presented to and then required of the students.

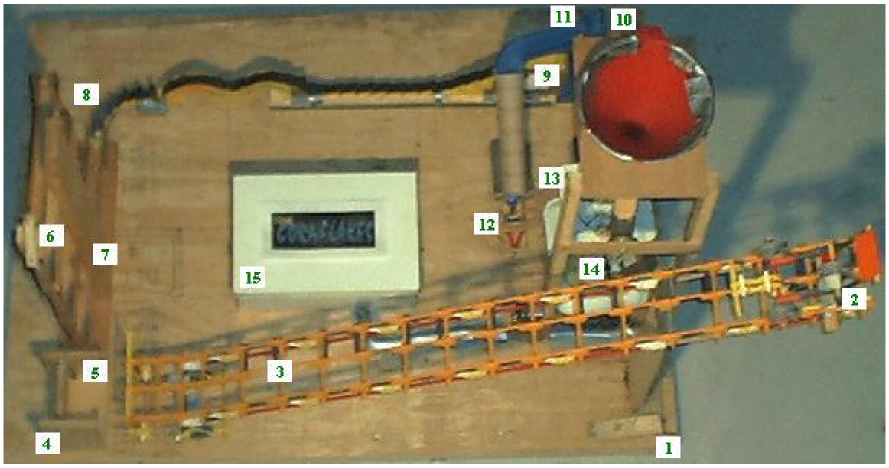
The students are first presented an overview of technical report writing. Comparisons are made to other types of writing so that they can see the importance of presenting technical data and information in a structured, organized fashion. The major components, 1) Introduction 2) Report Body and 3) Conclusion, are discussed in general. Once the students understand what their report should accomplish, a structured list of what is expected can be given.

A cover/title page, with the project title, group name, and group members listed on it, is discussed. Good examples from previous years are shown. The creativity on these title pages never ceases to be amazing. For example, some project titles from this previous fall were "Operation: Don't Burn the Egg", "If You Didn't Have a Watch", and "1st Down & 3 Minutes To Go". Another was named "Acini de Pepe" in honor of the type of macaroni used in their machine. Group names included the usual "A-Team" but also "The Sons of Rube", "YSU Timeseekers", and "The Chrome Magnums". One team called themselves "Team Duct Tape" because of, as they said, the enormous amount of duct tape used in their machine. The artwork of the covers is equally impressive, with many teams displaying digital pictures of their final machines or an original Rube Goldberg machine.

Next, the necessity for a table of contents and a list of figures is discussed; with the individual groups deciding if they need one. An appendix is also discussed at this time, and examples of what should go in their appendix, such as a hand sketch of their machine, instead of in the report, are presented.

Required in the report introduction is the background research on Rube Goldberg and timers, project objective, scope/requirements/limitations, procedures and methodologies. Particular class time is spent on what constitutes an unambiguous, accurate project objective and scope as opposed to poor, vague ones. Included in this section of their report are the results of brainstorming sessions, therefore, instruction on the art of effective brainstorming is given in the lecture and class time is allotted for their first session. Flow charts of meetings, and step-by-step information of what was done on the project from inception to completion are also part of the report introduction. Poorly written and appropriately written examples are presented to the students in the lecture and a discussion is launched as to the differences between them.

Sections required in the body of the report include the theoretical/analytical background, the project description, the product development, assembly-testing information, and a discussion. The theoretical/analytical portion is the section where the students are to present their theoretical prediction and their experimental result of one of the three required events. All the formulas are to be developed, as well as a complete description of the corresponding experiment, in a manner fitting of an advanced research project. In the project description portion, the physical description, including materials and price lists, of the final machine is presented. Also in this portion, a detailed step-by-step explanation of how the machine works is required. Figure 1 shows an example of this from one group report. The students took a digital picture of their machine from a top view. They then altered the picture by adding numbers to the various events included in the machine. These numbers corresponded to a written explanation. The result was a very effective presentation of how their machine worked.




1. Machine begins by pushing a lever that is attached to a string.
2. This then releases a spring-loaded pin attached to the roller coaster.
3. From there the roller coaster is sent zooming down the track.
4. The roller coaster hits a trap door at the bottom of the ramp.
5. The trap door drops a weight attached to a string.
6. This pulls an arm at the top of the first marble ramp up.
7. The marbles are then set free to roll down the ramp.
8. Once the marbles have reached the bottom of the ramp they knock down dominoes.
9. The last domino hits another marble that rolls down a smaller ramp.
10. Marble hits a trigger at the bottom of a tower that is attached to a weight at the top of a tower.
11. The weight pulls the trigger up and knocks a bigger patriotic marble down a tube.
12. This bigger patriotic marble sets off a mousetrap.
13. The mousetrap releases a hanging door that allows sand to run out of the funnel.
14. Once there is enough sand on the scale the needle on the scale closes an electrical circuit.
15. This finally sets off the car alarm to end the 3:00 minute timer.

