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Building a Rube Goldberg Machine in an Undergraduate Business School Course to Learn Principles of Project Management and Leadership Skills

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Abstract

The International Rube Goldberg Machine Competition (Rube Goldberg, 2015) provides the foundation for a class project in an undergraduate business school course designed to teach principles of project management and leadership skills. The project provides a challenging, ill-structured task that allows students to apply project management and leadership theory and develop their skills. The article reports the results of a survey suggesting that students viewed the project positively and that student knowledge of project management and leadership skills improved as a result of completing the project.

Keywords: Rube Goldberg, project management, leadership, teaching and learning

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1. Introduction

The importance of project management to good project outcomes is generally recognized (e.g., Bryde and Joby, 2007; Gowan and Mathieu, 2005; Hwang and Low, 2012; Keil, Rai,Cheney, and Zhang, 2003). Because of the difficulty of exposing students to real-world projects, a variety of pedagogical approaches have been suggested in the literature on teaching project management. These include quick exercises taking a single class session such as designing and building a skyscraper from uncooked spaghetti and marshmallows (Cook and Olson, 2006), the use of project management simulations (Bollin, Hochmuller, and Mittermeir, 2011; Huang and Liu, 2008), the use of paper and pencil exercises based on real world scenarios such as the organization of an academic conference (Ivanovic, Putnik, Budimac, and Bothe, 2012), the application of project management concepts to hypothetical projects through role playing exercises (Giralt-Mas, Pala-Schonwalder, del-Aguila-Lopez, and Bonet-Dalmau, 2005), and the application of project management principles to campus-based or community service projects with which students are involved (Mengel, 2008).

This paper describes an adaptation of the International Rube Goldberg Machine Competition task (Rube Goldberg, 2015) in an undergraduate business school course designed to teach principles of project management and leadership skills. The class project is based on the task and rules of the International Rube Goldberg Machine Competition (Rube Goldberg, 2015) with modifications to fit the course goals and format. The paper describes the course, the Rube Goldberg Machine Competition task as modified for the course, and the results of a survey conducted at the end of the course to measure student perceptions of the project.

A Rube Goldberg machine is a complex machine designed to perform a simple task (Rube Goldberg, 2015). For example, the machine in Figure 1 is a self-operating napkin (Rube Goldberg, Public domain, via Wikimedia Commons). The Rube Goldberg Machine Contest is an international contest held annually to foster innovation, creativity, and problem solving skills (Rube Goldberg, 2015). Contest participants compete to build a Rube Goldberg machine to perform a specific task. For example in 2014 teams competed to build a Rube Goldberg machine to zip a zipper and in 2013 to hammer a nail (Rube Goldberg Contest History, 2015). Teams can be composed of groups of middle school, high school, or college students.

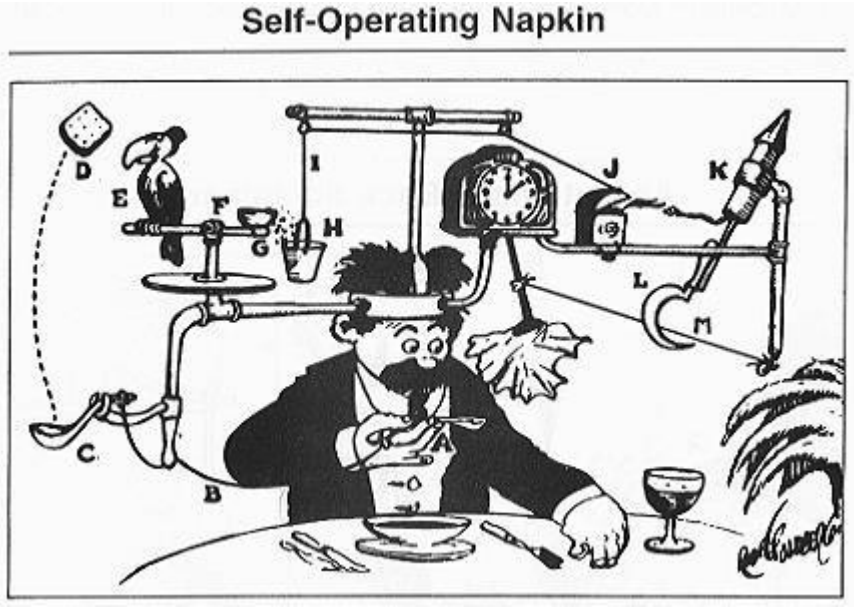

Figure 1. Example of a Rube Goldberg Machine (By Rube Goldberg, Public domain, via Wikimedia Commons)

