AC 2010-76: INTELLIGENT RUBE GOLDBERG USING VEX ROBOTICS DEVELOPMENT SYSTEM

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Intelligent Rube Goldberg
Using Vex Robotics Development System

Abstract

Rube Goldberg development is commonly used in early engineering education, especially in first-year programs and introduction to engineering courses as well as secondary school engineering activities. Regardless of the problem, the concept of utilizing Rube Goldberg in engineering education is about having engineering students understanding the problem solving process by experiencing it. They generate a design and see it through its development for a successful outcome. In the process of developing Rube Goldberg mechanisms, the students are able to practice skills such as communication, teamwork, time and project management, and experimentation. Rube Goldberg projects also assist in maintaining students' interest in science, mathematics and engineering. These projects are great way to teach engineering applications of basic science concepts such as magnetic induction, gravity, friction, or drag. This paper starts with a background on Rube Goldberg mechanisms and their utilization in engineering education. However, the main focus is given to employment of microcontrollers in Rube Goldberg mechanisms. The authors worked with a multidisciplinary group of freshmen software and mechanical engineering students to complete an Intelligent Rube Goldberg mechanism to assemble cheese sandwiches. VEX Robotics Development System was selected to complete the task at hand. The project was accomplished by generating an automated assembly line with Rube Goldberg contraption elements controlled by a VEX microcontroller. The Robot C programming language was used for programming. The project details, project evaluation and student responses are also included to conclude this paper.

Background

Accreditation Board for Engineering and Technology (ABET) and the industry demands that engineering students be able to "do" design, to work in teams and to be effective communicators[1]. Freshman engineering course "ENGR1010: Introduction to Engineering" introduces engineering students to the design and developments processes through an implementation of a Rube Goldberg device. Rube Goldberg is used to trigger and maintain student motivation for engineering as it provides a mechanism for "learning while having fun". The development process used facilitates teamwork and emphasizes on communication.

Webster's dictionary defines the Rube Goldberg concept as "Accomplishing by complex means what seemingly could be done simply"[2]. This is how for 55 years Reuben Lucius Goldberg, a Pulitzer Prize winning artist, portrayed machines and gadgets which he saw as excessive. He was sometimes skeptical about the technology as well. His cartoons combined simple machines and common household items to create complex and wacky machines that accomplished trivial tasks. While most machines work to make difficult tasks simple, his designs made simple tasks complex. For instance he designed a simplified pencil sharpener, a safety device for walking on icy pavements, and dealt with problems like putting a stamp on an envelope, screwing in a light bulb, or making a cup of coffee in 20 or more steps. Throughout the years more and more Rube Goldberg implementations have been seen. *"The Way Things Go"*, a 30 minute film produced in

1987 by Peter Fischli and David Weiss depict 100 feet of physical interactions, chemical reactions, and precisely crafted chaos worthy of Rube Goldberg[3]. This Rube Goldberg implementation utilized fire as the main element to drive the chain reaction. *"The Cog"*, Honda Corporations two-minute long commercial for their Accord model automobile, is yet another Rube Goldberg implementation used to present their product in an attractive way [4]. Similar mechanisms are made worldwide but go by different names. In Japan, these contraptions are called "Pythagorean Devices", named after the Greek Mathematician, Pythagoras. These devices are shown in a 15 minute educational television program for kids called, Pythagora Switch, which encourages children to learn and to think. In the U.K., they are named after a similar cartoonist, called, Heath Robinson, and are called Heath Robinson contraptions. Likewise in Denmark, they are called Storm P. Maskiner after the Danish animator Robert Storm Petersen[5].

Rube Goldberg's work continues to connect with adult audiences who are well immersed in the modern technology as well as younger fans intrigued by the creativity and innovation factors involved in the designs. Today Rube Goldberg inspires hobbies, competitions, and course projects in the academia. The most widely known Rube Goldberg competition is a national event held annually at Purdue University. The National Rube Goldberg Machine Contest has for 22 years invited teams of engineering students to design and build complex machines that perform basic chores. The competition brings Goldberg's inanimate cartoons to life in a way that moves students away from traditional ways of looking at problems and sends them deep into imagination. The resulting inventions are collections of bits and pieces, parts of useless machines scraped together to achieve an innovative and imaginative contraption to resolve the problem at hand. The contest began as a rivalry between two Purdue engineering fraternities and was popular at Purdue in the 1940s and 1950s. Since it's revival in 1983, winners have appeared on various TV shows including Jimmy Kimmel Live, Late Night with David Letterman, NBC's Today, CBS's This Morning, CBS News, Beyond 2000, CNN and ABC's Good Morning America[6].

