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120th ASEE Annual Conference & Exposition
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June 23-26, 2013

Paper ID #6385

An Undergraduate Research Project on Developing a 3D Vision System for an Industrial Robotics Project

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Abstract

Engineering and Engineering Technology Students need to learn to innovate and embrace new technologies as they develop and progress through their careers. The undergraduate degree program can provide this first opportunity at innovation allowing the student to gain experience and confidence at solving technological problems. This paper describes the learning experience of an undergraduate student team composed of mechanical engineering and mechanical engineering technology students. The paper relates the successful attempt the students had in developing and using innovation through the design and creation of a 3D vision system to work in concert with a SCARA type industrial robot system. The undergraduate student project team was self-directed and had to use innovation to develop a 3D vision system comprised of a single industrial laser proximity sensor. The students used the sensor to develop a 3D array. The 3D array developed was used to first characterize the 3D part that was randomly delivered by a conveyor system and then program the robotic system to analyze and determine if and where the 3D part would fit. The student team developed the ability for the robotic system to simulate complex assembly problems by using the system they designed to take randomly shaped 3D blocks and assemble them into a single cube. The project was in effect a real life 3D Tetris game using the robotic system developed. The project was an excellent way for the student team to demonstrate their ability to innovate using new technology to solve a complex problem. The confidence and process used to solve this problem will provide a basis upon which they can formulate new strategies to incorporate new technologies throughout their career. The paper relates not only the professor's view of the experience but a student view as well.

Introduction

New paradigms are required for undergraduate teaching in Engineering and Engineering Technology that are "student centered" [1]. In forming these new directions within the laboratory experience, we need to rethink traditional methods to become more flexible and challenging to the individual student. Accomplishing this requires a new method of delivery that is different from the traditional laboratory instruction [2, 3, 9 and 10]. Allowing the student to use higher order leaning including problem development, experimental planning and most important implementation all though the use of active learning styles will help reinforce the theory given in lecture [1, 2, 3, 4 and 5]. Undergraduate research as a laboratory experience can affect career decisions leading to graduate school and relieve the monotonous aspects of learning while instilling a sense of accomplishment [6, 7, 8 and 10]. All of these lead to students that are willing to innovate which is one of the most important aspects of education that will stay with a student and serve him well no matter what new technologies he will encounter in the future. The ability to explore and use innovation, not just memorize and recite is the engine that will propel students to a promising future. The project described below was one of the projects used in a Robotics and Automation course for the Bachelors of Science in Mechanical Engineering (BSME) and Bachelors of Science in Mechanical Engineering Technology (BSMET) programs at Eastern Washington University. The instructor for this course gives the students very general parameters and then asks the students to formulae their own group's experiment within the confines of the parameters of the course [1, 7]. The students must first understand the capabilities of the equipment then formulate a problem for the robotic equipment to perform and finally demonstrate the project for the rest of the class. Projects are always different, student designed and unique and therefore something the student team feels and takes ownership in. Students tend to conceive and perform projects far more complicated and time consuming than any the instructor would normally assign for a laboratory assignment. Often this is the first college opportunity for the student to experience undergraduate research and innovate while using active hands-on learning. This paper presents the project from both the professor's view and the student's viewpoint. Both the professor and a student from the project are co-authors of this paper. The Student has since graduated and entered the engineering field.

Project Description

The overall goal of this robotics project was to fulfill the professor's sole criteria: "Impress me." The Student team accomplished this by enabling an Adept i600 SCARA robot to play a 3-d version of the game Tetris. The Tetris pieces are assembled from Mega Blocks in random configurations, scanned by the robot, picked up, and then placed in the appropriate position with the correct orientation. With limited time and resources, the algorithm developed to operate the robot had to be as simple as possible, yet still perform its required task.

