Use of a Rube Goldberg Design Project for Engineering Dynamics

Dr. Devin R. Berg, University of Wisconsin, Stout

Devin Berg is an Assistant Professor and Program Director of the B.S Manufacturing Engineering program in the Engineering and Technology Department at the University of Wisconsin - Stout.
Use of a Rube Goldberg Design Project for Engineering Dynamics

Introduction

Rube Goldberg was a cartoonist and engineer who is best known for his series of cartoons which show complicated gadgets designed to complete simple tasks. The phrase “Rube Goldberg” has since been adopted as an adjective used to describe the act of accomplishing something simple through complicated means. When Rube Goldberg design is incorporated into the engineering classroom it allows for a unique blend of creativity and challenge that is often hard to accommodate in introductory engineering curriculum.

This paper presents a first look at my use of a semester long Rube Goldberg design project as a tool for teaching engineering dynamics. Students were divided into groups and assigned a theme picked from the topic areas covered in the engineering dynamics curriculum, for example: instantaneous centers of rotation, damped vibration, or impulsive motion. Each group then built one stage of what would become a class Rube Goldberg machine under the stipulation that their stage must demonstrate the assigned topic area. Further, a report was submitted, describing the assigned topic area and how their stage demonstrated that topic area. At the end of the semester, each stage was assembled to build the full Rube Goldberg machine. As such, the student groups had to communicate with each other to determine how to transition between stages. This aspect was intended to incorporate an additional layer of communication and collaboration early in the undergraduate engineering curriculum.

The use of a Rube Goldberg based design project has been found previously to be successful in the educational setting both at the pre-college\(^1,2,3\) and university levels\(^4\). Through these and other similar works, it has been found that the Rube Goldberg design project can trigger creative thinking processes as well as reinforce the students’ motivation for pursuing an engineering degree.\(^5,6\) This could therefore lead to increased retention in engineering programs by utilizing such a design project early in the students’ curriculum. The use of a project in which student teams must work together to produce a completed machine has been shown to enhance communications, teamwork, time-management, and experimentation\(^7\).

Methods

The use of a Rube Goldberg based design project was incorporated into an engineering dynamics class with a total student population of 47. Students were divided into small groups ranging from three to five members, resulting in a total of 11 project groups. Each project group was assigned a topic from the course curriculum. These topics included:
1. Relative motion
2. Fixed-axis rotation
3. Potential energy
4. Kinetic energy
5. Newton’s 2nd law
6. Projectile motion
7. General planar motion
8. Impulsive motion
9. Instantaneous centers of rotation
10. Natural frequency of vibration
11. Damped vibration

The structure of the project was such that students were given freedom to design an individual stage of a Rube Goldberg machine which demonstrated their assigned topic in a physical way, the full project description as provided to the students is presented in Appendix A. In the end, each stage would be assembled to produce one machine that demonstrates each of the topics listed above. This aspect was intended to require inter-group communication as each group would need to work with the groups before and/or after their stage to determine how they would transition between stages.

During the semester, occasional class time was allotted to provide students with time to communicate/collaborate. However, significant out-of-class work was also expected. Construction materials were not provided with the exception of a two foot square piece of oriented strand board to serve as a base or support structure. The only design constraint imposed was that the overall footprint of their stage must not exceed a cube of two foot side length.

The final deliverables for this project included a written report detailing the topic background and stage design, a group presentation showing how the group’s stage demonstrates the assigned topic, and a presentation as a class at a college exposition. Periodic deadlines were established to ensure project progress was being made. During the 14 week semester, a verbal design proposal was due during week 6, a brief project update during week 9, a draft of the final report during week 12, and the final report and presentation during week 14. An informal deadline was also imposed on the construction of each stage during week 13 to allow for a test-run of the assembled machine. This made it possible to test and troubleshoot each stage prior to the final presentation.

