Utilizing Technological Innovation to Improve the Problem-Solving Skills of Middle School Students - One Group of Educators’ Experiences with the LEGO® Mindstorms Robotics System - Part II

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[This is the second installment of a two-part series of articles examining the role that the Lego Mindstorm Robotics system can play in improving the problem-solving skills of middle school students.]

In the summer of 1999, forty middle school students from seven local school districts were invited to Bloomsburg University of Pennsylvania for a week-long camp. The purpose of the camp was to introduce the LEGO® Mindstorms robotics system to the students, propose a challenge to the students, examine the methods by which students solved various problems that arose during the challenge and to evaluate the role the Mindstorm system played in the process.

Before discussing the workshop, an examination of the LEGO® Mindstorms kit is appropriate. LEGO® Mindstorms is a programmable robotics kit that utilizes an interfaced computer program that enables students to design, construct and manipulate their own robotic creations. Each LEGO® Mindstorms kit contains an RCX unit, sensors, motors and a variety of standard LEGO® building pieces. The RCX unit, the "brain" of the LEGO® Mindstorms kit, is a microcomputer that interfaces with a standard computer equipped with the Mindstorms software included in the kit. The RCX unit is equipped with three "output" ports labeled A, B and C, and an equal number of "input" ports, numbered 1, 2 and 3. A variety of sensors, including touch and light, can be attached to the input ports. The touch sensor, which is sensitive to pressure, and the light sensor, which reads varying light conditions, can each be set to change some aspect of motor control. Both sensors send data back to the RCX unit. The RCX unit processes the signals and can, if programmed and linked properly, signal various motors attached to the output ports, thereby initiating a "counter motion" of whatever design the programmer/builder envisioned. The motors are fairly straightforward in terms of design, but can be adapted to perform some ingenious functions from powering lifting mechanisms to propulsion at various speeds using different gears.

The size, complexity and number of functions any robot can perform is largely a function of programming creativity. Students are able to program the RCX unit using RCX code shown on the PC screen. RCX code is created with interlocking graphics (which look similar to box-like puzzle pieces) that symbolize basic programming code. These graphics make it possible for middle school students to program on their own, without complex or confusing directions. The graphic boxes can be interlocked in a column-type format to create entire programs. When students have created a program, they can then download the program to the RCX unit.
As for the students participating in the Bloomsburg experience, their task was deceptively simple: design and construct a robot capable of grasping a ping pong ball, and maneuvering the ping-pong ball along an obstacle course in the shortest amount of time. After learning the basic RCX codes from a tutorial that comes form the LEGO® Mindstorms kit, students were placed in groups of four and each member was assigned a specific task. One student was the builder of the LEGO® robot, a second programmed the robot, a third organized the LEGO® pieces and a fourth student was the group’s journal keeper. Each task was rotated among all four group members so each could experience the various roles integral to the project.

Students had to solve many problems during the design phase of this experience, not least of which was the construction of the robot itself. Almost every group initially came to the conclusion that they wanted to create a robot that was as lightweight as possible because they assumed that a light machine would be a faster and more maneuverable machine. Each individual group brainstormed possible ways to create the lightest robot. There were two different schools of thought as to how to accomplish this goal. The first "school of thought" was that the robot should be made with the smallest amount of material. Since the RCX unit (which must be attached) was of a given dimension and weight, this first school tried to use the smallest wheels and the least amount of building blocks to construct the robot. Although they succeeded in constructing a comparatively light robot, the students discovered that the overall design simply could not support the relatively heavy RCX unit. Most groups who fell under the "lighter is better" school of thought discovered that either the robot failed structurally or, if the robot did manage to stay together, the smaller wheels simply could not turn under the burden of the RCX unit. The second "school of thought" maintained a more "proportional" outlook on robot design and construction. Although weight was a consideration for these students, they were more concerned with keeping the overall structure of the robot in proportion to the RCX unit. Most robotic designs that fell within this design parameter were a success in terms of their ability to both support the weight of the RCX unit and remain maneuverable.