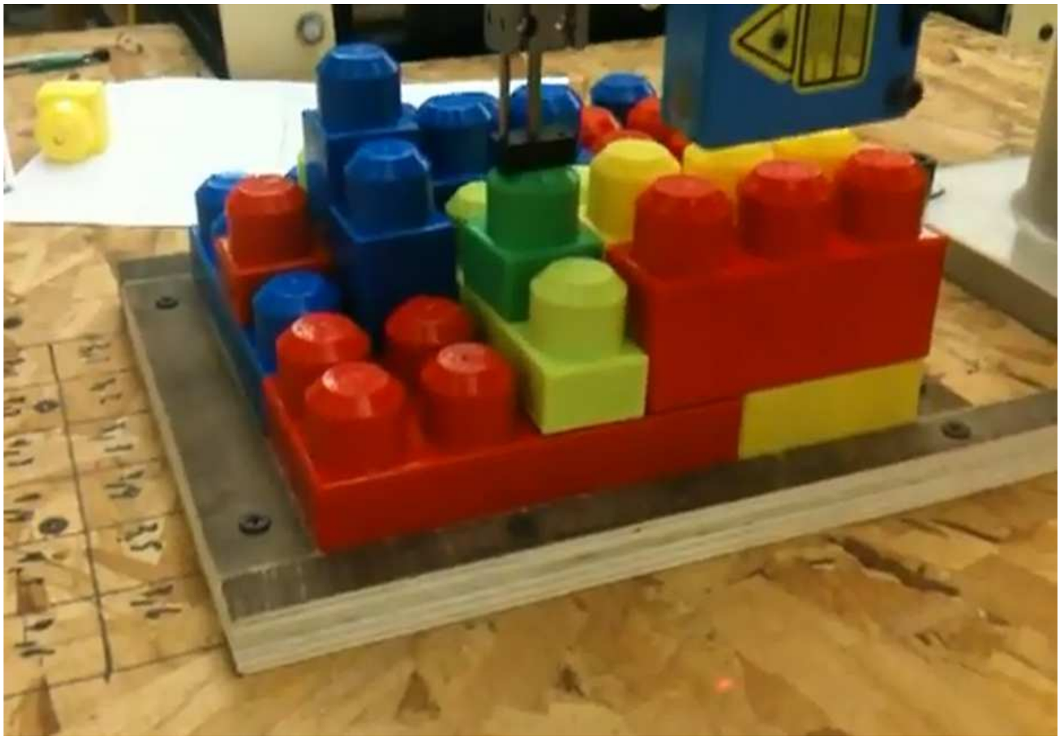


Figure 1. Game Board with Piece Being Placed

The "game board" is a 6-row X 6 column X 5 layer high 3-D array of cells, which the robot individually fills automatically, with a portion of a Mega Block. There is a filled layer of Mega

Blocks underneath to allow for proper alignment of new pieces, as the robot places them. Figure 1 shows a picture of the bottom layer, some placed pieces above the bottom layer, and one piece the robot is currently positioning. For gameplay, listed below are the limited number of rules that the robotic program must comply with during its operation:

1. All pieces must fit in the 6 X 6 X 5 array of cells
2. A new piece cannot cover an empty cell, leaving a hole for future play
3. Pieces that presently do not meet requirements 1 and 2 need will be placed automatically in one of four holding areas. They are reanalyzed by the program for a fit after every "next piece" that is added to the game board and if the "held piece" will fit at this time it is moved from the "holding area" and placed in the appropriate place on the game board automatically.
4. A cell is to be considered "filled" when the rectangular body of a Mega Block occupies that cell, not just the tip extending upward.

