INTRODUCING SCIENCE TECHNOLOGY ENGINEERING AND MATHEMATICS IN ROBOTICS OUTREACH PROGRAMS

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Abstract

Outreach programs organized and supported by universities, government and industry have been used to mobilize educational resources and to address current social, cultural, and economic issues facing the world. Robotics has been an instrument of outreach programs that has found wide support in many middle and high schools. There are various options for implementing a robotics program and many organizations that sponsor regional competitions of these programs come out with a different theme every year. In addition to the robot, which is the central piece of the overall activity, the competition includes research on a prescribed topic, presentation of findings, team work, construction of the robot and its accessories, and programming to perform a specific task using an object-oriented language or simple programming. Although these activities are designed to inspire Science, Technology, Engineering and Mathematics (STEM), a connection with them is missing during the preparation for the competition. In this paper the author discusses a formal presentation of topics from mathematics, physics, engineering and technology—which are used directly or indirectly in the final product—to a working robot that performs a specific task. Various topics such as mathematics, physics, engineering and technology that are already studied in school are integrated into the robotics program. Other topics may or may not be so familiar to all members of the team. Abstract topics are applied and used to solve practical problems along the way.

Introduction

Various studies have addressed the subject of poor performance by students in Science, Technology, Engineering and Mathematics (STEM) [1]. Robotics has been proposed as a way to improve performance in the various STEM fields [2]. During the Third International Mathematics and Science Study (TIMSS), fourth-grade students from the U.S. tested well in both mathematics and science compared with their international counterparts; eighth graders performed near the international average, while the twelfth graders performed below the international average [3]. Four years later at the Third International Mathematics and Science Study Repeat (TIMSS-R), the U.S. students showed no improvement since TIMSS [4]. The reported results indicate that the progress in STEM is inversely proportional to the grade for U.S. students. The House Science Committee developed a new National Science Policy, which aimed to strengthen STEM in preschool through college [5].

As an approach to increase interest and, hopefully, the number of students seeking to study and have a career in a STEM-related field, outreach programs have been developed, funded and supported by various government agencies (personal communication with the Naval Undersea Warfare Center Division outreach program which provides equipment and housing resources to the First Lego League), private companies [6], universities [7] and associations [8-10]. An extensive report of STEM programs can be found in a report published by the Office of the Under Secretary of Defense, Acquisition, Technology and Logistics [11]. States are passing legislature in support of STEM [12].

Outreach programs have been developed all over the country and middle schools, high schools and universities are promoting the STEM effort [13]. The usual outcome in robotics is the construction of a structure, usually a “robot”, that performs a specified function. Other efforts have also been developed that use computer-based construction [14], construction and simulation [15], and mathematical modeling in physics [16]. Hands-on learning opportunities are necessary for providing students with the essential excitation to explore science, technology, engineering and mathematics. Currently, hands-on experience usually stops at the build and program phases [17].

Robotics and STEM

From this analysis, the author proposed a number of topics from science, technology, engineering and mathematics to be integrated with the various activities in robotics. The goal of the proposed enhancement is to introduce students to the applicability of the various topics, possibly already known from the STEM-related courses, to stimulate the thinking process on how to apply principles already known to the problems under consideration and, finally, to clarify misconceptions and provide deeper understanding. Due to space limitations only a limited number of topics are presented here.

Problem Solving

Problem definition, solving and optimization are among the basic functions that need to be taught, studied and practiced. There is extensive literature on the subject [18]. The typical problem is of the form "Design a robot that can accomplish a number of tasks." Most of the time among the various robotics teams, the solution follows in a trial-and-error approach for both construction and programming. This, clearly, is the synthesis process. Although the trial-and -error approach is appropriate in a number of problem scenarios, more typical robotics problems can be solved in a more efficient way by a student that has experience in the analysis process, knowledge of basic physics, mathematics, and technology, and can integrate all these towards the final goal. There is no unique approach to problem solving. Nevertheless, the first step should be the implementation of a formal solution process that includes a definition of the problem.

Programming

Programming is the ordered listing of a sequence of events designed to accomplish a given task. Computer programming is a plan or a routine for solving a problem on a computer. A combination of computer instructions and data definitions enable computer hardware to perform computational or control functions. The trade-off is the parametric analysis of concepts or components for the purpose of optimizing the system or some trait of the system [19].

