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Experiences in Teaching Writing Unit Design Courses to Engineering Students with Advanced Rube Goldberg Projects

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Abstract

Teaching design and communication skills to engineering students is always a challenging and evolving process. Many design courses compromise a project in order to provide students a hands-on experience to address different aspects of design. Project selection is very important to motivate and encourage creativity in the students. It also alters the teaching efficiency significantly.

Principles of Design course has been taught as a part of Engineering Science curriculum at a private Liberal Arts University since 2010. It gives engineering science students the opportunity to work on several of the steps in the engineering design process: formulation of a problem, creative approaches to solving the problem, analysis, materials selection, and economics. This course is also a Writing Unit course, where formal writing is a substantial mode of learning. Authors of this paper were co-instructors of the course and assigned different projects to the students during the first four offerings, every year improving the projects according to the observations and student feedback to better address the course's learning objectives. In spring 2013, the assigned project was the design and implementation of a Rube Goldberg machine. Based on student outcomes and course evaluations, it was decided to repeat the same concept with some technical modifications to make the Rube Goldberg machine more advanced and challenging for junior level engineering students. This paper presents the assigned Rube Goldberg projects, writing unit requirement of the course, teaching method, and an analysis of the effectiveness of the different project assignments over different offerings. Course outcomes and assessment results of the different projects are also discussed.

Introduction

Muskingum University, a traditional liberal art institution, established a new engineering program in 2008. Principles of Design is a junior-level writing course focused on improving students' communication skills. The course has the objective of providing students a thorough overview of design procedures, educating students about design principles and practices to assist them in making informed design decisions and in solving complex problems. Students taking the course are already equipped with basic design skills and concepts. In the course, students are exposed to a semester long design project in which they carry out most of the steps of engineering design process.

The design project of the course is used to address student outcomes a, c to h, and k of ABET accreditation criteria[1]. In addition, the course satisfies the upper-level writing unit requirement of Muskingum University's general education courses. A writing unit is a course that utilizes formal writing as a substantial mode of learning. To fulfill this requirement, students have to document their design process, write a formal design project report, and present a poster describing their work at the end of the course.

In the first three offerings of the course, different design projects were assigned. These projects were based on solving simple day-to-day problems that students or surrounding people have. Some examples are the design of a treadmill for small animals in the Biology Department, a desk extender for the seats in the auditorium, an automatic pet feeder, amongst others. Each of these projects addressed the main learning objectives of the course. However, students focused on the design and building of the prototype and didn't dedicate much time to the documentation of the process. Also, since some of the student feedback received at the end of the course were specific to the assigned projects, it was more difficult to make improvements on some topics. It was decided to have a uniform topic for all students.

In the fourth offering, design and implementation of a Rube Goldberg Machine (RGM) was considered and assigned as the design project. Rube Goldberg (1883-1970) was educated and worked as an engineer before he turned into a cartoonist famous for his incredible machines which complete a simple task in a complex and humorous set of interactions[2]. His work became very popular and his name is used as a descriptor for an over-engineered apparatus that accomplishes little. The originality of his concept made it popular among the society and two Purdue engineering fraternities began a contest as a rivalry in the 1940s and 1950s, which later was revived in 1983 and became a nationwide Rube Goldberg Machine (RGM) contest in 1988[3]. The contest was expanded to the high school level in 1996 with the support of the US Department of Energy's Argonne National Laboratory. In 2012, an international online RGM contest was launched by Rube Goldberg Inc. for ages 11-14[4].

RGMs were also used in educational studies, especially those related with design. Several of these studies utilized Rube Goldberg projects in K-12 education and freshmen level engineering courses such as teaching engineering design to K-12 students enrolled in talent development program[5], using web-based instructional materials to learn with Rube Goldberg projects in K-12 classrooms[6], using Rube Goldberg projects as a design based learning tool for freshmen engineering students[7], providing early experience in multidisciplinary teaming and an early exposure to ethics in an interdisciplinary freshmen course[8], integrating design and experimentation to freshmen students with an electromechanical Rube Goldberg design project[9], introducing design early in the curriculum to improve motivation and increase retention[10], assessing engineering students' understanding of design after a short workshop given preceding the beginning of their first semester[11].

Besides K-12 and freshmen level, RGMs were also used in upper level engineering courses to accomplish different sets of goals such as evaluating design project creativity in engineering design courses[12], using solid modeling and simulations for the visualization of concepts of statics and dynamics[13], investigating the effects of design swapping to improve both the quality of design documentation and the quantity of discussions and feedback among teams[14]. Le Tourneau University has one of the longest ongoing Rube Goldberg projects in university level and reported their observations of thirty years of teaching design by RGMs[15].