Argonne National Laboratory defines a successful Rube Goldberg machine - the one that is competitive in Rube Goldberg machine contests[7]. Projects that depicted the following qualities are more favored by the judges in the competitions:

- The machine completes its tasks without any (highly desired) or with minimal human intervention.
- The machine steps are clearly visible and are adequately explained during presentations.
- The machine has more antigravity power steps (highly desired) or with minimal number of gravity power steps.
- The machine is not entirely powered by electrical motors or uses minimal electrical power to move objects.
- The teams show strong team spirit.
- The machine incorporates adequate safety features.

Rube Goldberg in Engineering Education

At a time when the U.S. is looking to inspire young minds, Rube Goldberg's legacy represents the best in American innovation, humor and unconventional thinking[6]. Engineering programs in the U.S. universities are using Rube Goldberg for two purposes: to expose younger students to engineering and to encourage engineering students to think outside the box. Rube Goldberg is a great way to teach basic principles of science like magnetism, gravity, and friction. In addition, Rube Goldberg projects also promote patience and discipline, and assist in maintaining students' interest in science, mathematics and engineering.

At Texas Tech University, Rube Goldberg engineering projects teach students how to take an idea from paper and turn into reality[8]. For the past eight years each fall semester Texas Tech civil engineering students, mostly freshmen, have their own chance at devising Rube Goldberg machines. Students have carried out projects to accomplish very precise engineering tasks such as leveraging a solid wooden cube onto a tall block and moving a small object two inches onto a platform. A pilot freshman curriculum has been designed and implemented in the Mechanical Engineering Department at the Rochester Institute of Technology[9,10]. The course sequence gives freshmen an overview of a broad range of mechanical engineering activities. The first course gives students most of the basic tools they will need and the second is centered on an electromechanical Rube Goldberg design project, undertaken by the whole class. Students develop the design concept, build the system, and prove that it works. They are able to practice skills such as communications, teamwork, time management, and experimentation. At Carnegie Mellon University a general robotics class requires students to design simple Rube Goldberg machines[11]. University of South Carolina (USC) is seeding a novel engineering curriculum in South Carolina middle and high schools as a part of a national effort to expose younger students to the vocational education. USC's Project Lead the Way program exhibits an elaborate Rube Goldberg apparatus in the basement of their mechanical engineering building[12]. Finally, at _________ University Rube Goldberg is utilized as a course project in ENGR1010, an introductory freshman engineering course.

Rube Goldberg Projects at __________ University

Since the Fall Semester of 2005 the Engineering Department at ___________ University has assigned Rube Goldberg projects in ENGR1010: Introduction to Engineering. Students are guided by the following constraints:

1. Minimum 15 steps are required for the mission to be completed.
2. Items easily found (not purchased) should be used as much as possible. (highly desired)
3. Worth of purchased items should not exceed $50.00.
4. Minimum human intervention is encouraged and will result in higher grade. (highly desired)
5. Mechanical or electrical components/devices could be used to accomplish the task.
6. Any food related projects' products should be edible.
7. Live animals should be excluded from all designs.

Students work in teams of four or five and are required to follow a detailed engineering design and development approach. The steps of the approach are presented below:

1. Inception (Problem Identification & Problem Statement Generation): In this phase the teams study the problem at hand. They first gather the facts about the requirements and then they define the problem and its constraints.

2. Conceptual Design (Alternative Concept Generation): The teams generate alternative concepts as potential solutions. Sketches are accompanied with explanations.
3. Product Design: After selecting the best feasible solution, adequately labeled engineering drawings of each component and of the entire product are prepared in assembly form. The Bill of Materials (B.O.M.) is completed.
4. Product Development: The Rube Goldberg contraption is fabricated.
5. Product Testing & Implementation: Adjustments are made to improve the effectiveness of the solution during testing.
6. Product Retirement: Product is disassembled or displayed at the laboratories.