The program follows the flow chart in shown below in figure 2:

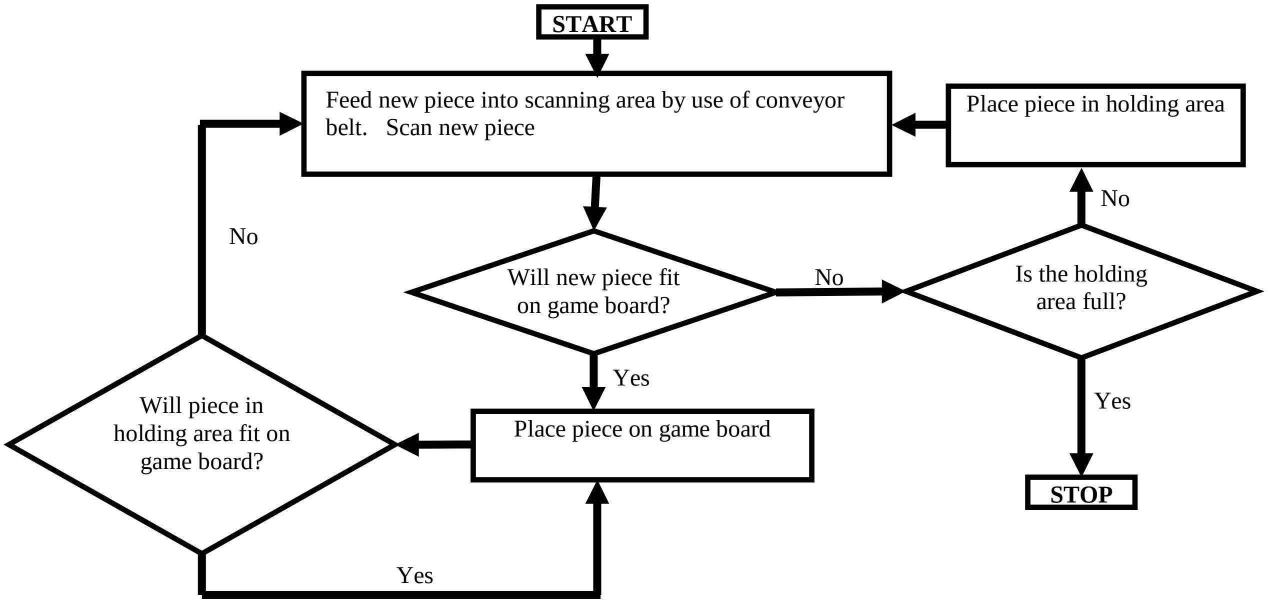


Figure 2. Project Flow Chart

New pieces consist of individual Mega Block pieces or several Mega Block pieces taped together in various random configurations. A new piece is subject to the following restrictions:

1. Must fit in a 2 row X 4 column x 2 layer high array of cells
2. There cannot be any overhangs on the pieces.

These two requirements were only a result of the mechanical abilities of the suction device used to move the pieces and the laser photo detector used to image the new piece, respectively. This allowed for over 1,000 distinct possible new pieces. Figure 3 shows the possible distinct footprints of a new piece, where each gray cell can either have 1 or 2 filled cells above it.

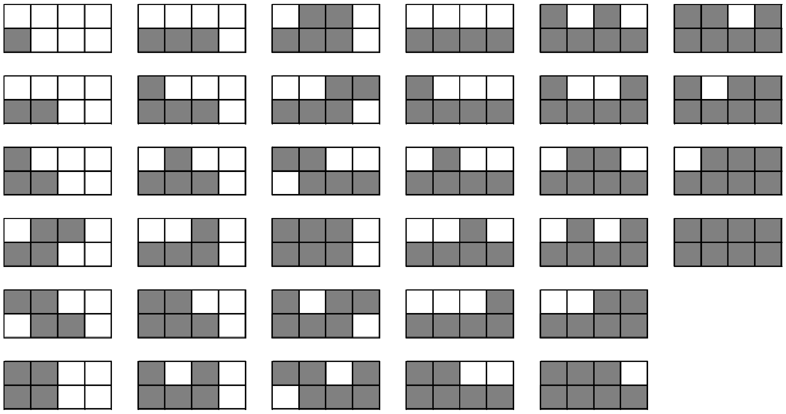
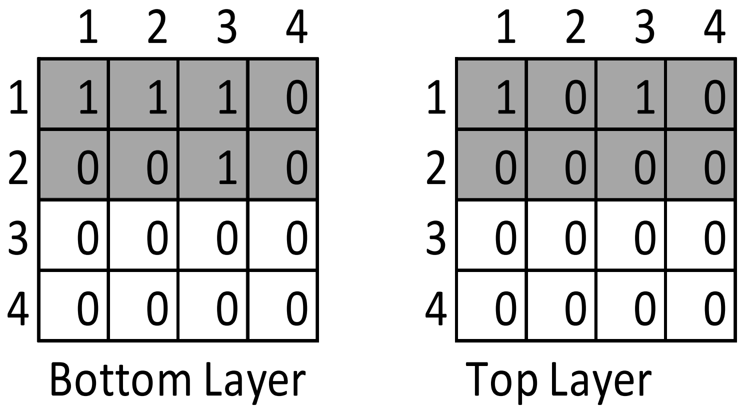