Most of the studies mentioned above found the use of Rube Goldberg projects beneficial in terms of their objectives and teaching goals. These studies emphasized on numerous different topics and concluded to provide students experience teamwork, hands-on experience, creativity, systems thinking, multidisciplinary projects, ethical issues, design documentation, public presentation, solid modeling and simulation, Murphy's Law, and learning from failures.

After the first time the RGM was assigned, it was noticed that this project addressed the course objectives more efficiently, in terms of engineering design and writing requirements. This conclusion was based on the instructors' observations, student feedback, and course assessment. For the second and third times the project was assigned, it was decided to make some technical modifications to the requirements of the RGM, which resulted even in better results.

Why Rube Goldberg Projects?

RGMs are fun projects with multiple steps that automatically grab students' attention. Students are excited to start working on the problem. Having multiple steps allows teams to be divided into subteams. All parts of the machine have to be interconnected which promotes communication within subteams. Also, all parts of the machine have to be fully analyzed and documented, which improves the students' technical writing skills.

The first time a RGM project was assigned, the rules of the Rube Goldberg Machine Contest that was launched by Rube Goldberg Inc. in 2013[4] were used. The project addressed the teaching objectives of the course and was a well fit for the writing unit requirement. The instructor observations and student feedbacks after utilizing the RGM as the design project for the first time were much more positive than the previous projects. Students were engaged in the problem and the fact that each design team was required to complete two report and presentation cycles encouraged them to build upon their learning experiences throughout the course.

The second and third times Rube Goldberg projects were assigned, some major modifications in the machine specifications were made. These modifications made the projects more challenging and interdisciplinary. The motivations for making the changes in the specifications of the assigned projects and the updated expectations from the students in the modified projects are as follows;

- Number of minimum steps was restated as twice the number of members in the team. Each student was responsible from building and documenting their own steps.
- The physical size of the RGM was reduced from 6 ft. x 6 ft. x 6 ft. to 36 inches x 28 inches x 14 inches. This size was required to fit the machine into half of department's display case. The other half of the case was used to display the posters.
- Since the physical size of the machine was reduced significantly, maximum single run time of the machine was decreased from 2 minutes to 45 seconds.
- Students were encouraged to use 3-D printers to build parts in the first Rube Goldberg project but only one of the groups did. Instructors decided to require every group to print at least one part in order to further improve their relevant skills.
- Most significant and unique change in the specifications of the second project was the requirement of a self-restarting mechanism. Different from the traditional RGMs, the machine had to reset into its initial state and be ready to run again after accomplishing the task without any human interaction. Furthermore, it was required to be activated by using an initiator (button, light source, etc.) that would be mounted on the window of the display case. Thus, any curious audience could run it.

These changes require the students to design the machine using more engineering tools and concepts. Students were allowed to use a microcontroller, electronic devices, and actuators to accomplish this task. Also, in traditional RGMs majority of the steps can be designed by only taking the outcome of the previous step into consideration. However, in advanced RGM designs, students must take all the steps into consideration as a whole and design the machine completely before they start building it since the machine is required to reset back to its initial conditions. A sample RGM project and student work are shown in Figures 1 and 2.

