Lego Mindstorms and the Growth of Critical Thinking

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Abstract. Goals in education of students in grades five through eight include the development of critical thinking skills. After observing the positive effect that the use of Lego Mindstorms robots had on problem solving skills in a fifth grade classroom, it was decide to formally test the use of the robots on critical thinking skills on this population. Pre- and post-tests are being administered to children before and after the use of Leg robots to teach math skills.

Keywords: Education, Critical Thinking, Robots

Introduction

Problem solving and critical thinking are two abilities widely considered important outcomes of education. Although these abilities are generally examined in high school and post-secondary education, there is no reason to think that they can not be fostered before high school. In fact, in the United States, where pre-college education is largely driven by state and/or national standards, there are a number of these standards that deal with these abilities. For example, in the state of Illinois, Illinois Learning Standards (ILS) Goal 11, "Inquiry and Design," explicitly includes such ideas as "design a device that will be useful in solving the problem." (Illinois State Board of Education, 2003)

In addition to the need for young students to develop critical thinking and problem solving skills, there is need for research into the development of these skills in students. Relatively little is known about the processes by which these students' problem solving abilities grow, and it is therefore difficult to integrate the development of these cognitive skills into the standard curriculum.

While there are many environments that may promote the development of problem solving and critical thinking, the use of an environment that involves robotics may be appropriate for young students for several reasons. First, the design, construction, and programming of robots can obviously be used to address standards such as ILS Goal 11. Second, from a student point of view, the work with robots can be quite motivational. Third, the use of robots may provide for opportunities to collect rich data about student thinking *in situ*. Fourth, a robotics curriculum would be in line with recent emphasis from the United States federal government on the promotion of science, technology, engineering, and mathematics (STEM) education (Bumiller, 2006).

The use of robots with college students has received some study (Fagin, B., Merkle, L., & Eggers, T., 2001; Kay, J. 2003; Klassner, F., 2002). However, there is been little formal study of the use of robots with pre-college students. While there may be many reasons for the paucity of information in this area, two issues are likely. First, a thorough literature search reveals that there is a general dearth of information about problem solving and critical thinking about pre-college students. Second, given that the recent standardization of curricula in the United States corresponds in time with the development of robot environments easily accessible to younger students, the innovations provided by these robot environments have not found their was into schools.

While there are many ways to implement a robotics curriculum, *Lego Mindstorms* provides an environment that is student friendly and able to support the data collection needs of researchers interested in the development of problem solving skills. *Mindstorms* consists of a largely graphical interface for writing programs and a flexible and simple means – the use of *Lego* blocks – for constructing the physical robots. Both the programs, which can be recorded as they are constructed and edited, and the robots, which can be described in some detail, provide excellent artifacts of student critical thinking and problem solving.

After experimenting with Lego robots in a fifth grade classroom, it was decided to conduct research testing the use of robots in classrooms to teach math skills and measure their effects on cognitive thinking skills.

Lego Robots in a Fifth Grade Classroom

The motivation for using *Lego Mindstorms* in the classroom was to put a practical twist to student learning. The exercises involved in the classroom using the robots covered many of the state goals required of all teachers. The goal was to teach mathematics, reading, language arts, and basic programming using the Lego software. When introducing new math concepts, we would implement the concepts using the robots. For example, when studying circumferences and diameters in math, students took these measurements on the tires of the Lego wheels. Students also used the scientific method when using the robots. The students had to read and follow directions, make a hypothesis, test their hypothesis, record results, and implement corrections for each run. Once a challenge was completed, it needed to be reproduced to validate results.

Using Lego bricks, light and sound sensors, motors, and gears, teams built robots to complete class assignments and eventually compete in a Lego Classroom Tournament. Groups of three students each, with each member having a specific job—builder, programmer, and scribe—were created; each member had to have knowledge of the other two jobs. Building the robots was the first step. The kit used was the Lego Mindstorm kit, Team Challenge Set; parts used depended on how the students built their robots and what functions they were trying to achieve. Time was spent on basic robot design and function. Students needed to be able to change their robot's tires and gears with little or no rebuilding of the basic structure (see figure 1).The first exercise in basic geometry (radius and circumference) was conducted by measuring the circumference on all the tires on the bots and recording the results. This was done by wrapping a string around the tire, marking it, and measuring the string for circumference. Students then measured the diameters of the tires, recorded the results in journals, multiplied all results by 3.12, and calculated the circumference. The calculated results were compared to the measured results.