The teams are required to submit the following works throughout the project:

1. Project Proposal: The teams submit an engineering proposal consisting of a problem statement, project objectives, preliminary B.O.M and a plan of action. This is due one week after the project is assigned.
2. Project Progress Updates: The students provide a weekly update to the instructor and their team either via email or through pre-scheduled meetings. Altogether 9 updates are required. In these updates the teams are required to communicate the following:
    a. What happened the past week?
    b. What will happen this week?
    c. What are the major issues the team is facing?
3. Project Report: At the end of the term the teams submit a comprehensive project report. This report provides the details of how the project is executed. It constitutes an abstract, the project objectives, the plan of action, a Gantt chart depicting the management plan (including tasks, resources, timeline) and an important section on discussion and results. In this section the students describe each step of the design and how it functions to support the entire Rube Goldberg mechanism. Students are also required to include a summary section on project post- mortem.
4. Project Presentation: At the end of the term the teams present their product to the class and guests. The presentation consists of both a Power Point Presentation and a successful execution demonstration of the Rube Goldberg mechanism. Students are evaluated by the instructor and by their peers. Time durations and rules for the presentation are:
    a. Total Time: 15 minutes per team - 10 minute Power Point presentation, 5 minutes for Questions/Answers following up the presentation.
    b. Presentation of the working implementation.
        i. Explanation of each important component in detail.
        ii. Demonstration of the working implementation successfully in three attempts.

As Rube Goldberg development is heavily based on creativity, students are asked to use all of their imaginations to come up with a design that functions, is feasible within the cost limit, and is fun to work with. In the past, students have used electricity (AC and/or DC), hydropower, robots and simple weight-based mechanisms to build their projects.

In addition to the criteria briefly discussed above, the students are required to accomplish the following elements:

- Communication: The teams are required to effectively communicate with each other to ensure project success. Project proposal, team meetings, project construction, project progress updates, and project report provide mechanisms for team communications.
- Teamwork: The teams are required to practice the 5 growth stages of a team: Forming, Storming, Norming, Performing, and Adjourning. The teams are told that “No Teamwork means No Successful Project” and “A successful project that lacks teamwork is a failed project”. The team meetings, project construction, and project demonstration provide mechanisms for teamwork. The teams are also encouraged to bring up matters that are counter-productive to the team in a timely manner. However, they are requested to resolve the matter within themselves and the instructor will intervene only as a last resort.
- Recycle: The teams are encouraged to utilize previously used items which are easily found (but not purchased).
- Fun Factor: Teams are encouraged to enjoy the process as they go through the engineering design and development steps. It is believed that the fun factor helps establish ownership of the project and passion for project completion.

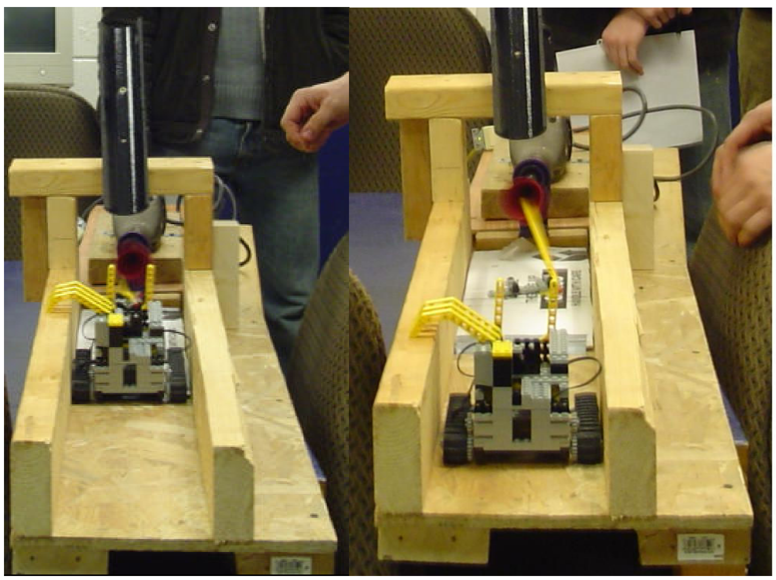

Figure 1. LEGO Mindstorms equipment being utilized for a Rube Goldberg mechanism

Over the years students have worked on projects that make scrambled eggs, sharpen pencils, crush empty soda cans, and assemble cheese sandwiches. A wide variety of means have been employed by the students including robotics as shown in Figure 1. Other project examples using more conventional means are illustrated in Figure 2. In this paper, the authors present in detail an intelligent Rube Goldberg device that makes use of Vex Robotics Development System to assemble a cheese sandwich.

