The Rube Goldberg Experiment: Year 2

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Abstract

As a follow-up to our previous paper on the successes and limitations of using Rube Goldberg machines in a first year engineering design course, in this paper, we outline how we addressed some of the limitations from our first attempt to use Rube Goldberg machines in our course. As pointed out in our previous paper, the first year engineering curriculums of many engineering programs are heavily loaded with science classes and have very little exposure to engineering. Engineering schools must find ways to introduce students to engineering in a fun, engaging fashion. For the past two years, we have been using Rube Goldberg machines to help achieve this goal. Our first year design and communications course attempts to engage students by challenging them to design and build a working Rube Goldberg machine as part of a group project. By working to achieve specific design goals that are subject to constraints, students get to work on a mini-engineering project that is fun, creative, and challenging. The long-term goal of the Rube Goldberg Experiment is twofold: (1) to give first year engineering students a positive engineering design experience in their very first semester and (2) to develop a culture of anticipation in Grade 12 students who might be considering an engineering education at the University of Regina. In this paper, we outline changes made to our approach that address shortcomings identified from our first semester and provide results from student feedback, which demonstrate a positive response to the project.

1 Introduction

Last year, we reported on our initiative to change the first-year engineering design and communications course at the University of Regina and make it a more inspiring, hands-on learning experience [1]. At that time, we felt that the utilization of Rube Goldberg machines was an effective method for teaching engineering design in first year, but we had identified areas for improvement. Additionally, we had nothing besides anecdotal data to suggest students enjoyed the

projects. Therefore, in our second semester, we made an effort to improve the management of the course and collect concrete feedback from the students. This paper discusses strategies for offering Rube Goldberg machine design projects in engineering curriculums and presents data that shows that the vast majority of students enjoy this type of project.

1.1 A Note on Curriculum Changes

Rube Goldberg machines were first used in the Winter 2009 semester in ENGG 113 (Engineering Communications and Design). The faculty then underwent a curriculum change that resulted in this course being renamed and moved to the fall semester. As a result, Rube Goldberg machines were used for a second time in the Fall 2009 semester in ENGG 123, (Engineering Design and Communications). This course is currently taught with two instructors who also handle the laboratory portion of the class.

2 ENGG 123

This class combines engineering design strategies with project management skills and technical communications. Lectures are based on the material presented in Dym and Little [2]. The fall class had roughly 200 students that were divided into 35 groups of five and six members. Each group was required to design, build, and demonstrate the successful operation of a Rube Goldberg machine. Their work had to be documented in a formal report and be presented to the class at the end of the semester.

2.1 Rube Goldberg Projects

Six differently-themed Rube Goldberg projects were randomly assigned to the 35 groups. Table 1 outlines the themes used in the Fall 2009 semester. Each theme had a primary task, starting action, and six sub-goals that needed to be achieved in order for their machine to be considered complete. The themes and sub-goals were carefully selected in order to provide challenging but fun Rube Goldberg projects. Groups were encouraged to be creative with their interpretations of the project sub-goals.