The Rube Goldberg project described in this paper is consistent with previous calls for improvements in student engagement and the development of problem solving and critical thinking in project management courses (Ojiako, Ashleigh, Chipulu, and Maguire, 2010) and for the inclusion of cost and budget considerations in the project management course (Maples, Greco, Heady, and Tanner, 2005).

The Rube Goldberg project is typically used to teach the application of technical subjects. For example, the Rube Goldberg project has been used in the past to introduce engineering students to the principles of engineering design (Acharya and Sirinterlikci, 2010) and to teach physics to high school seniors (Pinkerton, 1993). In this paper it is argued that the project provides a task that is general enough to be understood by non-technical students pursuing undergraduate

degrees in business and that the task is complex enough to provide a context in which students can begin to apply the principles of project management. The remaining sections of this paper will (1) provide background on the project management and leadership skills course, (2) describe the Rube Goldberg Machine project as implemented in the project management and leadership skills course, and (3) discuss the results of a survey measuring student perceptions about the project.

2. A Course on Project Management and Leadership Skills

The Rube Goldberg Machine competition project was used in an undergraduate course on project management and leadership skills that is required of all undergraduate business students in a mid-sized public university. The course description is shown in Table 1. The business school in which the course is taught offers majors in accounting, digital marketing, finance, human resource management, information technology management, management, marketing, and supply chain management; and students with all majors are required to take the course on project management and leadership skills.

Table 1. Course Description

This course is intended to be a writing intensive program based interdisciplinary course in project management skills. Topics covered will include benefits of project management, definition of a project, development of a project plan, execution of a plan, and management of change. Leadership skills will be emphasized as they relate to conflict resolution, motivating and coaching team members, and listening to team members. Students will complete and present a project plan using the appropriate project management and presentation software. The course will also emphasize under what conditions the traditional project management may or may not be appropriate.

Course objectives include understanding the principles of project management, breaking down a project into tasks, developing a project schedule and budget, managing the schedule and budget, closing out a project, developing leaderships skills needed to execute a project, learning to manage project risk, and using project management software. Instructors teaching the course commonly confront a difficult challenge creating a course project in which students can actively apply the project management and leadership skills they are learning in the course. Ideally students will practice the skills taught in the course through an ill-structured and complex project. However, since students in all majors in the business school must take the course and because students often take the course before completing introductory coursework in all of the required business disciplines, it is not possible to assign a course project that requires advanced discipline-specific knowledge and skills. For example, it is not possible to assign a computer programming project (e.g., Huang, Dai, Guo, and Lei, 2008) because only the students pursuing degrees in information technology management have the knowledge and skills needed to complete the project. Because of this challenge, the International Rube Goldberg Machine Competition task (Rube Goldberg, 2015) was piloted in a section of the project management and leadership skills course. This competition presents students with an ill-structured, complex, interdisciplinary project that can be completed by teams of students pursuing a variety of majors.

3. The Rube Goldberg Machine Project

The International Rube Goldberg Machine Competition is described in full on the Rube Goldberg website (Rube Goldberg Contest, 2015). A rule book is published each year describing the rules and task for teams that wish to enter official Rube Goldberg competitions (Rube Goldberg Contest, 2015). The rules and official details of the contest will not be repeated in this paper. Rather the competition as used in the project management and leadership skills course will be the focus of this paper.

Consistent with the 2014 International Rube Goldberg Machine Competition, the objective of the class project was to build a machine to zip a zipper. In contrast to the official International Rube Goldberg Machine Competition in which teams design and build complete Rube Goldberg Machine to complete the assigned task, in this course each of ten teams was given the task of designing and building a single component of the Rube Goldberg Machine using a piece of plywood measuring twenty-four inches by twenty-four inches. The ten pieces of plywood were then placed next to each other end to end to form the complete machine. Students were required to research, design, create, and test their individual components. Each component had to interact with the adjacent component(s). There were ten teams in the course, and the ten components of the machine built by these groups were placed end to end to create the complete Rube Goldberg machine. Prior to designing their individual machines, the teams had to agree on the interfaces as each machine was to trigger the adjacent machine, until the final task was accomplished.

