BUILDING AND PROGRAMING ROBOTS – A GROUP ACTIVITY FOR ENHANCED LEARNING OF UNDERGRADUATE GENERAL PHYSICS

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Abstract

The activity of robot-building and programming was introduced during the first semester general physics-I course to enhance student participation, motivation, and effective learning. Students were instructed to design and build a robot that can carry out several functions to enhance project-based collaborative learning of fundamental physical concepts such as speed, acceleration, rotational speed, angular velocity, linear and angular momentum. Additionally, concepts such as electric motor power and energy transfer, etc were studied. Students learnt about the sensors and actuators in the robot and how to utilize them to manipulate the motion of the robot. The students collaboratively learnt physical concepts related to the robot’s functionality, built the robot, programmed the robot using estimated parameters to perform assigned tasks. The data collected was tabulated, analysed, modified the original parameters and reprogrammed to perfect the robot’s performance with the given tasks, and submitted a final report. During the process, the students made measurements of various physical quantities and learnt modelling, simulation, and programming. One class period at the end of the semester was allocated to demonstrate the robot’s performance in executing the assigned tasks, to explain the physical concepts used in the experiment. Ten percent of the class grade was allocated for the robot-building and programming group activity.

The students in the class were divided into groups of four students per group. The students were given the opportunity to select their own group members. Each group was given a robot kit and the assignment of tasks the robot needs to perform. Ten different project assignments were developed using the kinetic concepts for the students to build and program the robot, demonstrate the assigned task by the robot, and submit a written report by the end of the semester. It has been asserted that the purpose of group project is not only designing, programming, and performing assigned task by the robot but also for the group members to interact each other for collaborative learning and problem solving. From time to time, the students were enquired of collaborative learning and those who were not actively involved in group learning were encouraged to be more proactive. The study indicates that the group activity of robot-building and programming helped the students to develop their engineering design and computer programming skills, group learning skills to study physics concepts, and increased their motivation to study.

Keywords: Robots, General Physics, Physics Concepts, Group Learning, Robot building and programming.

1 INTRODUCTION

It is a well-known fact that science and mathematics programs suffer from low enrolments [1] and two major reasons considered are 1) a perception that jobs in these disciplines are scarce and offer low pay, and 2) the myth that science, particularly Physics and Mathematics, are difficult subjects. The problem is aggravated within minority communities due to the implicit bias that minorities are not good in science and math, and that stigma greatly affects the individual’s performance [2, 3]. The concern of validating the stereotype negatively affects performance reinforcing the perception of the veracity of the stereotype, a self-fulfilling prophesy [4-7]. These factors act as deterrents to students who otherwise could have made a career in science. The rate of African American students who intend to major in STEM disciplines then switch to a non-STEM field before graduation is twice as much as white students [8].

By introducing interactive group learning projects into traditional lecture method of teaching, we can expect to see a remarkable impact on retention and graduation rates, and the quality of the education students will receive that will further help them to pursue higher education or careers in STEM fields. Project-based learning, research experiences, and participation in learning-communities are proven to improve student’s confidence, motivation, and persistence for academic success [9, 10]. Introducing group learning projects as learning tools provides students with the project ownership, intellectual
challenges, and enhances teamwork. The attrition at freshman and sophomore levels in STEM majors is mainly because of the introductory courses being uninspiring under the traditional teaching methods. New teaching strategies need to be tested. Involving group learning and hands-on experience projects to promote active learning where students think, create, and solve problems, is a possible option to attract their attention and motivate learning. Active learning improves understanding and retention of concepts. The robot building and programming project targets in-groups and, in some cases, multidisciplinary groups including students from Math and Physics together with other programs such as Engineering and Technology and Computer Science. The building and programming of a robot to perform given tasks is one of the active learning projects introduced in General Physics-I.