Intelligent Rube Goldberg

The Center for Intelligent Machines at McGill University defines intelligent machines as “machines capable of adapting their goal-oriented behavior by sensing and interpreting their environment, making decisions and plans, and then carrying out those plans using physical actions" [13]. Along the same lines the authors define an

Figure 2. A Rube Goldberg project with conventional means

Intelligent Rube Goldberg as those machines that are capable of accomplishing a Rube Goldberg goal through physical actions initiated through the interpretation of environmental data obtained through sensors. During fall of 2008, students in ENGR1010 were assigned a Rube Goldberg project with an objective of assembling a cheese sandwich made up from two slices of sandwich bread and a slice of cheese. The students were guided by the rules and deliverable requirements listed in the previous section. 90% of the grade was allocated for accomplishing the given set of requirements and an additional 10% of the grade was designated for creativity. While different groups made their intelligences and experiences in different areas useful, one group decided to control the Rube Goldberg mechanism with a microcontroller meeting the definition of an Intelligent Rube Goldberg machine. The group explained their design concept by stating, "Where most teams built a traditional elaborate mechanism, our team uses software to accomplish the task at hand".

Students were recommended by the authors to use the VEX Robotics Development System. A conveyor was built using the tank threads of the VEX Robotics Development System as shown in Figure 3. This solution was chosen due to such system's ability of being consistent in terms of placing the bread and cheese slices at the same locations in repeated operation. This is an automation principle, repeatability. While the conveyor was driven by a DC VEX motor, dispensers were actuated by VEX servomotors. Wood and PVC were utilized to build the conveyor frame and the dispensers. Along the conveyor 4 VEX limit switches were placed to be tripped by the plate used for the sandwich assembly. 3 identical dispensers were designed and placed above the conveyor for dispensing the bread slices and the cheese slice. Each dispenser operated by a servomotor that flipped the lever of dispenser dropping the bread or cheese onto the plate. Appropriate time delays are applied before each critical activity of the control sequence.

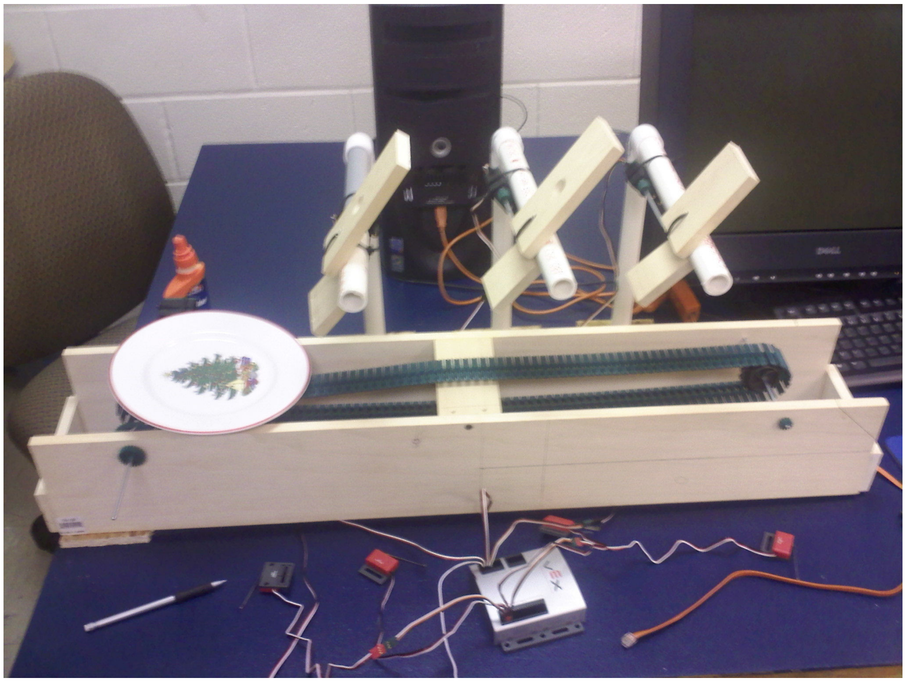

Figure 3. Intelligent Rube Goldberg Mechanism/cheese sandwich assembly line – construction in-progress

The intelligent machine accomplished the following 17 steps to meet its goal:

1. Flip the microcontroller switch – The machine is turned ON and the levers are reset.
2. During the ten second interval (time delay) the machine is loaded with bread and cheese slices.
3. DC motor starts (motor[port1]) and plate begins moving along the conveyor.
4. First limit switch (touchSensor1) is triggered by the plate.
5. The conveyor belt stops.
6. The servomotor turns ON (motor[port2]) flipping the lever and the first slice of bread falls.
7. The belt begins moving again with the bread on the plate.
8. The second limit switch (touchSensor2) is triggered by the advancing plate.
9. The conveyor belt stops.
10. The second servomotor turns ON (motor[port3]) flipping the lever and the cheese slice falls.
11. The conveyor belt starts moving again with the plate, bread and cheese.
12. The third limit switch (touchSensor3) is triggered by the advancing plate.
13. The conveyor belt stops.
14. The third servomotor turns ON (motor[port4]) flipping the lever and the second slice of bread falls.