Students were assigned to one of ten teams within the class. Because of the nature of the Rube Goldberg Machine Competition task students were placed in heterogeneous groups with a mix of abilities and skills in the groups. The instructor had students complete an exercise in which they listed their three favorite childhood toys. To ensure that each team had at least one member with basic skills in designing and building three-dimensional structures, teams were formed by placing one student who listed a building toy such as Legos® as one of their favorite childhood toys in each team. The remaining students were placed in groups so that there were a variety of majors represented in each team.

3.1 Project Requirements

Students were given a list of rules governing the operation of their component. These rules were adopted with some modification from the rules for the International Rube Goldberg Machine Competition (Rube Goldberg Contest, 2015) and are presented in Table 2.

Table 2. Rules for International Rube Goldberg Machine Competition as Adapted for Class Project (Rube Goldberg, 2015)

- The instructor will provide each team with a 24" x 24" piece of plywood. This is the base of your component and must be used – losing it would be bad for your grade. The full machine will have all ten components lined up end-to-end. You may affix items to the base as needed, but no portion of the component may be taller than 24". The instructor will identify the point at which each component interacts with its neighboring component. Student teams are responsible for coordinating those interactions with each other.
- Any loose or flying objects must remain within the set boundaries of the component's plywood base. This includes, but is not limited to, drops of water, balls, and other small objects. Inert gasses are exempt from this rule. Steps/operations which trigger the next component are allowed to cross into the next plywood base if approved by the adjoining team.
- Each component (individual team machine) must have at least three steps/operations. There is no maximum number of steps.
- Each component must complete its run of steps/operations in less than one minute with no interference from team members.
- The component will have a maximum five minute reset time in which only two team members may touch the component.
- No animals may be used in the components. The component must not contain profane, indecent, or lewd expressions. No flames or electrical arcing may be used on or within the components.
- Any destructive action against another component is grounds for disqualification and the team will receive a grade of "zero."
- Teams will have three minutes before the first run where they will explain their component and its planning.
- Components must be safe and not harm team members, judges, the audience, furniture, or equipment outside the bounds of the components. No hazardous materials, explosives, or flames may be used on or within the machine. Questions about the safety of specific steps should be directed to the professor during design. The machine must be safe to the satisfaction of the professor.
- The professor must approve all functions of the component.

Each team was given an eight dollar credit with which they were allowed to purchase items for use in building their component of the Rube Goldberg Machine. The items available along with their prices are given in Table 3.

Table 3. Items Available for Purchase with Eight Dollar Credit

Please note, these items have been purchased and are available for you to use on your Rube Goldberg project. While no money will change hands for these parts, you can only use eight dollars in total value of these items. Teams may exchange items with other teams on their own terms, but all items must be included in budgets. All sales are final. First come, first served. Limited quantities of items.

Golf Ball	1 for $1.00
Ping Pong Ball	1 for $1.00
Dominos	4 for $1.00
7 Ounce Solo Cups	5 for $1.00
20' Length of Kite String	1 for $1.00
10" Length of Dowel Rod (between .25 and .5" diameter)	2 for $1.00
Duct Tape Roll (10 yard length)	1 for $1.00
10" Length of PVC Pipe (2" diameter)	1 for $1.00
6" Length of Wood Block (3/4" by 1/2")	4 for $1.00
12" Length of Wooden Angle (1.5" by 1.5")	2 for $1.00
8" Length of Cardboard Angle (approx. 2.5" by 2.5")	1 for $1.00
Large Popsicle Sticks	5 for $1.00
Wooden Paint Stirrer	1 for $1.00
¾" Sheet of Styrofoam (approx. 14" by 24")	1 for $1.00

Since the Rube Goldberg Project was completed in a course on project management and leadership, students were told that the emphasis of the project was on planning and tracking their work on the project. Specific instructions given to the students about the project deliverables and the acquisition of component parts for assembling their piece of the machine are given in Table 4.