Figure 1. A Lego Robot and a Laptop

Various experiments using the robots were conducted. The first set involved the understanding of the relationship between tire and gear size. Students ran their robots using different size tires and gears, and compared the results. Overviews of these experiments follow.

First:

- place tires on robots, a set at a time
- program their robot to go ten seconds
- record the results after each run to determine how far their robot has traveled with direct drive.

Second:

- put gears on their robots; start with a small gear on the motor and the medium gear on the axles

- run their robot using all three different size tires to see how far their robot has traveled with this type of gearing
- record their results after each run

Third:
- place small gear on the motor and the big gear on the axles
- run their robot with all three sets of tires and record results after each run

Fourth:
- place the medium gear on the motor with the small gear on the axles
- run all three tires and record their results after each run

Fifth:
- place the medium gear on the motor and the large gear on the axles
- run their robot with all three different tires and record their results after each run

Sixth:
- place the large gear on the motor and the small gear on the axles
- run their robot using all three sets of tires and record their results

Seventh:
- place large gear on the motor and the medium gear on the axles
- run their robot and record their results

Results were collected, written in journals, and compared. Although students did not always understand gear ratio, they did understand how different size gears coupled with different sized tires can affect a robot's travel. Students wrote reports comparing and contrasting the results. The next experiment involved programming the robots to go varying distances –twenty, fifteen, ten, and six inches. This exercise gave students a better feel for their robots capabilities.

A challenge board, designed for that year's theme, was constructed. For approximately a month, students were required to work though the tasks on the board. For each task, students ran the task, recorded results in a journal, and decided how to fix problems that were encountered. Programs needed to be written in the journals so they could be retrieved and run in the future. Students were reluctant to perform this task until their programs crashed, they lost all their work, and had to start over again. A competition was conducted at the end of the month. Each team ran the tasks, their scores were recorded, and an overall placement in the class for each team was posted.

For the second challenge, students had to program their robot to remove all plastic bottles out of a nine-by-nine, or eighty-one square inch area. (The size of the area was determined by the amount of space available for this exercise). Students needed to refer to their journals and determine which combination of gears and tires produced the fastest results. The program required one light sensor that enabled the robot stay within the black lines. Teams were given a week of practice before competing with other teams. The team that got the bottles out the fastest was recorded for placement in the Lego Classroom Tournament.

The next challenge was to make the robot stay within black lines, remove clear bottles, and avoid the black bottles. (Note that any color can be used if the right sensor is selected.) A race was conducted to see who could remove the clear bottles without moving the black bottles.

The last challenge was to see which robot could travel around a circle the fastest. Robots needed to stay on a black line forming the circle. Teams are given two weeks to practice this and record their results. There were two goals: staying on the circle and going the fastest while doing it. Teams were ranked by results.

At the end of the tournament, all scores were averaged to determine class ranking. The top three teams were given a trophy built using Lego pins. It was the teacher's observation that students were scoring better on problem solving tests because they were practicing these skills with the Lego robots.

Certain practices worked well in the classroom. Allowing the students to explore on their own was highly motivating. The time required for this activity was two hours a day, two days a week. While longer time periods cause students to lose interest in their robots, shorter time blocks were not adequate for students to make corrections to their programs and robot design. Limiting group size to three students per group allowed each member of the group to take turns being the builder, programmer, and scribe. All team members must have input into the process, if they are to stay interested. Pairing high achieving students with low achieving students was very successful. It was observed that the low achieving students have great ideas on how to build and gear their robots, while the high achieving students do much better in programming and writing. Changing job assignments provided the opportunity for each student to "teach" the others and increase their own understanding through self-explanation (Aleven & Koedinger, 2002).

Current Research

Due to the student success observed in the 5th grade classroom discussed above, we are expanding our research to include other schools. Currently, we are conducting research in an eighth grade classroom in a private, parochial school. Future research is being planned for other schools, including a Montessori environment.

Overview

This project has four main goals:

1. To observe and interpret the development of programming skills as a language
2. To study the growth of problem solving skills in context
3. To begin an exploratory study of the evolution of cognitive structures
4. To investigate the relationship between a given curriculum and student outcomes

Since the interest here is the dynamics of the development of critical thinking, and not merely on the presence or absence of gain in critical thinking, a dynamic systems perspective is appropriate. While dynamics systems thinking has multiple roots, Thelen & Smith (1995) and Smith & Thelen (19xx) provide an excellent introduction to the field. In particular, Thelen & Smith (1995) look at the ways in which internal schema interact with environmental factors to produce new schemes. They further look at *canalization*, the ways in which one chooses among schemes in particular situations. For example, babies develop a number of methods of locomotion – crawling, walking, hopping, etc. – and over time certain schemes become preferred for certain situations. The process of the development of programming skills is being examined in a way similar to that of infant locomotion.