**Student Contributions and Results**

During the semester, the eleven project teams were tasked with designing, building, and understanding their stage of the class Rube Goldberg machine. Utilizing both a limited quantity of in-class time and out-of-class time, each group accomplished the creation of the machine stage
using the materials available to them in work-spaces on campus, workshops at home, or the recycling bin. An example of a machine stage is shown in Fig. 1. This design was constructed using scrap materials and was intended to show the effect of damping on oscillatory motion.

Figure 1: Example of a machine stage designed and constructed by a student project team.

The open-ended nature of this project required teams to use their creativity when determining how to demonstrate their assigned topic. For example, to demonstrate the concept of potential energy, one project team constructed a crossbow which stores energy in the elastic deformation of the prod, constructed from a saw blade in this case (see Fig. 2a). The group also included a demonstration of potential energy stored within an object at a height. This was presented by a toy car resting at the top of a ramp held in place by the handle of a table tennis racket. Upon conversion of the elastic potential energy stored within the crossbow prod to kinetic energy of the projectile, the projectile struck the table tennis racket thus releasing the energy stored in the toy car, as shown in Fig. 2b. This use of multiple forms of demonstration was particularly useful for explaining a topic as broad as potential energy.

The complexity of the student designed stages varied significantly across each group as did the process used for developing a design. It is expected that this is due to the varying backgrounds of the students on each team. While several of the group utilized a “trial-and-error” design procedure, one group made use of a solid modeling software to first conceptualize their design prior to building. The details of this stage are shown in Fig. 3. Here it is shown that each component of the stage was modeled as in Fig. 3b along with the physical realization of these components in Fig. 3a, c, and d. This particular group also made use of a two-dimensional wireframe model to show the complex motion of the connecting rod within their design as it relates to the topic of their presentation, “instantaneous centers of rotation”, as shown in Fig. 4. The assembled class Rube Goldberg machine consisted of 39 individual steps. For the eleven project groups there was a range between two steps and ten steps per stage. This demonstrated a wide range in complexity with which the students chose to demonstrate their assigned topic. Typically, stages with a higher number of steps included multiple demonstrations of their topic showing the various ways in which the same topic could be presented.

During the final weeks of the semester, it was time for the students to come together as a class and
Figure 2: (a) A student constructed projectile launcher and (b) a machine stage to demonstrate potential energy.
Figure 3: Example of the use of solid modeling to design a stage.

Figure 4: Wireframe model showing the complex motion of the project team’s design.
attempt to assemble each group’s stage into the full Rube Goldberg machine. During this time, multiple trials were necessary to identify performance issues and failures in communication between the project groups. After the first test period, a list of required adjustments was formulated and a follow-up trial was scheduled. At the conclusion of these trial runs, the class had not yet achieved a working assembly of the Rube Goldberg machine. The final assembly and demonstration of the project was to be completed at the college-wide exposition, as shown in Fig. 5. During the exposition, the students set up the class machine and performed last-minute refinements. Each attempt at running the machine seemed to introduce a new complication. However, the students learned quickly how to troubleshoot and ultimately were able to demonstrate the Rube Goldberg machine in its entirety for onlookers.

Figure 5: Full class Rube Goldberg machine on display at the UW-Stout STEM exposition.

The other aspect of the project conclusion was a written report that included all necessary information about the project such as background, theory/calculations, and a description of the physical design. In general the submitted reports included a thorough analysis of the dynamic principles being explored. Students measured and reported the masses of each relevant object and performed calculations to predict the performance of their stage of the machine. Few of the groups validated the estimated values such as velocity or energy through experimental measurement due to the difficulty associated with such a task. While the accuracy of the information or calculations varied across the project groups, in general the students demonstrated an ability to apply the theoretical framework covered in the course curriculum to an ill-defined situation. An example of a student project report is shown in Appendix B.
Discussion

The overall goal of developing a class Rube Goldberg machine that demonstrates the principles of dynamics was successful in that the class was able to come together and design and build a working machine which consisted of 11 stages and 39 steps. As an outreach activity, the display at the student exposition was successful and garnered much attention from the exposition attendees. Through the completion of this project, the students were faced with challenges in terms of limited access to materials and work-space as well as the realities of interpersonal communications.

