AC 2010-2179: UNIVERSITY AND URBAN HIGH SCHOOLS TEAM TO USE LEGO ROBOTS TO TEACH PHYSICS

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Abstract

Under a National Science Foundation (NSF) Research Experience for Teachers[1], project leaders a the University of Cincinnati, College of Engineering and Applied Science (CEAS) recruited six high school science and math teachers teaching in low income urban schools. The schools that were selected had less than $200 per school year for equipment and the classes were usually 26-30 students. Some of the goals of this RET effort were to provide a better understanding of the role of engineers in industry and society, expose teachers to university research and its application in industry, and promote engineering and STEM careers among high school students by engaging them in hands-on events and activities.

This Research Experience for Teachers (RET) was a year-long project of two parts. The first part was a summer research experience in which the teachers came to the campus for three hours each day for six weeks in the summer. They studied readings focused on active learning and how the teachers could use some of the strategies learned in their own math and science classes. Classes were held on the university campus in the College of Engineering lab sponsoring the experience, the NSF Industry/University Cooperative Research Center (I/ICRC) on Intelligent Maintenance Systems IMS. The focus of the experience in this lab was active learning using sensors such as the ones in Lego Robots to encourage learning and interest in science by using familiar objects. During this summer experience the teachers designed activities for their students that would be used during the school year. They developed classes that included using sensors in Lego Robots but not only in the robots but in many areas of everyday life.

The Lego Robots used in the physics lab projects had a familiar component for the students, most of whom have had experiences playing with Lego toys. The added use of the computer to program the robots was designed to broaden their experience in technical science. The projects were geared toward finding ways to attract more students to STEM careers, and to the advanced science classes needed to prepare for these careers. We observed enough enthusiasm for the project to conclude that all students derived benefit from it. The sample size was too small to draw statistical conclusions about the effect of the project on the choice of careers of the members of the class, but their attitudes stayed positive, as measured by the attitude surveys. The project provided experience in problem solving in a three-dimensional way that is different than traditional paper-and-pencil problem solving, since it requires planning, application of concepts, testing, evaluating, and re-testing. This process is a good example of the types of skills and processes the STEM fields require.

Introduction

The National Science Foundation (NSF) Research Experience for Teachers (RET) described in this paper is funded under a multi-campus NSF Center of Excellence in an urban environment. The project for 2008-2009 was to address the:

- Need for more students and graduates in science, technology, engineering and mathematics (STEM)
- Need for more women in STEM fields
- Need for better understanding of the role of engineers in industry and society
- Need for better relationships among higher education and local high school teachers.

According to United States Bureau of Labor Statistics, June 28, 2007, the need for scientists and engineers is projected to increase by 22% as a whole between 2004 and 2014 in the fields of science, technology, engineering, and mathematics (STEM).[2] The growth of this need comes at a time when the rate of women and girls entering the STEM fields has steadily decreased.
To address these issues, our RET efforts concentrated on the establishment of strong relationships with high school teachers in the urban schools. Specifically the summer enrichment program was to accomplish the following objectives:

Part I

- Introduce six teachers from different high schools to engineering research at the university;
- Provide a research experience that teachers can use to develop related curriculum to be used in their classrooms;
- Have each teacher produce sample activities, based on what they have learned during the RET for use in their classrooms.

Part II

- Provide in-class instruction in project based learning by faculty from the education college;
- Provide access to research being done in the lab, particularly the research being done with the use of sensors since this is an area of expertise and projects with students using sensors could easily be used to introduce them to science and math activities the teachers were to design for their classes;

Part III

- Benchmark methods of assessment and establish an assessment plan to measure the effectiveness of the activities offered, and the teachers' research findings.

The teachers agreed to participate in the program by attending sessions to learn about using project based learning in the classroom and to learn about the research being conducted, participate in lectures and hands-on activities, develop materials for classes for their students and implement the programs they developed in their classrooms, following the summer experience. Teachers agreed to develop materials appropriate for targeted students and write reports describing the implementation of the learning experiences of the summer. Special attention was to be paid to recognizing how engineering and the research being done is important to the lives of the teachers, students and the community as a whole.[3]

Project Description

In 2008 and 2009, teachers from six area high schools were recruited for the summer RET. The objective of the partnership was to introduce the teachers to the research being done and how engineering plays a key role in the success of business and industry, as well as in our everyday lives. The teachers worked together to identify ways in which high school teachers could introduce the concepts learned and activities performed during their experiences in this RET program to students in their classes. The close relationship established between the university faculty, students, and the high school teachers during this project provided an additional benefit of helping to make teachers and students' comfortable working with, and in, a university research environment. In addition, participating in this program introduced students to cutting edge research in science and engineering and encouraged them to seek careers in STEM fields.