The next significant problem encountered by the students involved the creation of a "cradling system" for the ping-pong ball. Those students who were primarily concerned with weight found that if they constructed a light version of a cradling system, it could not withstand the rigors of vibrations and movement. Students that constructed larger cradling systems found that this tended to destabilize their robot. This instability was most evident in turns when the units would often tip over. A "cradling system" problem that plagued nearly every team was the various ways in which the ping pong ball could become lodged under the robot during forward motion. Students overcame this obstacle through the creation of different barriers which essentially performed the function of keeping the pingpong ball from rolling under the unit.
The final set of problems encountered by the students involved the creation of the computer program that would move the robot through the various stages of the obstacle course. An illustrative map of the obstacle course was provided to student groups prior to the construction phase. This map, however, did not reveal uncertainties about the course, uncertainties such as:

- If the robot failed to negotiate a part of the course, how could it be directed to return?
- Could a robot programmed to push a ping pong ball through the course be programmed to somehow retrieve the ball if it were to become dislodged?
- How could the possible unevenness of surfaces of the floor be overcome?

In observing the student groups, most concerned themselves with construction then programming - consideration of course uncertainties came after the robot was "finished." In these cases, teams often found themselves reconstructing large components of their robot (sometimes more than once) to accommodate the changes. More savvy teams approached the process with a more solid sense of what the robot might face in the obstacle course and therefore planned for these uncertainties as construction progressed. These groups experienced far fewer incidents of robotic deconstruction.

The number and quantity of various problem-solving skills explored and used by the students involved in this program cannot be overstated. The entire process, from beginning to end, was a concrete, meaningful lesson in cooperative problem solving cloaked in a world of robotic fun. Clearly students spent a great deal of time forming and articulating hypotheses, determining which hypotheses were most worth exploring given the time constraint, testing, making modifications, and drawing conclusions.

One of the most wonderful features of using the Robotics Invention System in a group setting is that most students find themselves on a "level playing field" when it comes to skills. Some students were clearly most comfortable in the role of designer/engineer; others in the role of builder, other in the role of computer programmer, and still others in the role of "troubleshooter." Most satisfying is the need for all group members to not just interact, but to understand a good deal about each role integral to the group’s success.

If any program designed to develop student problem solving skills is to be successful, it must grasp and hold the attention of the participants. The LEGO® Mindstorms Robotics kit held the attention of the student groups throughout the entire program. This was due in large part to the way in which the students dealt with the difficulties they encountered along the way. Frustration and failure are incompatible with working with the Robotics system because constructing a working robot is viewed as exciting, challenging and for lack of a more precise word, fun.

Nearly every student that participated in this program came away from the experience with many positive things to say. Informal student evaluations of the program focused upon the "real world experience" gained from their participation. Students also enjoyed working in teams and especially enjoyed the rotation of roles, as it allowed them to experience the program from different perspectives.

From an educator’s perspective, the program was very successful. Teachers' comments focused mainly upon how engaged students were for the entire experience. Teachers also noted that a great deal of independent learning took place during the course of the program. Students were forced to brainstorm solutions to many problems. Students could not simply run to the teacher for help with the answer - they had to rely on their ability to problem solve as a group, independent of significant "outside help."

The program is still plagued by two significant problems. Any teacher interested in using the LEGO® Mindstorms System within their classroom needs to have large blocks of time at their disposal. The program simply does not lend itself to the forty-five minute a day typically allotted to today’s classes. The other significant problem posed by this program is the cost of the Mindstorms system. The basic system costs approximately $250, well out of the budget range of the average teacher. While it is encouraging to see some intermediate units purchasing a number of Mindstorms systems for classroom use, the LEGO® Corporation could take a very positive step by offering an "educators discount" for those teachers, administrators and districts wishing to purchase a limited number of LEGO® products for classroom use.