The specific programming language to be used depends on the robot setup, but the programming principles are universal. The programming language "C" is used mostly with the FIRST (For Inspiration and Recognition of Science and Technology) Tech Challenge (FTC) and FIRST Robotics Competition (FRC), while the First Lego League (FLL) uses the object-oriented language NXT-G. The programming environment for FLL is shown in Figure 1.

Algorithms

Before the program code is written (the equivalent of the solution process), an algorithm must be developed using the steps needed to solve the problem under consideration. Two components of an algorithm are the actions needed to go from the statement of the problem to the solution of it, and the order in which these actions need to be processed. The development of an algorithm can be a one-person job, but final development and optimization demands a brainstorming session. Algorithm development offers the opportunity to introduce the concept and practice of brainstorming and team work. Software tools are available to assist in this process [20]. Both approaches have been used successfully by the author with a number of LEGO FLL teams.

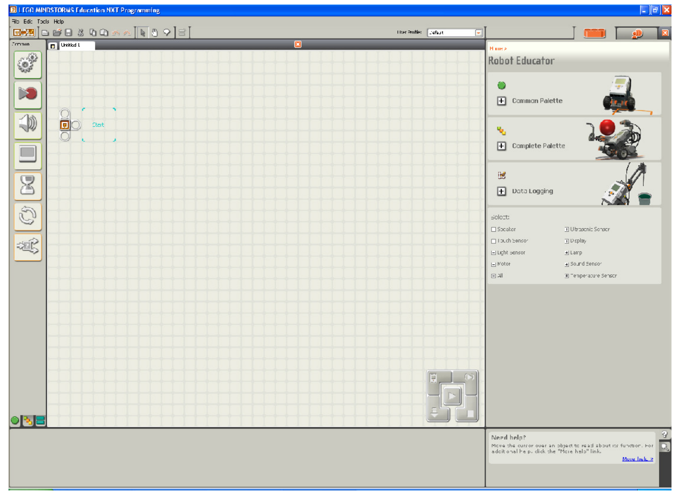

Figure 1. The Programming Environment for LEGO Robotics using Mindstorms NXT-G

Flowcharting

An advantage of flow-charting is the pictorial view of various events. A serious disadvantage is the fact that such a diagram becomes complicated for a complex problem. But even in this case, flowcharting can still be used if the main problem is split into smaller problems. Furthermore, it can be used to describe the overall programming approach. Flowcharting should start with learning the basics and then proceeding to the use of modern computer flowcharting tools.

Structured Programming

Structural programming is any software development technique that includes structured design and results in the development of structured programs. And, structured design is any disciplined approach to software design that adheres to specified rules based on principles such as modularity, top-down design and stepwise refinement [21]. An advantage of structural programming is the use of various constructs. These can be used to demonstrate the development of logical statements. Figure 2 presents the three basic constructs of Sequence, Repetition and Selection. Figure 3 illustrates the implementation of the Repetition (loop) construct in Lego Mindstorms NXT-G Robotics programming language.

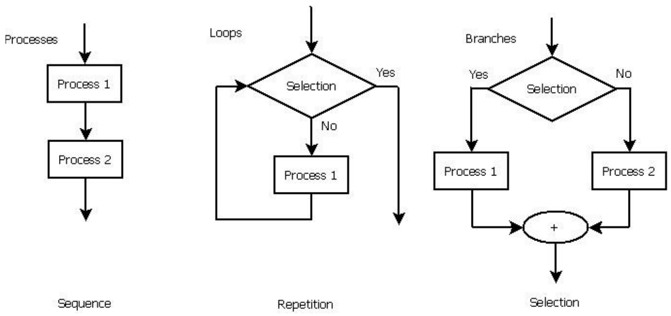

Figure 2. The Three Basic Constructs of Sequence, Repetition and Selection

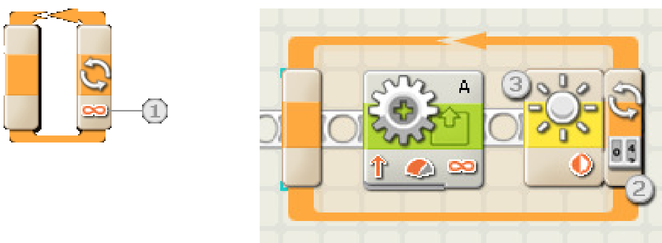

Figure 3. The Repetition (loop) Construct (a): Implementation (b) in Lego Mindstorms NXT Robotics Programming Environment