The high school teachers met with education and PhD students at the sponsoring engineering lab for three hour sessions twice a week for six weeks. An orientation was held at the first session to introduce participants and explain the focus of the research in the lab, as well as the overall goals of the RET program. These bi-weekly meetings included discussion of journal articles on project based learning supplied by the faculty and presentations of research particularly those concerning use of sensors by PhD students in the lab. Meetings were used for the discussion of project based learning and the magnitude of the use of sensors in daily life and how this knowledge could be used to engage students in the study of math and science in classes in the high school. One of the outcomes of the summer experience was for the teachers to produce lesson plans based on learning during the summer.

The high school teachers reviewed the research presented and participated in detailed discussions with faculty and researchers during each meeting. They brainstormed multiple ways in which the research could be related to subjects being covered in the classroom. Each teacher then developed activities and lessons that would utilize existing classroom materials that were modified to give them an opportunity to use the technologies and methodologies to which they had been introduced. LEGO robots were available from previous summer enrichment programs and the teachers brainstormed how these could be used in their lab assignments. Lab View provided an instructor and a week of special afternoon sessions doing exercises in a computer lab. This gave the teachers additional practice working with the robots and getting a rudimentary sense of how the programming with the LEGO sensors works. Extra time was spent discussing LEGO Robots as a means of introducing sensors into the classroom or offering special Saturday camp.

Figure 1. Teacher working with Lab View to program LEGO robots

One of the RET teachers developed new curriculum for her physics class using the LEGO Robots. Using the LEGO Robots to teach physics is an example of an outcome of this RET experience. The balance of this paper is how this teacher used LEGO robots in her high school physics class.

Background

The teacher selected has 23 years experience as a classroom teacher of physics and chemistry in five different high schools in which students in the district often leave high school unprepared for college level science, engineering and math courses. The difficulty of the situation is compounded by the lack of technology available to them in middle and high school. The gaps in experience working with technology based materials create the need for a larger adjustment to college level work, often proving overwhelming for a young person new to the demands of college.

The students in the physics class described in this study are 16-18 year olds from an urban background. Most of the students will be first generation in their families to go to college. They are Appalachian, African-American and Asian descent. The classes are large; usually 2-30 students per classes and classes are 46 minute single periods. The budget for lab equipment is less than $200 per year. Lab activities are a special challenge when money and time are n such short supply.

The physics teacher in this example had several questions she wanted to investigate based on her experience in the RET.

- Does the project based curriculum in physics have a positive impact on female student attitudes toward challenging coursework;

- Does using LEGO robots in a project-based physics class increase the information all students have about engineering and technical fields, and improve the level of positive responses on assessments such as written tests and attitude survey
- Does the use of LEGO robots create more interest in taking physics in prospective students the next year?

The specific activities chosen for this project are meant to address the challenges mentioned earlier in exposing students to technology based learning tools. The LEGO robots used in physics project have a familiar component for the students, most of whom have had experiences playing with LEGO toys. The added use of the computer to program the robots is designed to broaden their experience in technical science.

This project was divided into four sections, one for each main unit of mechanics studied in the physics class. The class consisted of 12 students, 5 of whom were girls. All students were Appalachian, Asian or African-American descent. The topics included in the project were 1) Newton's Laws, 2) vectors, friction and projectile motion, 3) momentum and energy, and 4) circular and rotational motion. Upon completing each unit in traditional types of classroom instruction, such as lectures, lab experiments, seminars on solving physics problems, etc., the robot challenges were issued and students were graded by 3 judges using a rubric made specifically for this project. The judges consisted of one professor from the college, another physics teacher from the district, and the home teacher. The students were also assisted by one graduate student and one undergraduate student computer engineering major. During the progression through the units, changes were made to the challenges and to the rubric sheet used to assess the students' performance. Each unit and the resulting changes to the project, including the rationale for each change, will now be described in more detail.