Figure 3. Distinct Footprints of New Pieces

The operation of the robot follows the flow chart shown in Figure 2. Random new pieces were delivered to the robot by the use of a conveyor belt that is a modified treadmill the project team designed and fabricated. One of two normally closed relay switches operated in parallel activates the conveyor. The student team wrote a computer program that is interactive with the robot, which operates one switch and the other, is operated by a photo-detector that senses whether a new piece is in the alignment bracket. Since the switch is normally closed, the conveyor will run whenever there is not a new piece in the alignment bracket, greatly increasing operating speed by allowing for parallel operations of receiving a new piece and placing the previous one.

Figure 4. Conveyor Belt

Alignment of the piece is accomplished using the passive bracket and an active “kicker”, and then the laser sensor was used to scan the new piece. The sensor started at the highest position possible above a vertical column, attempted to sense a piece and if nothing was detected it was moved 2 mm downward and repeated this process until something was detected. Once a new piece was detected, the height of the laser determined how many cells below it were filled by Mega Blocks and recorded this by filling a 3-D array with either a 0 (empty) or 1 (filled). The sensor was then moved to another vertical column and the process was repeated until all 8 vertical columns were scanned or two vertical columns next to each other, skinny-way-wise, were empty. To aid in determining where to place the new piece, two extra empty columns were added to allow for easy rotation of the digital image, see Figure 5.