2 METHODOLOGY

The robot building and programming project is designed for freshmen students and it is inspired in LEGO-league robot competitive learning [11]. LEGO robots can be instructed to execute simple tasks, like moving forward or backwards, turn, push, lift, carry, etc. The robots consist of a few electrical motors that are controlled by an onboard computer that is programmed through a port connected to a computer where students can write the code to control the robot’s motion. A combination of simple tasks can be executed via appropriate gears and attachments. LEGO MINDSTORM EV3 is a programmable robot construction set that gives the student the power to build, program and command his/her own LEGO robots. LEGO MINDSTORMS EV3, has made building and programming your own robot fun and interactive. Because of its simplicity and user interface, this brand robots are incorporated into the syllabus for application of basic physics principles which students are unable to grasp in a traditional lecture class setting. The EV3 set comprises of the Lego parts, two large motors (for powerful action), one medium motor, EV3 Brick (a user-friendly microcontroller), touch sensor, color sensor (recognizes seven different colors) and an infrared sensor (detects objects). The package is also equipped with its own program software called the EV3 programmer which allows the user to program their robot using a computer. The programmer and EV3 software tutorial videos are available and vast amounts of literature regarding the building and programming of the robots are also available online.

Students are asked to progressively increase the complexity of the tasks to be autonomously completed by the robot. They are trained in the programming of the robots using the laws of physics that students normally learn in General Physics I, as opposed to relying on ‘trial and error’ throughout the experiment. For instance, concepts of circular motion will allow the students to convert turns of the motor into distance travelled by the robot, angular speed into linear speed to complete timed tasks. Students are offered a training module to learn how to design an algorithm that they will use to formalize the coding of the robot.

The class is divided into groups with four students in each group. At first the students were given option to pick their own group members and the remaining students were grouped randomly. Each group received a LEGO MINDSTORM EV3 robot kit and an assignment describing the tasks they need to demonstrate using the robot they built and programmed. The students were given the entire semester to collaborate in designing, building, and programing the robot. At the end of the semester, one class period is assigned to demonstrate the robot tasks (as seen in Figure 1) to the class by explaining the physics concepts involved in the project (see Figure 2) and each group is required to turn in a written report. Ten percent of the class grade is allocated for the group activity of robot building and programing. Out of these 10 points, 30% is for demonstrating the assigned tasks, 30% is for presentation describing the physics concepts involved, and 40% is for written report. The entire semester is more than adequate time to just build and program the robot to perform given tasks, but the idea behind the group activity is to interact each other for collaborative learning and problem solving. The collaborative group learning aspect of the group project has been emphasized and reiterated time to time throughout the semester and the progress in that aspect is continuously assessed. The students who were not actively involved in group learning were encouraged to be proactive. The students were given free access to the Collaborative Methods for Addressing Student-Success in Totality (CMAST) computer lab facility for the group learning activity, using computers to program the robot and to access the EV3 software tutorial videos. CMAST also provided scheduled peer tutoring sessions using senior STEM majors as tutors. For specific questions related to building, designing, and programming the robot, the instructor and a senior student (one of the authors) were readily available.
Figure 1 shows a student group demonstration of a robot started at a green block, travels at a set speed, and stops at the red block. Figure 2 shows a student group explaining to the class the physics concepts learnt from their robot project.

Ten different robot projects were designed to cover most of the physics concepts covered in the General Physics-I course. One of these ten projects is described below as a model project.

### 2.1 Model Project 1: Distance and Speed

*In this challenge, students will learn to use their robots to measure distance and velocity using the different robot power levels.*

Program your robot to go straight forward for one rotation.

- How far (in centimeters) do you think your robot will move forward in one rotation?
- How far did your robot actually move? Measure and record that number below.

On the floor, create (with tape) or find 2 parallel lines.

- Measure the distance between the two lines and record that number below.
- Estimate how many rotations are needed to make the robot move from one line on the floor to the other? Record that number below.
- Program your robot to go forward the determined number of rotations and test it. Did your robot move exactly from one line to the other? If not, what adjustments did you have to make to accomplish this task? Write down the actual number of rotations needed.
- What do you expect to happen if the number of rotations stays constant, but you change the power level? Test your assumption using two different power levels (20% and 100%). What effect does power level have on rotations?

Program your robot to go at different power levels. The goal is to determine the average velocity at which the robot travels for each of these power levels.

- What is the setup of your experiment and what do you intend to measure?
- Run your experiment three times each for power levels 10%, 30%, 50%, 70%, 90% and fill out the following table. Don’t forget the units.
- For each power level, determine mean, median, and range for the velocity.
- Graph the average velocity as a function of the power level. What is the relationship between power level and velocity?