Table 4. Instructions on Project Deliverables and Acquisition of Component Parts

- This is a project management class, so the emphasis will be on the planning and tracking of progress of the project. Before constructing their component, each team must submit a rough sketch of their component for approval by the instructor; a detailed budget, a coded work breakdown structure, and a project network for building the component; and estimates of time requirements for team members.
- Each week of the project, teams must update their budget documentation of the materials used and the time spent by each team member. This will act as the tracking for the project process. This documentation needs to be a running log including time sheets signed by each team member attesting that the effort and costs are accurate. It should also evolve to cover any communication issues or risks encountered in the process.
- Teams may acquire some of their materials from the professor for no actual cost, but there are prices for those materials that must be accounted for in the budget and tracking. There is a limit to the amount of materials teams may acquire from the instructor and loose items provided by the instructor (dominoes and balls) must be returned.
- Teams may purchase additional materials with their own money, but are encouraged to keep out-of-pocket costs per component to less than $20 (or $5/student). These materials must be included in the budget and tracking documents at cost. Found or recycled materials (such as paper towel rolls or small toys) may be used, but an estimated value should be included in the budget and tracking documents.
- Any major changes to the approved design or budget must be submitted via a change order for instructor approval.
- An intermediate update of the project process including budget and time is due approximately halfway through the project. This will include a personal reflection as to the challenges of the project.
- A final close out report that includes the accounting of time and materials, lessons learned, and a summary of the project is due the night of the project demonstration.

Additional instructions given to students about the operation of the Rube Goldberg Machine are shown in Table 5 (Rube Goldberg Machine Contest 2015 Official Rule Book, 2015).

Table 5. Additional Operational Instructions

- The full machine will have three runs on the project night. A successful run is each of the steps progressing within each component and on to the next team's component until the zipper is zipped. Teams will be judged on the best run of the three. Additional runs by the full machine or individual components are at the discretion of the instructor and judges.
- Only two team members may interact with the component once the run has begun. This includes resetting the component. If a component does not function properly, the instructor may give permission for one of the two team members to intervene. Otherwise, the component should function without any human interaction.
- A step or operation in the component should be considered a transfer in energy from "one action to another action." Identical transfers of energy in succession should be considered one step. For example, a set of dominos falling into each other should be considered one step. (Rube Goldberg Machine Contest 2015 Official Rule Book, 2015).
- Gravity is your friend. Each component will be set up on the ground for its run. You should be creative in using height to give each step/operation momentum to engage the next step/operation.
- Each component must have three unique steps or operations. For example, it cannot use dominos in more than one operation per component.

3.2 Management of the Project

Early in the semester student teams were required to meet with the professor to discuss their initial project plan and budget. About a month later they were required to submit a sketch of their component of the Rube Goldberg Machine along with an updated project plan and budget. Near the end of the semester student teams again submitted updated documentation of their project plan and budget. At this time individual students also submitted a short paper discussing their role in the project to date, their expected role moving forward, and a critical reflection of what had and had not gone according to plan. A close out report covering an updated project plan and budget along with a narrative on the lessons learned in the project was submitted along with the final component of the Rube Goldberg machine on the last day of class. Project planning and tracking was done in Microsoft Excel®.

Throughout the semester students were told that the goal of the project was to plan and track a project from project initiation to completion rather than building the best possible Rube Goldberg machine. They were told that being over or under budget would not affect their grade on the project and that part of the learning experience associated with the project was to gain an understanding of difficulties associated with project planning, project control, and change management. They were urged to be honest and transparent in their updated project plans.

3.3 Judging of the Rube Goldberg Machine Components

Project components were judged during the last class of the term by invited judges. Judges were given a judging form (shown in Table 5) and were told that they could either use the form or judge the machine components without using the form. The entire machine was run three times and judges then met to select the top three components. Prizes were awarded to the teams who built the top three components.

Table 5. Judging Form (Adapted from the official Rube Goldberg Machine Contest Judging Form, Rube Goldberg Machine Contest 2015 Official Rule Book, 2015)

The purpose of the group project was to have students plan and manage a project in a setting where they would need to coordinate with other teams to build separate components to a system. Their grade is determined by how well they planned and tracked their project plan for their component. Quality and complexity of the component will not be stressed as part of the grading process. However, in the spirit of Rube Goldberg and differentiating their work, students understand their projects will be judged to win prizes and personal/group bragging rights.