The Design Process

The design process is applied equally well to algorithm development and the solution process of a problem. Students have the opportunity to immerse themselves in the design process. Due to the nature of the design process, many solutions are possible (parametric solutions). Students have the opportunity to evaluate each one of the solutions based on the specifications and constrains of the problem and to select the one that best fits the current needs. It was applied by the author to a group of middle school students to teach construction skills using the step-by-step approach to build various LEGO-based structures [22].

Algorithm and Top-Down Design

Simple problems can be solved using an algorithm, following the top-down approach, which provides the solution in sequential steps. For more complex problems, the principle of "Divide and Concur" can be applied again and again until the problem is reduced to a number of simple problems that can be solved in sequential steps.

Pseudocode

Pseudocode is natural language like programming language statements. Pseudocode can help in the writing process of the programming code. The pseudocode normally only describes executable statements such as input, calculation and output.

Analysis

Analysis is a process of mathematical or other logical reasoning that leads from stated premises to the conclusion concerning the qualification of an assembly or components. Analysis is examination for the purpose of understanding [19]. Analysis is suggested as the first step in learning new concepts as it usually has a unique solution and can be found using sequential steps.

The Synthesis or Design Process

Students have to work in an opposite mode. The results of analysis are specifications for the synthesis. One approach must be selected and implemented. The differences between the analysis and the synthesis processes need to be stretched. Design is the process of defining the architecture, components, interfaces and other characteristics of a system or component. It is the result of the synthesis process that provides sufficient details, drawings or other pertinent information for a physical or software element that permits further development, fabrication, assembly and integration, or production of a product element. Design is also the act of preparing drawings or other pertinent information for a physical or software element during synthesis within the systems engineering process [19].

Analysis, Synthesis, Physics and Mathematics

Physics and mathematics can easily be applied in robotics. In particular, mechanics and Euclidian geometry are among the major areas of application. The motion of a robot takes place on a plane. Commonly, the robot moves on circular wheels and moves along a prescribed path. A common problem in programming the robot is determining how many degrees a wheel must rotate in order for the robot to travel the distance from one point to another.

Consider an example within the analysis phase: What is the rotation required by a circular wheel of radius R to cover distance L? [22]. Based on Figure 4, the distance traveled by a wheel of radius R or diameter D after rotation of d degrees can be determined by Equation (1):

$$L = C\frac{d}{360°} = 2\pi R\frac{d}{360°} = 2\pi\frac{D}{2}\frac{d}{360°} = \pi D\frac{d}{360°} \quad (1)$$

The synthesis phase problem will be of the form: How many degrees, d, a wheel of radius R or diameter D needs to rotate in order to travel distance L? Based on the analysis, the answer would be

$$d = \frac{L}{C}360° = \frac{L}{2\pi R}360° = \frac{L}{\pi D}360°$$

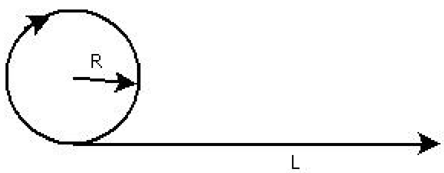

Figure 4. Wheel of Radius R Rotating Along a Straight Path

Virtual Prototyping

Virtual prototyping is used extensively today in industry. It allows the construction, evaluation and optimization of the performance of the design robot in a virtual environment. The designed structure and the satisfaction of the specifications are verified. Virtual prototyping can save valuable time, minimize cost and improve the overall design. Virtual prototyping generally precedes physical prototyping. However, for instructional reasons, the order can be reversed in order to give students the opportunity to grasp the physical reality before the virtual. The virtual components resemble the physical, and the closer the resemblance, the better and more accurate the simulation. Figure 5 shows a virtual prototype of an automobile using MLCad [23].