Unlike locomotion, however, the development of programming skills has an additional component that must be considered: meaning. Programming is a type of language, as the tokens of a program have meaning, and students create their own understandings of these tokens in a way that is likely to be similar to the construction of language: Students assign meaning to the tokens, and these meanings can be seen by virtue of the students' actions with these tokens. Lev Vygotsky (1986) was among the first to investigate the ways in which children assign meanings to tokens, and his methodologies are appropriate to a *Lego Mindstorms* environment; although the tokens of programming are more numerous and complex than the tokens Vygotsky used, they are still accessible through a similar methodology.

In addition to the development of programming skills, more general problem solving skills will need to be developed. This is providing an opportunity to examine the development of these skills in a particular context, that of *Lego* robots and the tasks the students are set. The choices of tasks limit useful student actions. These limitations reduce the complexity of problem solving and allow a cleaner interpretation of student actions.

Underlying both of these goals – the development of programming skills and the development of problem solving skills – is the question of cognitive growth. One dynamic of cognitive growth, *reflecting abstraction*, was proposed by Piaget. While there has been support in general for this process as a model of cognitive growth, most investigations of reflecting abstraction are too course-grained to actually catch the process in detail. It is hoped that our studies are fine-grained enough to allow for some of the processes of cognitive growth to be observed. Video recordings of student actions can be used to later guide student recall and reflection during follow-up interviews; these interviews may provide insight into the process of reflecting abstraction.

Lastly, the relationship of curriculum to student learning in this environment is being examined. Doll (1993) gives principles by which curriculum should be organized and Davis & Simmt give similar principles for the learning environment that implements a curriculum. The proposed *Lego* environment lends itself to at least qualitative studies of these principles. Outcomes, both of programming and problem solving skills, are being measured, and because the environment is separated enough from the normal school environment, these are being connected to the curriculum.

Within each of these goals, there is the ability to look at sub-groups of students, investigating similarities and differences across gender, previous student performance, and student interest.

Method

Since we are attempting to examine the process of critical thinking development, and not just the outcome, several types of data is being collected and analyzed.

Pre- and post-tests are being used to measure gains in critical thinking skills. A thorough search of existing instruments did not turn up a valid, reliable instrument to measure critical thinking in middle grades students. The use of instruments designed for older students, however, while likely providing skewed data on a pre-test should nevertheless provide a measure of critical thinking growth.

Program evolution is being measured via screen capture. Using software to record student computer screens, along with an audio recording of the students working at that computer, will allow the development and revision of programs to be recorded. Since students often talk as they work, an audio record may provide additional insight into student thinking. These screen records are being stored as digital video, and will be available for analysis.

Observations of students as they build and especially test their robots are being made. It is hoped that future studies will include, where possible, a video record of these observations. These observations can provide insight into student thinking and link that thinking to the experiences that triggered the thinking. These observations can also lend insight into the particular characteristics of a situation to which students attend, which can aid the study of reflecting abstraction.

Lastly, it is hoped that future studies will include guided interviews of students, where students observe a video of their actions as an aid to their recall and reflection, can help identify the parts of the curriculum that are of importance as the students work.

While there are a number of standard analysis techniques for these data, such as significance testing on the results of pre- and post-testing and ethnographic techniques for observations, because the emphasis here is on development, and not on a static situation, additional analysis will be performed.

Student programs are being coded, using a method similar to standard open coding and axial coding, and then either path analysis or a Markov analysis will be performed on the codes to investigate patterns of development. This should yield insight into both the canalization of programming techniques and the development of meaning for the tokens of the programs. Nonlinear time series analysis of student behavior during programming can yield further insight into the development of meaning. Other analyses may also be possible, but it is difficult to determine all methods before seeing the data; the particular fine- or course-graining of the data will influence the choice of methods.

Outcomes

There are several intended outcomes of the project. The first is a measurable gain in student critical thinking. This is an important pre-requisite for some of the other studies to be undertaken. Preliminary informal investigations with 5^{th} grade students lead us to be confident that such gains will occur as a result of the *Lego* robots curriculum. We will examine the growth of critical thinking and the process by which it occurred for the students in this study. We will also look at the development of meaning for the programming language. A close examination of the curriculum and its impact, particularly with respect to Doll (1993) and Davis & Simmt (2003) will be produced.

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