Please give each component a score on the below factors (maximum points listed next to each):

_____ Explanation of Component (0-10 points)
How well does the team describe what the component will do and the planning process to get to that point?
_____ Rube Goldberg Spirit (0-10 points)
How well does the component make a simple task overly complicated?
_____ Uniqueness of Steps (0-10 points)
How well did the team incorporate unique or creative items into their component?
_____ Coordination of Component (0-10 points)
How well does the team coordinate component resetting and working with the adjacent teams?
_____ Creativity and Theme (0-5 points)
How creative is the design or function of the component – both aesthetically and functionally?
_____ Quality of Design and Construction (0-5 points)
How well is the machine designed and built?

The Rube Goldberg machine assembled and run during the last class of the term is shown in Figures 2 and 3.

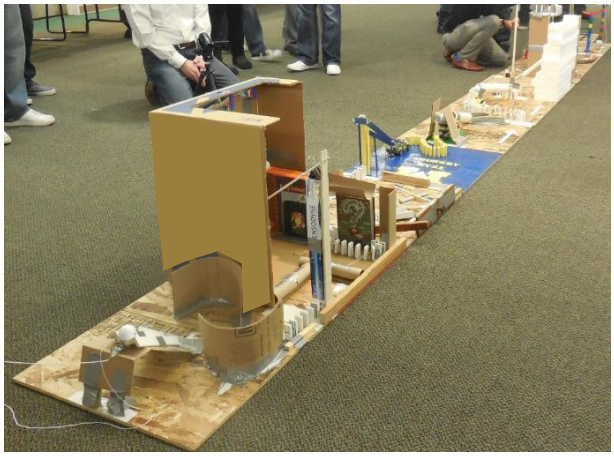

Figure 2. Front View of Rube Goldberg Machine

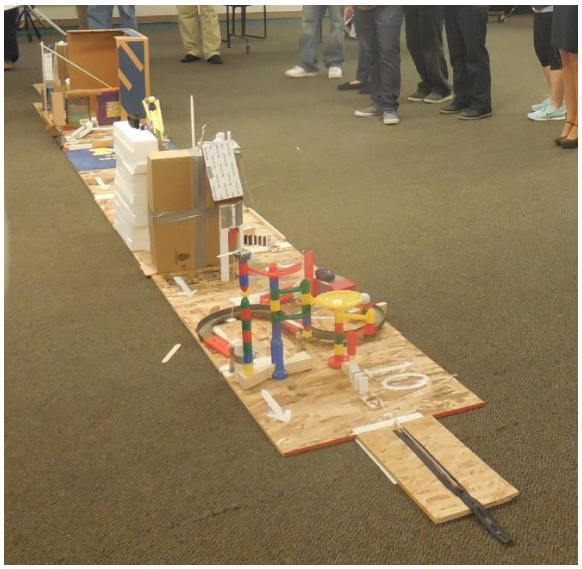

Figure 3. End View of Rube Goldberg Machine

4. Student Perceptions of the Rube Goldberg Machine Project

Students completed a survey about the Rube Goldberg Project during the last class of the term. The survey questions are based on a previously used survey (Izberk-Bilgin, Klein, Chandra, Lee, and Susko, 2012) and are shown in Appendix A. Thirty-six students completed the survey for a response rate of ninety percent. Half of the students (18) were seniors, seventeen were juniors, and one was a sophomore.

Table 6 reports student perceptions of the Rube Goldberg Project as measured by the survey. Items were measured on a 7-point Likert scale with 1 indicating "a little" and 7 indicating "a lot."