Student feedback received on this project included both positive and negative comments. Students generally appreciated the opportunity to do something with their hands and were satisfied with the fact that the machine worked in the end. Frustrations were expressed by some regarding the challenges of working on a collaborative project and the time spent doing so. Some students prefer the standard lecture and homework style of teaching and felt the project detracted from the time available for those activities.

Recommendations

Ultimately, it is the opinion of the author that the project provided a beneficial opportunity to explore the physical realizations of sometimes abstract concepts. Suggested revisions to this project include providing more structure to the project thus guiding students through the process, leaving it less open-ended. Further, the incorporation of low-level training in basic shop work would provide needed assistance to students who have little experience with building.

If the project were to be integrated as a recurring component of the course, a dedicated source of supply materials would need to be identified as well as regular access to campus work-spaces to better facilitate the construction process.

Acknowledgements

The author would like to thank the UW-Stout students in the Fall 2014 semester section of MECH-292 for their contributions.

References


Appendix A: Project Description

**Project:** Design and Construction of a Rube Goldberg Machine that Demonstrates the Principles of Dynamics

**What is a Rube Goldberg machine?**

A Rube Goldberg machine is a “whimsical machine designed with every-day objects that performs a seemingly simple task”.

**What are we going to do for this class project?**

We will modify the above definition slightly such that we will create a multi-part Rube Goldberg machine where each stage will demonstrate a different principle of Dynamics.

Each project group will consist of 4 or 5 students and each group will be responsible for one stage of our machine. Groups in adjacent stages will need to communicate to ensure that the mechanism continues to operate between stages. Your group’s stage should be constrained to an overall size of 2 ft. X 2 ft. X 2 ft.

Each project group will be assigned a principle from this course that your stage must in some way demonstrate. You will then design the mechanics of your stage appropriately and produce a written report which details what the stage is demonstrating and includes all relevant equations/calculations.

**When will we have time to work on this project?**

Some class time will be devoted to “project work time”. However, you should expect to need to meet with your group outside of class as well. This may be particularly important when it comes time to construct your stage.

**What about the final report?**

The written report should include all details of your design and how it demonstrates your assigned topic. Include sufficient background info on your assigned topic so that a reader knows what you are talking about. Show with equations and graphics the theoretical behavior of your stage and how it relates to the topic.
Appendix B: Example Project Report
**Introduction**

This part of Rube Goldberg machine utilizes the law of conservation of energy and conservation of momentum in physics. These are the two fundamental laws in physics and play an important role in derivation of other important equations such as Bernoulli’s equation in fluid mechanics and heat equations in thermodynamics. The objective of this project is to get familiar with application of law of conservation of energy and conservation of momentum, and build up a sound conceptual knowledge of how to apply these laws in real life scenario. Our machine will be triggered by the machine of group 2, and started from the drop of a plastic ball. The ball is connecting to a pendulum and will swing to the other side and hit a piece of paper. By the law of conservation of momentum and energy, the target ball will gain velocity as it drops to the bottom and will lose kinetic energy when it swings back up. Eventually, it will collide with a piece of paper with a plastic impact resulting with the ball being stuck with paper. During this process, all the energy will be absorbed and mostly will be transferred into heat and dissipate in the air. In real life, in the process of swinging, part of energy will always be transferred into heat energy due to air resistance. Therefore, in order to use conservation of energy during the swinging process, we need to draw up some assumptions. The first assumption is air resistance will be neglected so that the potential energy of ball will completely be converted to kinetic energy. Upon the collision, the restitution of the ball will be considered as well. Further, the friction on the ground is also neglected (sometimes the ball will accidentally kiss with the ground due to uneven floor).