15. The conveyor belt starts moving again and the cheese sandwich assembly moves toward the final limit switch.
16. The fourth limit switch (touchSensor4) is tripped.
17. The conveyor stops (motor[port1]) presenting the plate and the cheese sandwich assembly at the edge of it.

Block diagram of the process is depicted in Figure 4. In terms of the programming efforts, Carnegie Mellon University's Robot C programming environment and language was used. Since one of the team members was a software engineering major, the team took advantage of his expertise in programming. The program syntax is listed in Figure 5:

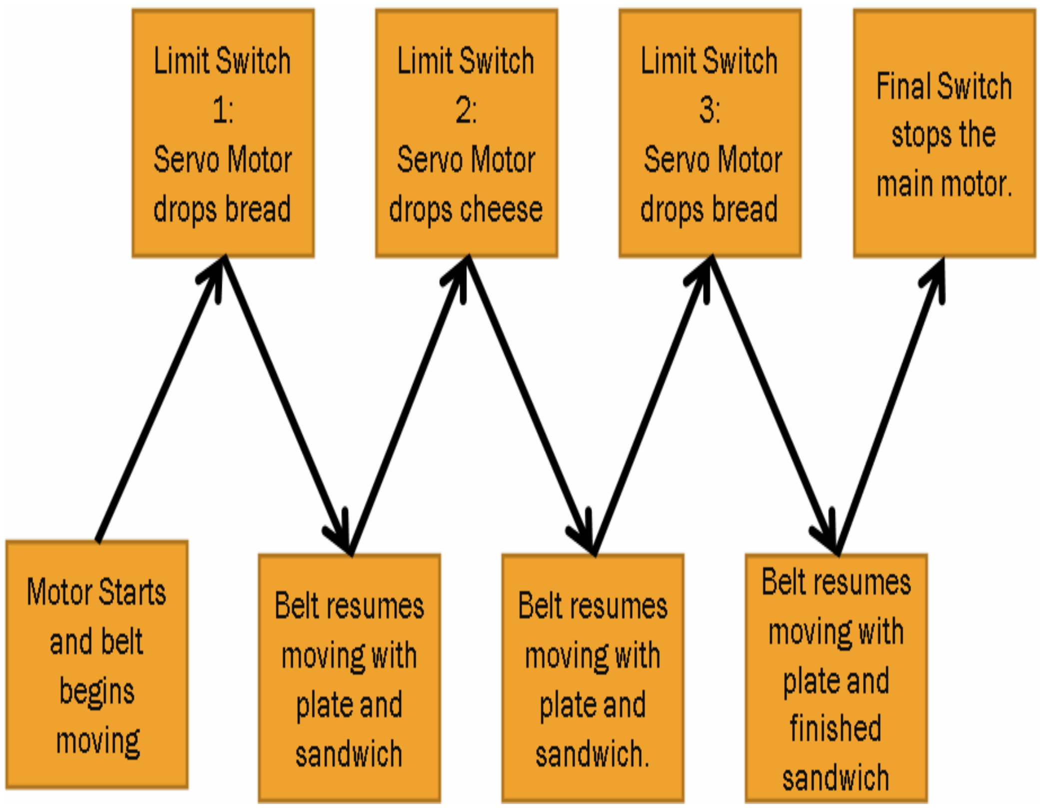

Figure 4. Block Diagram for the Logic

Rube Goldberg Judges' Evaluation and Student Feedback

Based on the Argonne National Laboratory criteria listed previously the Intelligent Rube Goldberg implementation was evaluated:

- The machine completes its tasks without any (highly desirable) or with minimal human intervention: This criterion is met. Once the program is initiated the software modules control the overall execution of the required steps. Human intervention is not necessary.
- The machine steps are clearly visible and are adequately explained during presentations: This criterion is met. The steps are clearly labeled in the program code as well as in the physical implementation.