Table 6. Student Perceptions of the Rube Goldberg Machine Project

Survey Item	Average Score
How much did you know about project management before taking this course?	3.0
How much do you know about project management after taking this course?	5.7
How much did you know about leadership skills before taking this course?	4.2
How much do you know about leadership skills after taking this course?	5.8
How much would you say your knowledge of project management improved as a result of participating in the Rube Goldberg project in this course?	5.2
How much would you say your leadership skills improved as a result of participating in the Rube Goldberg project in this course?	5.3
To what extent would you describe the Rube Goldberg project assigned in this course as fun?	4.8
To what extent did the Rube Goldberg project assigned in this course help you understand the course concepts?	5.4
To what extent do you believe you will be able to apply the skills you learned by working on the Rube Goldberg project in this course to other courses you will take in the future?	5.3
To what extent would you recommend that a friend enroll in a section of this course in which the Rube Goldberg project will be assigned?	5.6

Student feedback on the course and on the Rube Goldberg project was generally positive. Students rated their knowledge of project management before taking the course an average of 3.0 and after taking the course an average of 5.7 for an improvement of 2.7 points on a seven-point scale. They also rated their knowledge of leadership skills before taking the course an average of 4.2 and after taking the course an average of 5.8 for an improvement of 1.6 points. On average, they indicated that their knowledge of project management and their leadership skills improved as a result of

participating in the Rube Goldberg project in the class. They also viewed the project as fun and helpful in understanding the course concepts. Additionally they indicated that they believed they would be able to apply the skills they learned working on the project to their future courses and that they would recommend a section of the course in which the Rube Goldberg project is assigned to a friend.

Students also responded to a series of open-ended questions about the Rube Goldberg project. Students were asked to describe the strengths and weaknesses of the Rube Goldberg project. As illustrated by the student comments in Table 7, students mentioned the development of teamwork skills, project management skills, leadership skills, communication skills, and creativity when asked about the strengths of the project.

Table 7. Student Comments on Strengths of the Rube Goldberg Machine Project

The strengths in the project were teamwork, our team worked very well together and we had a fun time doing it.
Gave way for practice of project management skills.
Leadership skills improved. Team building. Time management. Different type of work. Fun.
Time management. Task management. Project management. Communication. Teamwork.
Teamcommunication/coordination.
Allows you to be creative.
Communication skills. Leadership skills. Planning. Budgeting.
Teamwork. Creativity. Time management.

As illustrated by the student comments in Table 8, weaknesses of the project mentioned by students include lack of structure; issues related to finding the time to meet and work on the project; problems related to team cohesion, anxiety, and stress; and the time required to complete the project.

Table 8. Student Comments on Weaknesses of the Rube Goldberg Machine Project

Loosely structured
Too long. Little guidance.
Long project duration.
The teams were not cohesive. Members didn't enjoy working with each other.
There was a lot of anxiety involved in trying to stay on task.
Stressful.
Takes too long to complete.
Required team members to meet often which was sometimes hard to do.

As illustrated by the student comments in Table 9, when asked to suggest improvements to the Rube Goldberg project students suggested that more class time be devoted to project work and that students be allowed to select their own team members.

Table 9. Student Comments on Proposed Improvements to the Rube Goldberg Machine Project

By scheduling run-throughs during class meeting times.
It would have been nice to have had more time during class hours to work on the project.
Allow extra time in class for work time.
We could pick our own team members.
Not random teams.

Students mentioned communication issues within and between project teams and scheduling and attending meetings when asked about the most challenging aspects of the Rube Goldberg project (see Table 10 for sample student comments).

Table 10. Student Comments on Challenging Aspects of the Rube Goldberg Machine Project

The most challenging portion of this project was the communication demands. We overcame this through using group text messaging and online communication.
Communication with team members and other teams.
Getting through to each other. Rather than using traditional email, we successfully used Google Hangouts.
Meeting with our group at convenient times and meeting with the other groups.
Meeting with the team. Completing tasks separately then putting them together at the end.
The biggest challenge was meeting with the whole group. We each took turns taking the plywood and working on it.

Students indicated that the Rube Goldberg project helped to improve their understanding of project management in a number of ways. As illustrated by the student comments in Table 11, they noted that the project helped them learn to work well in groups, helped them learn to apply the principles of project management, and helped them develop their project management skills.

Table 11. Student Comments on Project Management and the Rube Goldberg Machine Project

The project helped me learn to work well with groups, and work well others.
Allowed us to apply theories – skills.
Time management and organizational skills greatly improved.
It helped me to learn how to correspond better and how to handle situations more diplomatically.
It helped me improve my understanding of each process taken in project management.
The hands on approach made everything easier to understand.

Students also indicated that the project helped them improve their leadership skills (see Table 12 for sample student comments).