The first experience the students had with the LEGO Robots was to spend a class period assembling them and learning to program them using the software included with the robots. The teams consisted of one all female team of 5, and one team of 4 males, and another of group of 3 males. The programming practice required an additional 46 minute class period. As part of the practice, simple challenges were given, such as making the robot move in a square, and attaching the light sensor and programming the robot to stop when it detects a dark surface. The students all demonstrated very little difficulty in either assembling or programming the robots.

When the traditional unit of study on Newton's Three Laws of Motion was finished, the robots were again programmed by the student teams in order to meet the following challenge (Challenge #1): "Using what you have learned about the 3 Laws of Motion, program your robot to demonstrate any 2 of the 3 laws. You may use any items in the lab from the experiments you have done so far, in addition to any other materials you think appropriate. You must then submit a written description of the way in which your robot shows the laws you have chosen. Your team will be assessed according to the rubric provided." The teams were not asked to show all three laws due to the 46 minute length of the class periods. The challenge was meant to be very open-ended because the students had done 3 lab experiments on the topics and were now challenged to use what they learned to meet the project requirements. Results for each group were recorded on the rubric sheets by the judges. The final scores, which were assigned as lab grades for each team, were decided from the average of the 3 scores given by the judges. The scores from all 3 judges in this part of the challenge were very similar, which seemed to indicate that the rubric was reliable.

Students very quickly got into their teams and spent at least half the class period discussing, planning and assembling materials for their challenge. They divided the work among the members of their groups, with some looking through drawers of equipment, others making sketches, or programming initial steps and testing the robots' responses. They were truly independent and even somewhat secretive about their plan until they were sure they could get it to work. Unlike some other labs the students were eager to know their scores, and to know when they would have the next opportunity to work with the robots. Two groups even gave their robots a name. During the first few days after the challenge was over, they asked questions about how they could improve their scores on the next challenge. One of the changes that the teacher will be making to this project for next year is to use the robots inside the units of study as well, as it seems it will help to keep the enthusiasm going. The challenges will be more specific and of narrower focus.

The next round of robot challenges occurred at the end of the second unit, which included vectors, friction and projectile motion. The students again had done three traditional lab experiments during the unit, and were encouraged to use the results from these experiments to help them with the challenge, Challenge #2, which was: "Using what you have learned about vectors, friction and projectile motion choose any two of the three topics to demonstrate by programming your robot. You may use any lab materials you think appropriate. You must then submit a written description of the program and how it demonstrates the principles you chose. Your team will be assessed by the rubric provided." The results were again recorded on the rubric sheets by the 3 judges, and averaged together for the scores the teams received as a lab grade.

In this challenge, the judges were disappointed to find that the teams had all spent so much time on meeting the requirement regarding the creative use of outside equipment that they had extremely simple programs. Two of the three teams had only a straight line programmed into the robots. They pushed the start button and the robots traveled on different surfaces, such as sand paper and rubber mats to show the different effects of friction. They did show projectiles and vectors and friction successfully, just not with complex programs for the robots to execute. This spurred the teacher to change the rubric to include specific language about the number of different actions the robots were programmed to perform for the last two challenges. The new rubric was shared with the students in their next round, and was explained in the feedback on their performance on the written portion of their challenge in the vectors round.

Figure 2. 12th Grade Physics Students Designing Lab Experiment

Challenge #3 centered on the topic of momentum and energy. This challenged required some changes to the open-ended nature of the previous two sessions. The students had already demonstrated creativity in using outside materials in the previous two challenges, so this challenge was designed to get them more involved in what they could make the robots do by programming. This challenge combined the units for momentum and for work and energy because both units alone would be too limited in the possibilities for the robots' programs. The challenge was as follows: "Your robots must be programmed to push Styrofoam cups of various masses out of the circle of dark-colored tape, but the robots cannot leave the circle. Each group must also submit observations about the changes in, and transfer of, momentum and energy as the robots encounter the various cups." The rubric had been changed since the last challenge, so the students were given a copy prior to the day of the challenge in order to be prepared. The other preparations required for this challenge were to tape various slotted weights to the bottoms of Styrofoam cups, and to make a one meter circle on the floor from blue painter's tape. The cups are then positioned at random inside the circle. Students were offered extra credit if they could program the robot to start outside the circle and once inside, not go out of it again.