Table 1. ENGG 123 Rube Goldberg Projects – Fall 2009

Theme 1	Indiana Jones
Primary Task	Rescue Indy's hat.
Start Action	Replace a Golden Idol with a bag of sand.
Sub-Goals	<ul style="list-style-type: none"> • Indy escapes from a giant rolling boulder. • Tribal warriors shoot five poisoned darts at Indy (a distance of 50 cm). • The Ark opens and destroys the Nazis. • Indy falls into a pit of snakes and escapes. • Kill a bad guy with a plane propeller. • Indy shoots a cocky swordsman.
Theme 2	Winter Olympics
Primary Task	Raise a Canadian flag and play the national anthem.
Start Action	Light the Olympic flame.
Sub-Goals	<ul style="list-style-type: none"> • Send a bobsled down a track with at least three 90° curves. • Bury a Loonie under the arena ice. • Launch a ski jumper 100 cm. • Curl a rock to the button down the ice (a distance of 50 cm). • Shoot at least three of five biathlon targets. • Hang a gold medal around a Canadian athlete's neck.
Theme 3	Harry Potter
Primary Task	Catch the Snitch (the Snitch must fly 50 cm).
Start Action	Harry dramatically escapes from the Dursleys.
Sub-Goals	<ul style="list-style-type: none"> • Steal a golden egg from a Hungarian Horntail dragon. • Crash a flying car into the Whomping Willow. • Knock out a troll with a club. • Blow up Aunt Marge. • Have an Owl drop off the post. • Ride the Hogwarts Express
Theme 4	Pirates of the Caribbean
Primary Task	Bury a treasure chest.
Start Action	Launch a boat.
Sub-Goals	<ul style="list-style-type: none"> • Raise a pirate flag on a boat mast. • Attack a ship with a giant squid. • Rescue Jack Sparrow from being stranded on a deserted island. • Empty at least one bottle of rum. • Fire three cannon balls a distance of 50 cm at an enemy ship. • Make a hostage walk the plank.
Theme 5	Ghostbusters
Primary Task	Capture Slimer.
Start Action	Call Ghostbusters.
Sub-Goals	<ul style="list-style-type: none"> • Make three ghosts appear (can appear separately). • Drive the Ghostbusters car out of their headquarters. • Slime Venkman. • Melt the Stay Puft Marshmallow Man. • Fire a Proton Pack electron beam at Vigo the Carpathian. • Fill a 30 cm long sewer line with slime.
Theme 6	Natural Disasters
Primary Task	Rescue three survivors in a helicopter.
Start Action	Crash an asteroid into Earth.
Sub-Goals	<ul style="list-style-type: none"> • Block the Trans-Canada Highway in BC with a landslide (minimum of 30 cm). • Destroy the Hollywood sign with an earthquake. • Bury the U of R campus in snow and ice during a Saskatchewan blizzard. • Have a tornado in Kansas suck up Dorothy and Toto. • Melt the ice caps so that the rising ocean floods Florida. • Blow over a famous tall building with high winds.

2.1 Project Constraints

The Rube Goldberg projects were assigned with constraints in order to give each group a framework. While the use of constraints can limit creativity, they do help to prevent the projects from becoming unmanageable or too large and detailed. They also teach the students to work to constraints, which is essential in any engineering project. The constraints used for the Fall 2009 semester are listed below. These constraints were a modified version of those used in the Winter 2009 semester, as we had learned what did and did not work.

- a. Machine dimensions cannot exceed 8 feet long by 4 feet wide by 8 feet high.
- b. The project must be free standing.
- c. Hazardous materials/methods cannot be used without permission from the instructor.
- d. The machine run time must be at least 90 seconds, but cannot exceed 180 seconds.
- e. The machine must have at least 10 steps, with no individual step lasting longer than 15 seconds.
- f. All tasks must be completed in a distinct and sequential fashion. Parallel routes are allowed but tasks may not be executed simultaneously.
- g. Total spending on materials cannot exceed \$120.
- h. The Primary Task must be completed last.

Constraints d, e, and g were responses to identified shortcomings in the previous semester. In particular, the previous run time of 3 minutes resulted in many groups using long, boring steps, such as water draining, to increase their machine's run time. By reducing the run time to a minimum of 90 seconds and by limiting each step to 15 seconds, students were forced to be more creative about achieving their run times, making the machines more interesting.

2.2 Patents

In order to inject a bit of friendly competition into the design project, groups were given the opportunity to 'patent' innovative technologies or methods that they developed for any of their subtasks. Patents were only approved by the instructors if the method being proposed was truly unique. Groups that had a patent approved could prevent other groups from using that technology or method in their projects. Groups could also licence their patent to other groups if a licensing agreement could be negotiated. Patents were only valid in similarly-themed project categories.

Only one team applied for a patent in the Fall 2009 semester, but it was denied because the innovation was not extraordinary. In the Winter 2009 semester, two patents were applied for, one was approved and the other was rejected. In general, the use of patents is not

widespread throughout the course, but it does give groups an opportunity to protect their creativity and have some fun with the other groups.

3 Evaluation

The Rube Goldberg project accounted for 40% of the final grade in the course. This was composed of the project design or working machine (15%), a formal report (15%), and a presentation (10%). The grading categories for the project design and report are outlined in Table 2. The project design was graded based the functionality, complexity, and creativity, while the report was graded on its technical merit, description of design, and referencing. Several criteria were used to assist in grading the project design including the successful completion of tasks, clarity of design, and ease of fabrication. Extra credit was given when motion in the machine was achieved in a controlled fashion. Students were required to provide the following data in their report:

- Machine runtime (start action to final task).
- Machine re-set time.
- Number of iterations needed for a successful run.
- Repeatability
- A detailed list of parts and expenses.