- The machine has more antigravity power steps (highly desired) or with minimal number of gravity power steps: This criterion is not applicable as this implementation is executed by a controller through a program code.
- The machine is not entirely powered by electrical motors or uses minimal electrical power to move objects: This criterion contradicts the authors' definition of intelligent Rube Goldberg. Being an intelligent device it utilizes power that is controlled through a program code.
- The team shows strong team spirit: This criterion is met. The teamwork depicted was exceptional. The strengths and weaknesses of the team members were adequately utilized resulting in a successful implementation.

```
task main ()
{
            motor[port2]=-127;
        motor[port3]=-127;
motor[port4]=-127;
wait1Msec(10000);
while(SensorValue(touchSensor4)==0)
{
            motor[port1]=35;
                        if(SensorValue(touchSensor1)==1)
                        {
motor[port1]=0;
motor[port2]=127;
wait1Msec(2000);
motor[port2]=-127;
wait1Msec(2000);
while(SensorValue(touchSensor4)==0)
}
motor[port1]=35;
}
            }
            if(SensorValue(touchSensor2)==1)
                        {
            motor[port1]=0;
            motor[port3]=127;
            wait1Msec(2000);
            motor[port3]=-127;
            wait1Msec(2000);
            while(SensorValue(touchSensor4)==0)
            }
                        motor[port1]=35;
            }
if(SensorValue(touchSensor3)==1)
                        {
            motor[port1]=0;
            motor[port4]=127;
            wait1Msec(2000);
            motor[port4]=-127;
            wait1Msec(2000);
            while(SensorValue(touchSensor4)==0)
            }
                        motor[port1]=35;
            }
}
            }
            SensorValue(touchSensor4)=1;
Motor[port1]=0;
}
```

Figure 5. Syntax of the program

- The machine incorporates adequate safety features: This criterion is met. The implementation does not provide any safety hazards due to the design and process parameters chosen.

At the end of the project, the students are required to perform a self/peer evaluation and project reflection. The questions asked and some of the student feedbacks are listed below:

1. What did you learn from this project experience?
   - I understand that communication and organization are the keys to a successful team project.
   - I understand that keeping control of project timelines are important.
   - I learned that everyone in a project do not contribute equally.
   - I now understand that "divide and conquer" is an important strategy in engineering projects.
2. How will you use this experience to improve personally and professionally?
   - I have improved my ability to communicate with people.
   - My time management skills have improved.
   - I have learnt social skills to be a team player.
   - I am now a better problem solver.
3. If you were to go back in time what would you do differently?
   - I would have insisted on more group communication
   - I would encourage my team to start working on the project sooner.
   - I would encourage my team to assign tasks and be accountable.
   - I would spend more time on testing.

Conclusions

This intelligent Rube Goldberg project provided a unique engineering design experience for the students. Instead of using traditional devices and gadgets to accomplish the goal of making a cheese sandwich, a microcontroller with programming ability, and multiple sensors were used. Students successfully accomplished the task by strictly following authors' guidelines and the recommended detailed engineering design and development approach. All required work products were submitted and presented within the deadline. Students were evaluated for communication, teamwork, recycling, and fun factors. The team communicated amongst themselves daily and with the instructor weekly. They kept a log of their communications. During the presentations the team excelled by properly explaining all the steps and then successfully demonstrating their machine. The teamwork observed in this team was exceptional. Roles were clearly defined and timely executed. During the course of the project all three team members remained engaged and successfully completed their allocated tasks. As previously mentioned, one member conducted the programming tasks, while the other two members designed and assembled electrical and mechanical elements of the intelligent Rube Goldberg contraption. On top of their individual roles, members also learned from the expertise of one other. The budget for this machine was minimal with the bulk of the budget being used for fresh cheese and bread. Students borrowed the VEX Robotics Development System from the engineering laboratories and the PVC pipes and wood were picked up from scrap storage of the

_________Engineering Department. As a note on creativity, the students used VEX tank threads to develop their conveyor for the mechanism.

Student feedback during and after this learning experience were very positive. The students were observed to be having fun while working on the project. The project was voted one of the best by the observers and because of its compactness is being used currently by the _______ Engineering Department as a demonstration aid for visitors. In addition, 5 years of feedback from the students indicate their appreciation of these practical Rube Goldberg projects, and associated design and development process as well as innovative problem solving exercises. Most of the students also value other project requirements such as team work and communications, both written and oral.

A project of this nature, where a system, component or a process is designed through fun- filled and challenging activities, gives students a better understanding of the work of an engineer and assists in maintaining student interest in engineering. Students are able to capitalize on their early exposure to engineering design and related activities as they perform in other course-based projects later in their engineering education. An early start thus enhances students' design skills and makes them more confident and competitive, better preparing them for similar future challenges.

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