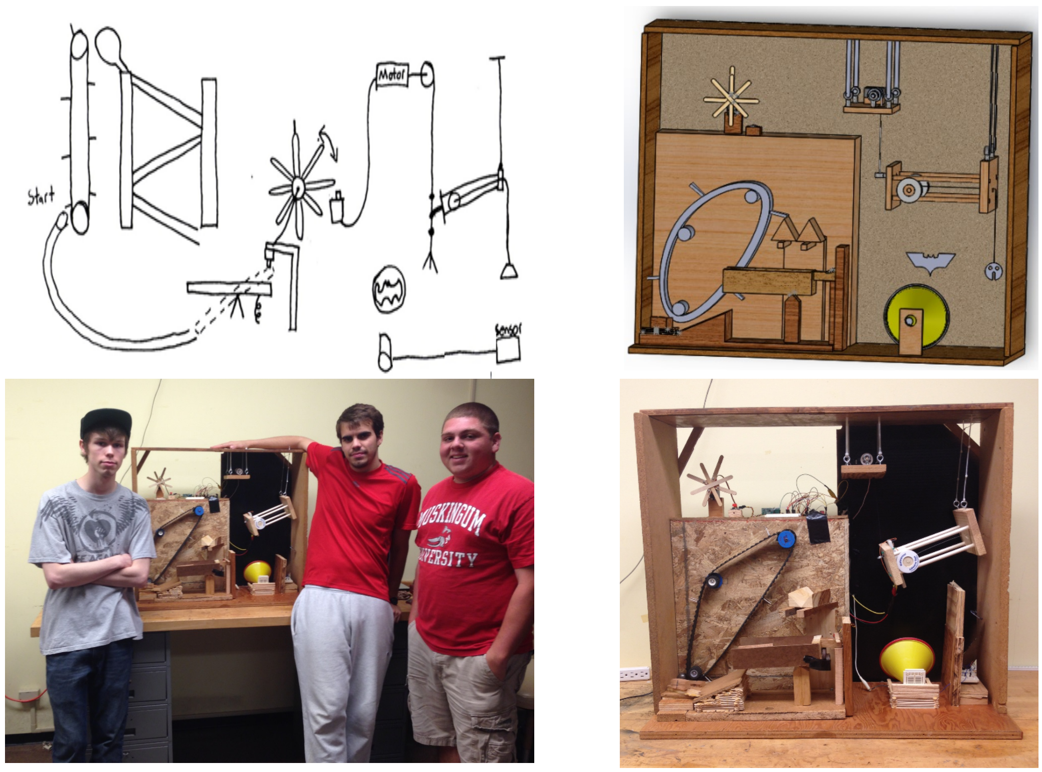

Figure 1. Sample Rube Goldberg project from 2014. Preliminary design sketch (top left), the CAD model (top right), the group working on it (bottom left), and the finished project (bottom right).

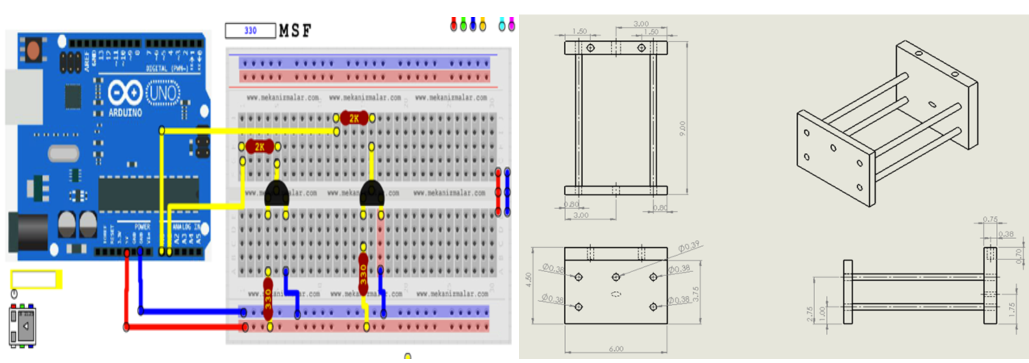

Figure 2. Sample student work. Electrical diagrams (left), detailed drawings (right).

Integrating Writing into the Course

Muskingum University requires that students take two Writing Unit courses: one low-level (first or second year) course and one upper-level (third or fourth year) course. There is no requirement on the area that these courses have to be taken. To lighten the amount of external courses that Engineering majors have to take as part of their General Education requirements, it was decided to make Principles of Design an upper level writing unit. The course is designed and offered as a writing-intensive experience that benefits Engineering majors and adequately prepares them to meet the needs of future industry employers or graduate studies in the area of written communication. It is intended to create a synergy between liberal education principles and engineering practice in the area of technical writing and communication.

Technical writing and communication topics are discussed in lectures during the semester. Topics include communicating the design through engineering drawings, oral and written reports, and technical posters. Writing assignments in the course include project updates or status reports, preliminary project report and oral presentation, and final project report and poster presentation. Grading is based on the solution of the design problem and writing assignments. Fifty to seventy percent of the grade (depends on the year) is based on writing assignments. Table 1 presents an example of the percent grade on the course based on weighted evaluations.

Table 1. Grading of the course based on weighted evaluations.

Evaluations	Weight
Classroom Activities and Homework	10%
Updates	10%
Preliminary Project Report	15%
Preliminary Project Presentation	10%
Project Prototype	15%
Poster Presentation	15%
Final Project Report	25%

All the writing assignments in the course are directly connected with the design problem. Iterations and revisions of the student work are required. Each update report requires the teams to build upon the content included in their initial design plan. The final report requires the teams to build upon the midterm report by including a results section that provides information for each of the steps included in the design plan. The process of returning to the same core of information for each of the reports and presentations encouraged the students to reflect upon the feedback and evaluation given on the previous report and address problematic issues in the current report or presentation they were working on. This allows students to build on learning as they apply their engineering skills to solve the problem. Besides writing reports, students were also required to present their projects to the campus community in a poster. A final poster is illustrated in Figure 3.