Two of the three groups present for this challenge programmed their robots to push the cups out by using similar steps, but the girl's group took a very unique and systematic approach. Their program had more detail, and was designed to sweep every inch of the circle, rather than randomly turning and backing up after it pushed each cup to the dark line. The boys did their programs more by trial and error, with less pre-planning than their female counterparts. All the groups were able to get the cups out of the circle, but the amount of time it took varied widely. The most obvious difference between the girls' group and the other two groups of boys was the level of attention to detail shown by the girls. The boys seemed to be satisfied with a less successful run as long as it worked, whereas the girls kept going back to the computer to tweak their program for better performance.

For Challenge #4, on rotation and circular motion, our computer engineering student suggested that the students do their written portion prior to the challenge. The students were required to pre-plan all facets of their programming and submit them to the judges for approval before they were permitted to actually use the computers to program. The challenge was: "Program your robot to demonstrate one principle of circular motion and one principle of rotation, using the apparatus of your choice. You must write and submit a detailed proposal illustrating every step that your robot is to execute before you do the actual work on the computer." The same rubric was used for this last challenge as for the previous challenge. The importance of the complexity of the program was again stressed to the students.

In this session, the anticipated result was that since the students had more experience programming, they would be better able to show a systematic plan before they programmed and assembled their robot's apparatus for the challenge. The goal for each challenge was for the students to tie the objective of the challenge to the content of the previous unit. They did not seem able to do this well for Challenge #4. Perhaps the skills of pre-planning should be stressed more from the beginning of the project in order to better acquaint them with the demands of an engineering approach to problem solving. The scores on the last challenge were somewhat higher than the vector unit challenge had been, but were still lower than the first two rounds. This may be due to the loss of novelty, or to the long span of time between challenges. This is information to be further examined in subsequent projects.

Data and results

Data was measured in two forms. The first was a Likert-type pre- and post-survey. Also, as previously described, the assessment of each group was recorded on a rubric form. Notes were also made after each challenge session on student reactions and ideas for future challenges. The following table has the average of each groups' scores out of 50 points for each of the four unit challenges.

Team	Challenge 1 Newton's Laws	2 vectors	3energy/momentum	4circ motion/rotation
1 (boys)	46	35	53*	40
2 (boys)	47	39	45	45
3 (girls)	47	46	50	45

The girls' team scored higher than, or equal to the two boys' teams consistently throughout the four challenges. Anecdotal records indicate that the girls paid more attention to details, did more thorough testing and retesting, and did more extensive work in the planning phase. They kept working at solving the programming and equipment problems longer than the two boys' teams. They tried more solutions out, and collaborated more on how well each new facet of the solution worked. The sample size of this project does not allow the assumption to be made that this is due to characteristics of females in general. The differences seem to also be attributable to the personalities of the girls in the class this year. More classes need to be studied to be able to draw sound conclusions of the differences in girls' attitudes and achievements in project based physics.

Results of Surveys

The overall attitudes towards STEM careers did not change significantly. The students, both male and female, who had a positive interest in STEM careers before the project also stayed positive about them after. One male student went from interest in an engineering career to being disinclined to study engineering. This student indicated that it was the hard work of solving physics problems that caused him to look for another area of study in college. When asked if the robot project had anything to do with his change of interest, he was very neutral in his answer. He said it didn't help, but it didn't turn him off, either.

The results of this project had several expected results. The girls paid more attention to detail and were more willing to put in more effort for the payoff of a good grade on the challenge. The boys' groups were willing to give up sooner and to accept a robot that could not do exactly what they had in mind for it to do. The girls urged one another to continue, and collaborated more in dividing the labor to get the robot to do the target actions. Students did not expend more effort to learn the unit content in order to be better prepared for the upcoming challenges. Additionally, all of the students lost enthusiasm by the last challenge. Instead of getting better at the programming and using that proficiency to get better results, they seemed to give less effort at the end. The last challenge was different in that they were required to pre-plan more, and this addition at the end of the senior year may explain why the effort decreased, even from the girls. Again, several more classes' data would clarify the causes for this unforeseen change in performance.