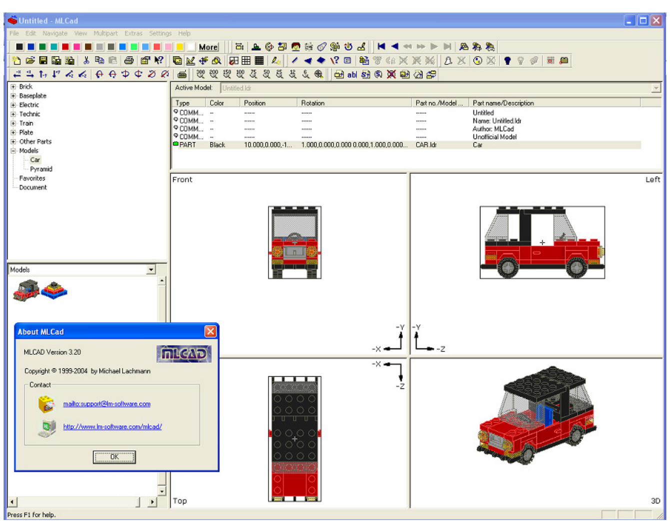

Figure 5. Virtual Prototyping of a LEGO Pieces-Based Automobile using MLCAD

Physical Prototyping

Various robotic constructions are available [24]. Students use current technology and basic skills to build a structure. This phase requires persistence and repetitive testing to evaluate the performance of the structure. Due to variations in parameters between two identical structures, one can get different performance. A common source is the voltage of the battery. Two identical structures have batteries at dissimilar voltages. This will have an effect on the current through the motor which, in turn, will have an effect on the angular speed and, eventually, on the performance of the robot. The effect of the voltage applied to a motor and its angular speed is shown in Figure 6 [25].

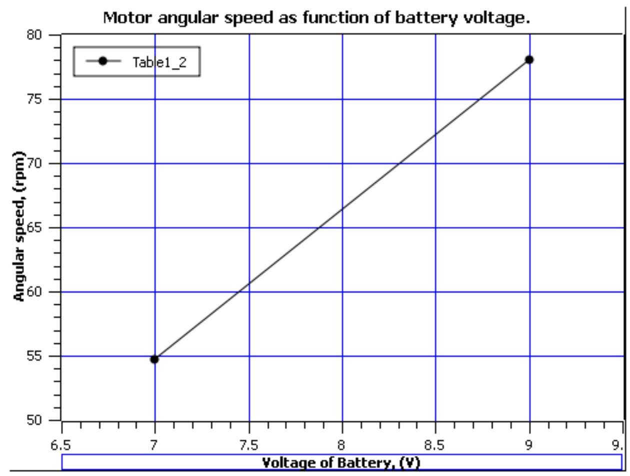

Figure 6. Angular Speed as Function of the Applied for a LEGO Motor

Plotting data

Visual communication requires the presentation of information in terms of tables, graphs or equations. In order to understand and evaluate performance, and plan future approaches, students need to tabulate collected data, plot them, and express them in the form of an equation.

System

A system is a set of interconnected elements that achieve a given objective through the performance of a specified function [19]. It is an integrated whole composed of diverse, interacting specialized structures and subjections. Any system has a number of objectives and the weights placed on them may differ widely from system to system. A system performs a function not possible with any of the individual parts and is generally a complex entity.

Example: The Self-Propelled Automobile

A self-propelled LEGO-based automobile was designed for straight-path and circular-path motion. The linear distance traveled as a function of the rubber band rotation of the wheel shaft provided material to discuss linear and non-linear behavior, validity of domain and breaking of the rubber band. Here, data were collected and presented in the form of a table (Table 1), a graph (Figure 6) and an equation to be determined. The linear approximation of the data is provided by a graphics program [26]. Approximation to a straight line is found using Equation (2).

$$y(x) = mx + b \quad (2)$$

Next, the slope, m, and the y intercept, b, must be determined. From physical considerations, $b = 0$, because there is no displacement when there is no winding of the rubber band. The slope can be found by selecting any two points to a first approximation. Selecting different pairs will give different, yet similar slopes. The concept of best fit of a straight line to data points can be introduced at this point for the appropriate level students. In the current study, the y intercept was considered as the first point because the straight line must pass from there with the last datum as the second point.