Note: The students are required to record, tabulate, analyze the data, and draw graphs to present the results (Tables are not shown here).
3 ASSESSMENT

In order to assess the progress of the group learning activity, a survey is conducted at the midsemester and at the end of the semester. The number of students participated in the survey are 25 at the midsemester and 26 at the end of the semester. The participants in both these surveys may not be the same students even though it is from the same class as some of the absent students are not the same during the time of these surveys. However, a general trend can be inferred from the comparison of these two surveys. The students in the survey are of various classifications and majors, but all are enrolled in the General Physics 1 course. The results from these surveys gave us clear insight of the progress made and some of the expectations of the students’ participation in the group learning activity.

The categories used are:
- SD = Strongly Disagree,
- D = Disagree,
- N = Neutral,
- A = Agree,
- and SA = Strongly Agree

Table 1: Robotics project survey results at the midsemester

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>SD</th>
<th>D</th>
<th>N</th>
<th>A</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>This project enhanced my understanding of basic Physics principles which were taught in class</td>
<td>2</td>
<td>2</td>
<td>9</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>The project's task was described precisely in the handout</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>I learnt new programming skills and have a better understanding of how robots work</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>I was able to work in a group setting</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Being able to work in a group improved my communication skills</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>The length of time given for the project was adequate</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>I have developed a new interest for Robotics</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>The project segment of the course made it exciting</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 2. Robotics project survey results at the end of the semester.

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>SD</th>
<th>D</th>
<th>N</th>
<th>A</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>This project enhanced my understanding of basic Physics principles which were taught in class</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>The project's task was described precisely in the handout</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>I learnt new programming skills and have a better understanding of how robots work</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>I was able to work in a group setting</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Being able to work in a group improved my communication skills</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>The length of time given for the project was adequate</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>I have developed a new interest for Robotics</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>The project segment of the course made it exciting</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>10</td>
<td>11</td>
</tr>
</tbody>
</table>

The comparison of these two surveys shows a clear-cut progress of the group learning activity from midsemester to the end of the semester. To simplify the survey results, we combined the ‘strongly disagree’ and ‘disagree’ categories of the tables to one category ‘disagree’ for the figures. Similarly, we combined the ‘strongly agree’ and ‘agree’ categories of tables to one category ‘agree’ for the
figures. Based on the results shown in the figures below, there is a dramatic shift toward progress in favour of increased group learning. The improvement was as a result of the instructor’s consistent encouragement to students to participate proactively in group learning and that persisted throughout the semester. Two important questionnaires’ results are presented in the figures below.

![Midsemester Survey Results](image1)

**Figure 3.** Response for survey question ‘This project enhanced my understanding of basic Physics principles which were taught in class’.

Figure 3 clearly shows an increase in the skillset as the group learning activity helped the students to understand the basic physics principles with gradual increase from 48% of the students ‘agreed’ at the midsemester to 61.5% of the students ‘agreed’ by the end of the semester. The low percentage ‘agreed’ at midsemester may be related to the first attempt to introduce the robot building and programming project. The enhanced student learning experience improved over the progression of the semester, and we expect further improvements during the next semester as we incorporate the input received from participating students.

![Midsemester Survey Results](image2)

**Figure 4.** Response for survey question ‘Being able to work in a group improved my communication skills’.

Figure 4 shows that working in group setting improved the students’ communication skills. The presentation at the end of the semester was found to be very helpful in enhancing the communication and scientific presentation skills.
At the end of the survey, a space is provided for additional feedback and comments. Many students expressed that they never learnt programming prior to the activity and this group project introduced them to programming. Others stated that they the collaborative group learning inspired them to be active learners and motivated them to be more responsible.

4 CONCLUSIONS

We have introduced active learning in General Physics-I course by implementing a group learning activity of building robot and programming them to perform assigned tasks using the concepts of physics learnt in the class. The group learning activity has been monitored and proven to enhance collaborative learning among the students and to increase their motivation to study and learn new concepts. Ten different projects were designed to incorporate most of the physics principles taught in the General Physics-I course. Students built the robot using the engineering design and computer programming skills they learnt, and they further demonstrated the assigned tasks to the entire class by explain the physics concepts involved in the assigned project. Each group has submitted a final report including data tabulation, analysis and graphing. The collaborative group learning has been monitored throughout the semester, and the improved active learning has been observed. The results lead to further improvement in administering the group project based active learning in the future semesters.

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REFERENCES