	1	2	3	4
1	1	1	1	0
2	0	0	1	0
3	0	0	0	0
4	0	0	0	0

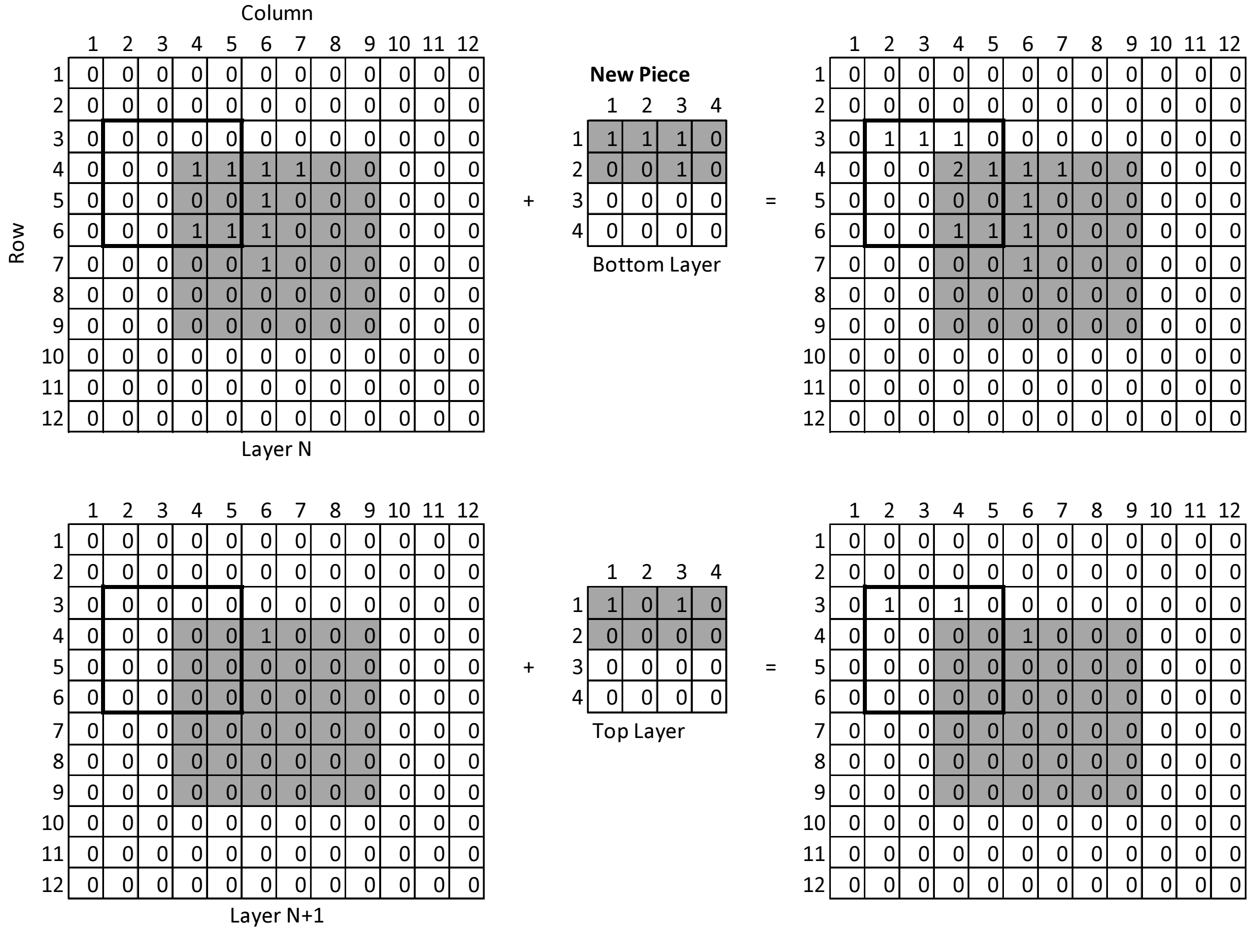
Bottom Layer

	1	2	3	4
1	1	0	1	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0

Top Layer

Figure 5. Digital Image of a New Piece

To determine where to fit the new piece, a pseudo 3-D matrix addition is performed with the game board and new piece digital images. The gray areas in Figure 6 show where a piece can physically occupy that space. There are only 3 prohibitions in the resulting addition matrix: a “1” cannot be in row or column: 1-3 or 10-12, there cannot be a “2” anywhere in the matrix, and there cannot be a “0” in a cell below a “1”. If none of the prohibitions exist, the piece is then placed in that position. If not, the program iterates the pseudo-addition by column, row, piece orientation in 90 degree increments, then by layer until an acceptable position is found. If an acceptable position is not found the new piece is put in the holding area for checking at a later time. When changing the orientation of the piece, the new piece matrix is rotated 90 degrees through a central vertical axis.