$$m = \frac{\Delta y}{\Delta x} = \frac{(5.23-0)\,\text{m}}{(4-0)\,\text{turns}} = 1.3\frac{\text{m}}{\text{turn}}$$

Finally, the equation takes the form shown in Equation (3).

$$y(x) = 1.3x \quad \text{m} \quad (3)$$

Table 1. Distance Traveled as a Function of Rubber Band Rotation

Number of rubber band rotations	Distance traveled (m)
0	0
1	1.57
2	2.92
3	4.42
4	5.23

The graphing program's linear fit option gives:

$$m = 1.33, b = 0.17, \quad y(x) = 1.33x + 0.17$$

Now students can go back and calculate, either from the graph or from the equation, the number of rotations of the rubber band in order for the self-propelled automobile to travel a specific distance. Although the current results point to a discrete system, the equation and graph transform it into a continuous system. An appropriate locking mechanism on the automobile will provide the fractional number of turns and, thus, the possibility of collecting more data.

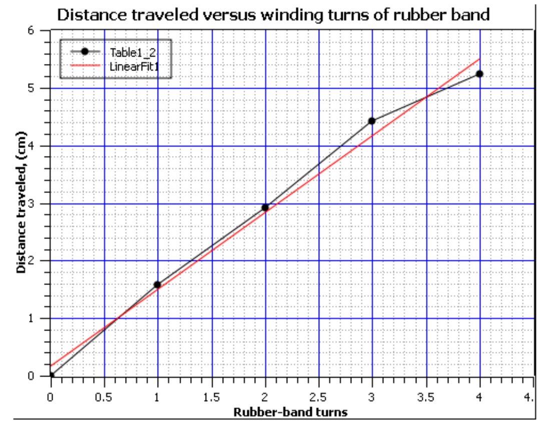

Figure 6. Linear Distance Traveled by the Self-Powered LEGO -Based Automobile

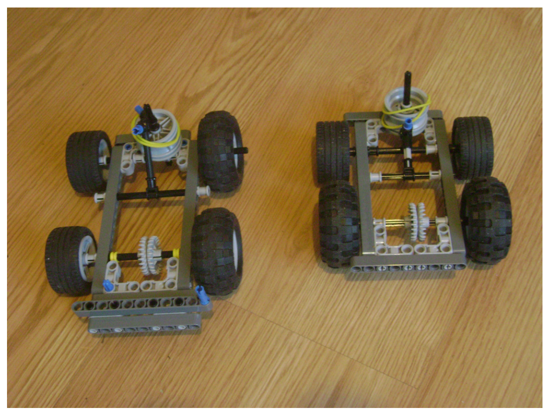

Figure 7. A Self-Propelled Car for (a) Circular (wheels of different diameter) and (b) Straight-Path Travel

Various configurations will travel different distances [27]. This is another parameter of the study, the effect that is, of the weight on the distance traveled. Further, the study can be extended by considering various surfaces. The number of rubber bands will be another parameter of the study. Extension of the study can be made by considering the physical reality of the system. There is no system when the rubber band breaks. This provides an upper limit on the domain of the function as well as on the range. In addition, winding of the rubber band in the opposite direction makes the automobile move in the opposite direction leaving all numerical results identical. Additional concepts to consider are even and odd function, domain of a function, direction of motion, limits of validity of a model, etc.

Conclusion

Problems related to low performance in science, technology, engineering and mathematics persists in education today. Robotics has been proposed and implemented as an approach to increase awareness and interest in the subject and the number of future professionals in the areas of STEM. The most popular approach has been to build a structure, a robot, and program it to perform a specific task by trial and error. In this study, the authors reviewed a number of topics from the STEM areas and proposed that they be included in the building and programming processes. Using a structured, methodological approach in implementing and interrelating concepts from all areas of STEM that apply knowledge acquired and resemble practice clarifies the various concepts and shows their value in solving problems and possible practical applications to the students.

Future Work

It is suggested that complete units of teaching either single-discipline or multidiscipline aspects of STEM be developed. Such units can be developed not only for the various robotics teams but also for elementary, middle, high school and university levels in areas such as mathematics, physics, programming, mechanisms, systems, sensors, etc. with emphasis on concepts and their use to solve problems.

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Biography

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