Figure 1 – Example of Report Machine Description

The product development portion includes the steps that were taken to build the machine as well as the problems that were encountered and corrected. The assembly-testing portion highlights the tests that were conducted, what was learned from them, and how corrections were made. Finally, the discussion portion is to include what was achieved, the knowledge that was gained, shortcomings of the final design, and reasons for those shortcomings. The discussion section proved to be a helpful indicator as to the effectiveness of the entire project. This is a place for the groups to summarize what they achieved. Statements from final reports include "…learned to work more effectively as a group…" and "…now have a better understanding of engineering principles". Some statements concerning the knowledge they gained include "…many simple machines are vital to the working success of a more complex machine…", "…there are so many different ways to accomplish the same task", and "…understand the idea of modeling the physical world."

The conclusion of the report must include discussion in three areas. First the students are to report on the extent to which their group met the objective outlined in the introduction. Second, they are to propose and recommend design improvements to their design. Lastly, they are to recommend new lines of study; to suggest where ideas contained within their work could be applied elsewhere. One group suggested "using Rube Goldberg's machines to tee off a ball or turn on a light." The students know, however, that this section is more useful in real life research projects. So, during the lecture on this portion, more meaningful examples were presented to show how important and powerful a conclusion could be.

Project Stage Four – The Machine Design

The students are given very few constraints in the design of their timer. There is a ten dollar limit on material costs, but any recycled item, old toy, etc. is considered free. No commercially available timers are allowed. The machine must perform a minimum of four unique events in the course of three minutes. It must have a clearly defined start and finish time that can be seen or heard. Once the timer starts, there may be no human intervention.

The students must design, build, and test their machines. The students bring their timers to school to see which team can most accurately time three minutes. It is quite exciting to see the halls lined with Rube Goldberg machines; all built for the same purpose, yet no two even remotely alike. To add to the excitement, there is a design competition. The members of the winning group all receive Youngstown State shirts for their efforts. After the students tweak their machines, two official times are taken using a stopwatch. Sirens and alarms can be heard, balloons popping, bells ringing, mousetraps snapping, bulbs lighting, and more as machines finish the three minutes. The winning team is the one whose best time comes closest to three minutes without going over. If there is a tie, the second time determines the winner. If there is still a tie, the group with the most unique events is crowned the winner. This past fall, two teams timed three minutes, twice. The winner out of these two teams had a design with 17 unique events….the most out of the entire 44 teams!

All the various disciplines of engineering end up being represented in the machines. There are simple machines, trusses, circuits, chemical reactions, levers, and ramps, to name a few. One group that was made up of students planning to enter the Chemical Engineering program had a Quick Dissolve Benadryl™ tablet at the bottom of a ramp. Water trickled down the ramp, dissolving the tablet to set off another event. The students in this group informed the class that the Benadryl™ tablet dissolved at a very precise rate, hardly changing within a reasonable temperature range. The machine previously shown in Figure 1, constructed by a group of intended Electrical Engineering majors, completed a circuit to set off a car alarm using the needle from a scale. Another team had steel balls push a piece of copper against a piece of steel to complete a circuit. Many groups used levers and dominoes as a transfer between events. The favorite seemed to be setting off mousetraps to pull strings in order to start a new event. Another machine used a series of pulleys to reduce the force needed to send a tiny American flag up a miniature flagpole. When the flag reached the top, it rang a bell signifying the end of the timing. These were just a few of the numerous examples of engineering concepts that are present in the machines. Therefore, at the conclusion of the project, a day is taken to further discuss the principles of science that were drawn upon in the making of the machines.

## Conclusion

The Rube Goldberg project is ideal as a design-based learning tool for freshman engineering students. At the end of the four-week project, the students have learned all the aspects necessary to conduct and report a comprehensive design project. In addition, the students get their first taste at being an engineer. The project provides the students comfort to utilize physical world knowledge that they already possess, such as funnel action. On the other hand, it challenges the students by requiring them to now scientifically identify and properly model these physical world occurrences. It also gives a practical application to the computer skills they are simultaneously learning in their lab classes. In addition to this, the students learn the pros and cons of teamwork, develop lasting friendships, and have a lot of fun while working the many hours building and analyzing their machines.

Bibliography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