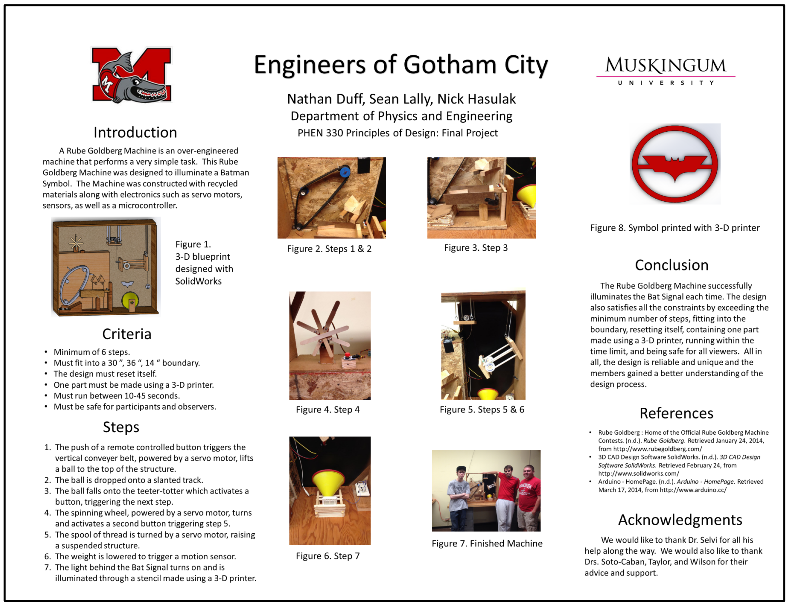

Figure 3. Final poster presented to the campus community

Assessment

Two different assessment methods were used to evaluate the RGM projects: direct assessment and indirect assessment. For the direct assessment a performance assessment rubric was used. The rubric uses a quality scale (0 =Unacceptable, 1=Marginal, 2=Acceptable, 3=Exceptional). To assess students' writing skills, the rubric evaluates report mechanics and content. For the report mechanics, the following areas were evaluated: organization, aesthetics, format, spelling, grammar, and punctuation. For content, parts of a technical report were evaluated: abstract/summary, introduction, problem statement, requirements and constraints, technical requirements, results, conclusions, and future work or recommendations. Citation format and appropriate references were also part of the evaluation. Functionality of the designed RGM was evaluated using a numeric scale (4=best to 1=bad design). The design was evaluated using the following categories: modification/testing, design knowledge, function, design criteria and constraints.

Results from the direct assessment showed that the emphasis on writing as part of engineering processes was effective. Final reports and presentations showed a noticeable improvement in their writing skills. The final work reflected more polished efforts and more evidence of revision than the ones in the past.

The indirect assessment was done using course evaluations at the end of the semester. The course evaluation is a set of eighteen questions that students answer using an agreement scale (5= strongly agree, 4= agree, 3=neutral, 2= disagree, 1= strongly disagree). These questions are grouped into six categories. Four of the eighteen questions and two of the six categories were used to assess students' satisfaction with the course and, specifically, the RGM project. The results per year are presented in Table 2.

Table 2: Results of the project assessment using mean scores of course evaluations.

Question (Q) / Category (C)	**First Three Years (2010-12)**	**RGM Projects (2013-15)**
(Q) The stated goals of the course are consistently pursued	3.68	4.70
(Q) In this course I felt challenged and motivated to learn	3.48	4.50
(Q) This course has effectively challenged me to think	3.67	4.55
(Q) I understand what is expected from me in this course	3.61	4.64
(C) Students Interest/ Involvement in Learning	3.74	4.50
(C) Course Goals and Objectives	3.70	4.70

Students' satisfaction with RGM design projects is noticeable in the indirect assessment results. During the years RGM projects were assigned, students' interest and involvement in learning increased when compared with previous years. This was reflected in their daily work; students were constantly working and improving their designs. Since class sizes were small, instructors had the chance to communicate directly with students through the projects.

Results similar to the self-evaluation results were observed by the instructors of the course as well. They spent more time and effort on evaluating and selecting the best physical design and electronic devices. Also, students had a better understanding of the course goals and objectives.

Conclusion

According to assessment results, student feedback, and instructor observations; advanced RGM projects efficiently addressed the learning goals of the junior level writing unit design course. They are quite suitable to assign in a writing unit course. Due to the sophistication level of the projects, students have to include many technical details and everybody has to be involved in report writing. Proper preliminary reports, final reports, and posters were prepared by the groups that worked on advanced RGMs. Advanced RGM projects require more advising, resources, and time to monitor/grade. Therefore, it might be difficult to handle them in big class environments but they are very convenient to teach at Liberal Arts Institutions where the class sizes are small. With small class sizes, instructors can advise and monitor all the groups, and students can use the necessary space and equipment whenever they need. Authors of this paper spent significant amount of time every semester, comparable to lecture contact hours, for each group.

Instructors' observations and evaluations, and student feedback prove it to be a more efficient teaching assignment than the previous projects. Students were excited to display their work in a unique way where any curious audience in the university can run their machines and see their posters. They felt motivated and challenged, and had a lot of fun working on it resulting in an enthusiastic teamwork.

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