Groups were also required to submit two videos. The first video was a walk-through of the machine that explained how it worked. The second video was to show a successful run of their machine. These videos were useful for grading because they made it possible to go back and make sure that the machine completed all of the required tasks. It also made it possible to assess the complexity of the machine and to make sure that all of the constraints were satisfied.

Table 2. Rube Goldberg Project Mark Distribution

Project Design (15%)	Project Report (15%)
Functionality (70%)	Technical (40%)
Complexity (20%)	Design Description (50%)
Creativity (10%)	References (10%)

The project report was given the same weighting as the project design because ENGG 123 also focuses on technical communications, an important aspect of the profession. Unfortunately, many engineering students struggle with writing, and the more practice they can get, the better chance they have of improving their skills. Reports were judged on whether they clearly communicated the design concept and methodology that was used. Groups were to explain the processes using technical language. The report was also expected to contain diagrams, an analysis of their project (with an emphasis on how each subtask and

constraint was met), and a conclusion that emphasized what was learned.

3.1 Project Presentations

Groups were required to deliver a fifteen minute presentation in front of the class to present their Rube Goldberg project. In the presentation, they were to explain and defend their design choices, discuss the selection of materials, outline their expenses, and show their machines in action, either by video or with a live demonstration. Groups had to answer questions from their classmates after the presentation, which became quite interesting since groups working on the same theme tended to be critical of each others' design choices. To ensure a reasonable attendance at all presentations, it was emphasized that questions from the presentations could appear on the final exam. Unfortunately this did not seem to be enough to convince everyone to sit in on all of the presentations as the attendance had dwindled to roughly one third of the class by the end of the presentations. Once again, few groups elected to give live demonstrations, but several brought parts of their machines as props for their presentations, which interestingly was successful for some groups, but resulted in a somewhat disjointed or less clear presentation for others.

4 Results and Discussion

The first time we ran the Rube Goldberg projects, in the Winter 2009 semester, we did not expect the students to build anything that was very spectacular. As it turned out, we were overwhelmed with the clever and creative designs the groups developed. This level of achievement was sustained in the Fall 2009 semester, as groups continued to produce complex, impressive Rube Goldberg machines that successfully met all of their project goals. Some of the notable methods used this past fall included:

- Solenoid valves to release compressed air.
- Electrical circuits and timers to control when devices were turned on or off.
- Plinko devices to slow down the machine.
- Incorporating other machines (a Perfection game set to pop after 15 seconds; a vibrating massager to simulate an earthquake).
- Linear actuators to fire objects.
- Augers to move marbles between levels.
- An entire project built in a portable wooden box.

As mentioned above, some improvements to the project that were identified in the Winter of 2009 were implemented this past fall. These included reducing the runtime, limiting the time for each step, allowing groups to build the machine on the floor instead of on

a table, and making the budget more strict. As indicated above, reducing the machine runtime and limiting each step to 15 seconds was very successful, as it resulted in teams building more dynamic machines that had 10 – 15 steps and still achieved the time constraint.

4.1 Student Feedback

Feedback from the students has been very positive. In general, students are happy that they were given an opportunity to work on a team project, from start to finish, that had tangible results. The most common problem that arose was related to group dynamics.

4.1.1 Student survey

When we first used the Rube Goldberg machine approach, we did not collect any concrete feedback from the students. However, following our second semester we conducted a survey to assess student satisfaction. We asked each student to answer three simple questions. Unfortunately, out of about 200 students who took the class, only 70 people respond to Question 1 and 65 to Questions 2 and 3. Despite these numbers, we still feel the sample size is large enough to represent what students think about this type of a design project.

The results from the first survey question are shown in Figure 1. Students were asked whether or not they enjoyed working on the Rube Goldberg project. Since this type of activity is very hands-on, it was important to assess whether students enjoyed the experience. The results indicated that 84% of the students enjoyed working on their project. It is quite likely that the use of themed projects enhances this level of satisfaction.

Figure 1. Survey response to “I enjoyed working on my Rube Goldberg design project.”

The second question asked students whether or not they felt the use of Rube Goldberg machines was a good way to teach engineering design. The results in Figure 2 show that an overwhelming 89% think this approach is suitable for teaching engineering design. This supports our belief that Rube Goldberg design projects are mini-engineering projects that include machine design, selection of materials, prototyping and testing, budgetary restrictions, and reporting.

Figure 2. Survey response to “I think that using the Rube Goldberg project approach is a good way to teach engineering design and project management in a first-year engineering design class.”