**Schematics**

![Schematics](image)

**Figure 1:** schematics
Figure 2: project set-up

The figure 2 shows how our project gets started. The group 2 will use their ball collide with our plastic ball
Figure 3: project set-up

The figure 3 shows the ball is connecting to a pendulum and will swing to the other side and hit a piece of paper. By the law of conservation of momentum and energy, the target ball will gain velocity as it drops to the bottom and will lose kinetic energy when it swings back up. Eventually, it will collide with a piece of paper with a plastic impact resulting with the ball being stuck with paper.
Procedures

Figure 3: first stage

The first stage is triggered by group 2’s project
After triggered by group 2, we can assume the initial speed of the ball is \( v_0 = 0 \text{ m/s} \).

The second stage will happen when the plastic ball begins swinging. During the second stage, the plastic ball on the top would perform free fall with a string attached. Thus the projectile of the plastic ball will be circular. Since the team assume the initial condition of the ball is \( v_0 = 0 \text{ m/s} \), thus at the beginning of second stage, the total energy is just potential energy where \( PE = mgh \) where \( m \) is the mass of the plastic ball and \( h \) is the initial height of the ball. After the plastic ball falls at the bottom location, it will swing back up and collide with a piece of paper sitting at rest. Right before the impact, the team could use the conservation of energy to calculate velocity of the plastic ball upon collision. In the meantime, restitution of the plastic ball will also be considered. Therefore, the team could apply the equation of restitution to calculate the final velocities of the two plastic balls after the collision.

In stage four, the plastic ball and paper will gain speed and push the attached pen move forward to trigger the project from later team.

Theories

Assumption
The friction from air and ground are neglected. The initial speed of the plastic ball is \( v_0 = 0 \text{ m/s} \)

Mass of the plastic ball
\[ m = 0.082 \text{ kg} \]

Diameter of the ball
\[ D = 0.043 \text{ m} \]

Restitution
\[ e = 0.688 \]

According to the figure 1, at position 1, the ball will carry the potential energy of
\[ PE = mgh = 0.082 \times 9.81 \times 0.2 = 0.161 \text{ J} \]
After the cue ball at position 1 falls to position 2, it will collide with a piece of paper.

Using the conservation of energy, we have

\[ \frac{1}{2}mv_0^2 + mgh_0 = \frac{1}{2}mv_1^2 + mgh_1 \]

Where \( v_0 = 0 \), \( h_0 = 0.2 \text{ m} \), \( h_1 = 0.08 \text{ m} \)

The initial velocity of cue ball before hit the target is

\[ \frac{1}{2}mv_1^2 + mgh_1 = 0.161 \text{ J} \]

\( v_1 = 1.535 \frac{\text{m}}{\text{s}} \)

The initial velocity of target is

\( v_2 = 0 \)

In stage 2, the conservation of momentum will be applied

Define \( v_1' \) is the velocity of cue ball after impact, and \( v_2' \) is the velocity of target ball after impact.

So we have

\[ e = \frac{v_2' - v_1'}{v_1 - v_2'} \] (1)

and

\[ mv_1 + mv_2 = mv_1' + mv_2' \] (2)

From (1), we have

\[ v_2' - v_1' = 0.688(1.535) \]

From (2), we have

\[ v_2' + v_1' = 1.982 \]

We solve for these two equation, we get

\( v_1' = 0.309 \frac{\text{m}}{\text{s}} \)

\( v_2' = 1.673 \frac{\text{m}}{\text{s}} \)

The results show the cue ball will continue to move with speed

\( v_1' = 0.309 \frac{\text{m}}{\text{s}} \)

And target will move with speed

\( v_2' = 1.673 \frac{\text{m}}{\text{s}} \)

Now we can also calculate the energy loss during the collision.

The total energy before impact is \( E = 0.161 \text{ J} \)

After the collision, the energy is

\[ \frac{1}{2}mv_1'^2 + \frac{1}{2}mv_2'^2 = 0.5 \times 0.082 \times (0.309^2 + 1.673^2) = 0.117 \text{ J} \]

So the energy loss is

\[ E_{\text{loss}} = 0.161 - 0.117 = 0.044 \text{ J} \]