Analysis

Overall, the students gained an understanding and appreciation of the type of skills needed for STEM careers. The requirements of project based activities are very different from traditional labs or problem sets in a physics course. The cycle of pre-planning, testing, revising, and re-testing are common to STEM fields. This project gave students firsthand experience with this type of cycle in a familiar setting and with competition between teams and guidance from college students in STEM majors. This guidance gave students valuable information about the challenges and requirements involved in studying these fields. The students were familiar with LEGO toys and computer games, which helped them acclimate themselves to this new type of learning environment more comfortably.

This increased use of STEM-based lessons will create a richer, more authentic science learning environment for all of my students. This session of challenge labs provided useable information about what is of interest to students, and how to tap into what they are already familiar with to motivate them to push further into their exploration of the nature of science.

There are some considerations for anyone wanting to do a similar project. As indicated by the recorded changes from cycle to cycle, the time available to do the challenges had a negative impact. A longer period schedule or block schedule of 90 minutes would definitely make this project easier and more effective to implement. In addition, the pre-planning phase should be emphasized from the very first challenge. This could really help in teaching time management.

Conclusion

There was sufficient enthusiasm for the project to conclude that all students derived some benefit from it. The sample size was too small to draw statistical conclusions about the effect of the project on the choice of careers of the female members of the class (the primary questions addressed), but their attitudes stayed positive, as measured by the attitude surveys. The project provided experience in problem solving in a three-dimensional way. This is different than traditional paper-and-pencil problem solving, since it requires planning, application of concepts, testing, evaluating, and re-testing. This process is a good example of the types of skills and processes the STEM fields require. When students, of either gender, experience success with this type of learning process they gain confidence in their own abilities. Having participated in project-based learning may play a part in their explorations of possible careers as they look back on their experiences during the project.

The secondary questions studied whether students of both genders benefit from this process, and whether they make more effort to learn concepts in order to gain an advantage in the robot challenges. There was some evidence of greater enthusiasm for STEM careers, and several of the boys indicated they were surer of their choice of college major because of the project. As stated before, this process helps illuminate the kind of daily work STEM majors do. There was no evidence of improvement of the traditional assessments in the course. Test scores stayed relatively consistent for each student, and did not improve over the course of the project.

The question of whether the enrollment would increase for next year has a definite answer of "yes". The physics enrollment of this school is small, but has almost doubled for next year, from 12 to 23. Most of the juniors who signed up for the course have questioned whether the robot project will be continued next year. This project has shown a great deal of value for student learning and for getting more girls interested in STEM careers. There is no substitute for direct experience in a classroom. The most skillfully delivered pedagogy can only go so far in instilling an interest in the STEM areas, and is necessarily even less effective at building confidence. Only actual hands on "doing" by students can accomplish this. If girls are indeed hesitant to go into science and technical fields because of a belief that they are by nature less able than their male counterparts, the chances for success in these types of projects will be proof to both genders that many girls are very skillful in these areas. It may take a while to gradually change the perceptions that both genders have about their relative abilities, but if project based learning is a regular part of the science curriculum, we will have produced students who are more experienced, more confident and more informed about the everyday activities of STEM careers. This has the potential to gradually erase the disparity between the genders in scientific and technical arenas. The exploration of their own questions, the satisfaction of creating and testing their own designs, and the experience of working in cooperative groups reflects the kinds of skills and demands of the STEM careers. The old saying "experience is the best teacher" has dramatic meaning here, and project based instruction provides that invaluable experience.

Appendix A – Survey of Attitudes and Feelings about Science and Engineering

Name ____________________________ **Grade** _______ **Gender** ________

Teacher ___________________ **Current Science Class** ___________________

Race/Ethnicity (circle one)

Black White Hispanic Bi- or Multi-racial Asian

Directions

Please respond to the following 25 questions using the scale described above the questions. The questions are about your attitudes and feelings about science, engineering and technology, there is no right or wrong response, so please be honest. Usually the best answer is what comes to mind first. The whole survey should take only a few minutes.