Table 12. Student Comments on Leadership Skills and the Rube Goldberg Machine Project

It allowed me to step up and lead our group.
I believe it helped bring out my leadership skills.
Taught us to take charge and help each other succeed.
It showed me how to take more control of a project.
I had to take initiative and coordinate my schedule with others, offer my skills/expertise and pick up slack where others fell short.

Finally, as illustrated by the student comments in Table 13, students mentioned team building, project planning and execution, and the opportunity for creative expression as the most useful aspects of the project.

Table 13. Student Comments on the Most Useful Aspects of the Rube Goldberg Machine Project

The most helpful part was that everyone was involved with the project.
It was a team bonding experience. Doing the documents helped.
The most useful was the planning and execution part of the project.
Most useful aspect of project is being able to use different objects. "No boundaries."
Creativity. "Making the project your own."
To be creative.

5. Conclusion

Colleges of business need to deliver project management and leadership skills to their students across all of their majors. A persistent challenge of courses designed to deliver these skills is the search for a meaningful and sufficiently challenging project that can be completed by students from a variety of backgrounds. The Rube Goldberg Machine Competition task piloted in the course and described in this paper provides a promising task for student teams to complete while learning the skills of project management and leadership. The task is sufficiently challenging so that key issues in project management and leadership are likely to arise, yet not so challenging that a great deal of specialized expertise is required to successfully complete the project. Initial feedback from students about the project is generally positive with the results of a survey of students completing the course suggesting that students believe that the project helped them improve their project management and leadership skills.

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Appendix A
Survey Questions

Student Level:_____Freshman_____Sophomore_____Junior_____Senior

Part I. Please answer the following questions by circling the appropriate number.

	A Little			Somewhat			A Lot
1. How much did you know about project management before taking this course?	1	2	3	4	5	6	7
2. How much do you know about project management after taking this course?	1	2	3	4	5	6	7
3. How much did you know about leadership skills before taking this course?	1	2	3	4	5	6	7
4. How much do you know about leadership skills after taking this course?	1	2	3	4	5	6	7
5. How much would you say your knowledge of project management improved as a result of participating in the Rube Goldberg project in this course?	1	2	3	4	5	6	7
6. How much would you say your leadership skills improved as a result of participating in the Rube Goldberg project in this course?	1	2	3	4	5	6	7
7. To what extent would you describe the Rube Goldberg project assigned in this course as fun?	1	2	3	4	5	6	7
8. To what extent did the Rube Goldberg project assigned in this course help you understand the course concepts?	1	2	3	4	5	6	7
9. To what extent do you believe you will be able to apply the skills you learned by working on the Rube Goldberg project in this course to other courses you will take in the future?	1	2	3	4	5	6	7
10. To what extent would you recommend that a friend enroll in a section of this course in which the Rube Goldberg project will be assigned?	1	2	3	4	5	6	7

Part II. Please answer the following questions about the course as fully as possible.

1. In your opinion, what were the strengths of the Rube Goldberg project?
2. In your opinion, what were the weaknesses of the Rube Goldberg project?
3. How could the Rube Goldberg project be improved?
4. What did you find to be the most challenging aspect of the Rube Goldberg project? How did your group deal with this challenge?
5. In what ways did the Rube Goldberg project help you to improve your understanding of project management?
6. In what ways did the Rube Goldberg project help you to improve your leadership skills?
7. What did you find to be the most useful aspect of the Rube Goldberg project?

Author Biographies

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Tim Davis is the Director of iLabs, the University of Michigan-Dearborn's Center for Innovation Research, and a Lecturer of Business Administration at the College of Business at the University of Michigan-Dearborn. Prior to joining the University of Michigan-Dearborn he worked in government assisting with economic development, business retention programs, and financial planning.

Ghassan Kridli is Professor of Industrial and Manufacturing Systems Engineering at the University of Micihgan-Dearborn. He received his Ph.D. from the University of Missouri-Columbia and his M.S.M.E. and B.S.M.E from the University of Miami. Professor Kridli has published in the *International Journal of Plasticity*, the *Journal of Materials Engineering and Performance*, the *International Journal of Mechanical and Materials Engineering*, the *Journal of Materials Processing Technology*, and other journals.