The third question addressed group dynamics. Figure 3 shows that roughly 31% had a less than desirable experience working with their group members. Therefore, additional course management strategies are needed to address this issue.

Figure 3. Survey response to “I had a positive group-work experience.”

4.1.2 Student comments

Students were given the option to submit comments that could be used to improve the course. Not very many students chose to do this, but the key comments from those who did are summarized in Table 3. In general, the comments are positive and many of the suggestions have merit.

Table 3. Comments Submitted by Individual Students

Student	Comment
1	The presentation was a bit overwhelming (to be on stage).
2	I loved the project. The different themes were awesome, and the actual building and testing of the project was fun.
3	It would be better if you let us select our own groups, as we would be able to coordinate our schedules with people we know.
4	The group evaluation needs to be done in private with each group member evaluating the others.
5	Rube Goldberg projects are a great way demonstrate the aspects of group work and design, and I think that you should continue them in the future.
6	The project and group work is more difficult for international students who are not used to the culture, environment, and lifestyle.
7	The project ended up being a lot more work than I anticipated, but even though it was a lot of work, it was fun.
8	The project is an excellent way to teach us about engineering design. I think that the Rube Goldberg project should be mandatory for all first year engineering classes in all universities. The design process, including prototyping, drafting ideas, building the machine, finding affordable materials, fixing the machine and numerous others mimic those of real-world engineering design problems.

Group selection was random and done by the instructors because it is very unlikely that everyone in the class is going to know four or five people to form a group. By managing the groups ourselves, everyone gets off to the same start. It also forces students to get to know others and be exposed to classmates from different cultures and backgrounds.

One method for dealing with the evaluation of group member participation is to use a group covenant [3].

We tried this in the Fall 2009 semester, but unfortunately it did not work as well as we had hoped. We will be switching back to silent, individual group member evaluations. While we like the group covenant idea, we feel that it may be more effective with senior students rather than the first-year students.

We have recognized that international students face more challenges with this project than their Canadian counterparts. Some of this can be alleviated by the way in which the instructors manage the project. More guidance needs to be given in the class and laboratory periods to make sure that teams work to include all team members in working sessions. We have found that some of the international students get left out of working sessions because they cannot get to the residence of local team members. Additionally, international students need more assistance with the report writing aspect of the project report. There are also cultural differences and language barriers that may make some international students reticent. We hope to introduce some mentoring from senior international students to address this issue.

4.2 Changes for Next Year

There will be two main changes for the upcoming semester. The first one will deal directly with team participation and group dynamics. Extra instruction will be given to make sure teams understand that everyone needs to be given an equal opportunity to participate. This may require finding space on campus where teams can build their machines. In the last round of Rube Goldberg projects, five groups built their machines in engineering laboratories on campus. Additional work space within the faculty may help alleviate some of the group member transportation problems of the past.

The second major change deals with the life-cycle assessment of the Rube Goldberg machines. So far, only one team has presented a plan to deal with the disassembly and recycling of machine parts once the project is complete. More supporting information will be provided in the lectures and laboratories to help groups plan for the decommissioning of their project.

4.2.1 Instructor confidence

We have now taught this course using Rube Goldberg projects twice and are confident that it is not a difficult course to manage. However, ENGG 123 is also taught in the spring/summer semester, and the instructor for that term has been reluctant to adopt the Rube Goldberg project approach. There is a sense that the shorter timeframe for the spring/summer course may be insufficient to allow groups to complete such a project. We recognize that some instructors may

worry about the potential problems this type of project could present and would prefer to stick with conceptual design projects. In time, we hope that more instructors will become comfortable with this style of teaching because we feel that it is very effective. Rube Goldberg projects provide students with an excellent experience and a more concrete introduction to real-world engineering concepts.

5 Conclusions and Future Directions

We have now used Rube Goldberg design projects in two successive academic years to teach first-year engineering design and project management. While there have been a few bumps, we feel that the methodology works and that students are satisfied with their learning experience. Over 84% of the student respondents enjoyed working on their Rube Goldberg project, and 89% felt that this was a very good method for teaching engineering design in first year. More work needs to be done to manage the course and improve the group work satisfaction level among students. We plan to continue using this approach and refine it each year so that it becomes a highly effective and memorable learning experience for our students. We intend to continue gathering data on student feedback in upcoming semesters. In addition, we would like to institute a more long-term follow-up to determine what impacts the use of the Rube Goldberg projects may have on the future performance of our students in later design courses, most specifically on their approach to and management of their fourth-year design projects.

References

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