SA = strongly agree **A** = agree **N** = neither agree of disagree
D = disagree **SD**= strongly disagree

Statement	SA	A	N	D	SD
1. Working with science equipment makes me feel important.					
2. I will use science in many ways as an adult.					
3. Women's aptitude (*ability)* in science or engineering is as great as men's aptitude.					
4. It is important for me to get top grades in science.					
5. I hate to keep records during science labs.					
6. I feel like I get to think for myself during science labs.					
7. I need to be an expert in science to succeed in engineering and technology.					
8. I do as little work in science as possible.					
9. When a question is left unanswered in a science class, I continue to think about it afterward.					
10. Science labs make science less interesting to me.					
11. I enjoy using mathematics during science labs.					
12. I see science and technology as subjects I will rarely use in my daily life as an adult.					
13. People in science and technology careers contribute positive information and useful inventions to society.					

14. For some reason, even though I study, science seems unusually hard for me.					
Statement	**SA**	**A**	**N**	**D**	**SD**
15. I like to be challenged by science problems.					
16. Science labs help me to understand how science can be used in the real world.					
17. I feel confident in my ability to use lab equipment well.					
18. Science and engineering are of little relevance (*importance*) in my life.					
19. I am confident that I can get good grades in science.					
20. I don't mind doing an experiment several times to check my answer.					
21. Science in enjoyable and stimulating to me.					
22. I feel like I am answering real questions during science labs.					
23. I don't like working with partners during science labs.					
24. I think that doing science labs in school is good practice for being a scientist.					
25. I would like a career in science, engineering or technology.					

Appendix B - Original Rubric Sheet for Robot Challenge

Topic of Unit:____

Group Members: ______________________________ ______________________________

______________________________ ______________________________

Scoring is based on the following:

Design met Challenge (20 possible) _________

All aspects of challenge were demonstrated-20
¾ of aspects of challenge were demonstrated-15
½ of aspects of challenge were demonstrated-10
less than half of aspects of challenge were demonstrated-5

Execution of Program (20 possible) _________

Robots performed all intended tasks-20
Robots performed ¾ of intended tasks-15
Robots performed ½ of intended tasks-10
Robots performed less than ½ of intended tasks-5

Originality and Creativity (10 possible) ___________

Judges are looking for use of outside materials for interaction with robots, imaginative ways of demonstrating challenge objectives, assembly of robots in creative formations, use of "appendages", etc

TOTAL _________________

Appendix C - Revised Rubric Sheet for Robot Challenge

Topic of Unit:____

Group Members: ________________________________ ________________________________

________________________________ ________________________________

Scoring is based on the following: Circle one box per row.

Scoring Categories					**Comments**
Design Met Challenge	**20** All aspects demonstrated	**15** 75% of aspects demonstrated	**10** 50% of aspects demonstrated	**5** Less than 50% demonstrated	
Execution of Program by Robot	**10** All tasks performed	**7.5** 75% of tasks performed	**5** 50% of tasks performed	**2.5** Less than 50% performed	
Complexity of Programming by Student	**10** Robot is programmed to do multiple tasks	**7.5** Robot is programmed to do a few tasks	**5** Robot is programmed with one task.	**2.5** Robot is not programmed; student must start and stop robot.	
Originality and Creativity	**10** Use of outside materials, imaginative ways of demonstrating objective, use of creative formations, use of "appendages", etc.	**7.5** Showed 3 out of 4 things listed in 10pt box	**5** Showed 2 out of 4 things listed in 10pt box	**2.5** Showed 1 out of 4 things listed in 10pt box	

Total points: __________________________

The following page contains a copy of some learning exercises from the Lego software used to teach the students programming at the beginning of the project.

[1] University of Cincinnati Intelligent Maintenance Systems Center under an NSF I/UCRC an NSF Industry/University Cooperative Research Center (I/UCRC) promotes effective working relationships between industry and academia and allows the IMS Center to apply for supplemental funding for such programs as the Research Experience for Teachers (RET) which funded this program.

[2] US Bureau of Labor Statistics. (2007, June 28). BLS STEM occupations and growth.

[3] Agajanian, A., Timpson, W., Morgan, G., “A Multiple Regression Analysis of the Factors that Affect Men/Female Enrollment/Retention in Electronics and Computer Engineering Technology Programs at a For-Profit Institution”, Proceedings of the 2008 ASEE Annual Conference, Pittsburgh, PA, June 222-25, 2008.
http://www.bls.gov/opub/ted/2007/jun/wk4/art04.htm