	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	1	1	1	1	0	0	0	0	0
5	0	0	0	0	0	1	0	0	0	0	0	0
6	0	0	0	1	1	1	0	0	0	0	0	0
7	0	0	0	0	0	1	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

Layer N

New Piece

	1	2	3	4
1	1	1	1	0
2	0	0	1	0
3	0	0	0	0
4	0	0	0	0

Bottom Layer

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	1	1	1	0	0	0	0	0	0	0	0
4	0	0	0	2	1	1	1	0	0	0	0	0
5	0	0	0	0	0	1	0	0	0	0	0	0
6	0	0	0	1	1	1	0	0	0	0	0	0
7	0	0	0	0	0	1	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	1	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

Layer N+1

	1	2	3	4
1	1	0	1	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0

Top Layer

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	1	0	1	0	0	0	0	0	0	0	0
4	0	0	0	0	0	1	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

Figure 6. Pseudo 3-D Matrix Addition

Students Perspective

By not defining any specific criteria at all for a project, the student changes the question in their head from “What do I have to do?” to “What do I want to do?”. Once the student gets involved in a project that they want to be working on, a lot more effort will be put into the question “How do I it?” It is in answering that question, that innovation blossoms. During this project, we setup parallel switches never discussed in class, used a treadmill as a conveyor belt, developed a simple 3-D vision system from absolute scratch, and created a new mathematical operation: 3-D matrix addition between non-identically sized matrices. This 3-D Tetris project was a constant string of “How do I…” questions in which there were no textbook answers. Quite often in working out the details of this project, one innovative idea led to another question that had to be solved by yet another innovative idea.

Project Outcomes, Conclusions and Future Plans

The design of the course does allow students to stretch their minds and their abilities to explore the possibilities that can be obtained using automation to solve a unique problem of their own design. The very process of fulfilling the course requirements forces the student to innovate and work collaboratively with other students on the team. The professor uses the same method of grading as an Olympic diving competition for the laboratory. The projects are graded on both difficulty and execution. This discourages projects that are too simple and those that are too difficult to be accomplished within the "time frame" given in the course. The team is required to demonstrate the project to the rest of the class, film the demonstration and provide a detailed written project report. The report must include an abstract, introduction, project description, conclusion and a printout of the program used. The project receives a grade for the entire team. The instructor has had to add a peer review by all the team members to the grading. This is an attempt to prevent a student from "taking a ride" and not performing his own duties on the project. The students have been very receptive to the format and are willing to spend the extra time required to accomplish an interesting project. The laboratory part of the course is 2 quarter hours and is scheduled for 4 required hours per week. Students have access to the lab outside of scheduled hours by the use of electronic access cards. Most students tend to spend 8-10 hours in the lab. The lab has an undergraduate research component because they have to research, and design their own project. Students have been encouraged to enter their projects under the university's undergraduate research and creative works symposium held each year at Eastern Washington University. Several students have presented at the symposium and the projects entered were very well received. This experience also helps them build their vita.

The professor takes on a different role in this laboratory experience he becomes a mentor at the lab and a facilitator versus a lab monitor and dictator of preplanned lessons. This simulates the "real world" of these future engineers that will be required to be problem solvers and innovators of open-ended challenges and not just doing what has been done before.

The biggest challenges the student have faced are as follows. First, the time commitment and expectation of time required to do the lab successfully. This was mitigated by explaining up front on the first day of the class, what is expected and how much time outside of the scheduled lab hours the average student spends in the robotics lab. The students have also heard from other students who have taken the course and adjust their course loads as needed. Second, Students need a clear sense of what type of projects is good and reasonable to accomplish. The professor shows films of past projects on the first day of class and approves all projects before the student teams begin the project. Third, the team environment is often a challenge that is as big as the project itself. This team effort and the "sink or swim together" grading is the reality of the modern work place. One cannot tell his boss that he did a great job even though the project was a failure. Results are what count. It is better that they learn how to work in this type team environment while at the university were miss steps do not have career consequents compared to their first job out of school.

The major challenges for the professor included mentoring several different projects at a time and helping with team dynamics. Grading also consumes more time than normal, as each project is different and therefore takes much more time to grade the project reports.

The authors hope that this paper will spark ideas on how other universities can alter a traditional laboratory course they are teaching to become a similar open-ended research experience for the student. The altered new paradigm of teaching will help us all train the next generation of engineering innovators.

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