Scaffolding Knowledge Construction through Robotic Technology: A Middle School Case Study

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ABSTRACT

Various forms of robotic technology are currently moving from the confines of the research labs and into the hands of teachers. One area of robotics that is readily available for technology integration into elementary and middle school science and technology classrooms is produced by LEGO® (Mindstorms for Schools™). Such technology offers the possibility to teach various scientific, mathematical, and design concepts through the designing, building, and programming of robots. Students can creatively explore computer programming, mechanical design, physics, mathematics, motion, environmental factors, and problem solving in a collaborative group setting. This paper describes phases of a case study that integrated LEGO robotic technology into computer and science middle school classroom environments. Data were collected in the form of student projects, reflective journals, observations, and video. Observational results indicate that students had more success during robot building and programming tasks when they used flowcharting to help scaffold their knowledge construction.

INTRODUCTION

Children use computers in science and technology education to gather information, learn new material, and solve problems in ways that were previously unimaginable. One only has to review the contents of any recent undergraduate education textbook to see the wide range of curriculum initiatives related to science education and involving computer technology (e.g., Forcier & Descy, 2007). Emphasis is often placed on using computer technology as a tool for productivity and problem solving in a constructivist learning environment, generally in the context of clearly defined standards (ISTE, 2002). However, one area that has received little attention is the integration of robotics in the classroom to enhance critical thinking and promote higher-order learning (Wagner, 1998).

Recent advances in computer technology have allowed for the design and development of robotic construction kits. For example, LEGO® has designed several introductory robotic kits such as the *Mindstorms for Schools™ Team Challenge Kit #9790* (LEGO, 1999a) which utilize an iconic programming language called ROBOLAB™. Designing, building, and programming robots allow students to creatively explore computer programming, mechanical design, physics, mathematics, motion, environmental factors, problem solving, and group collaboration (Druin & Hendler, 2000). Students are given ownership for their learning within an active, enjoyable, and non-threatening environment. They can make choices and solve problems as they meet the challenges that are a natural consequence of robot design. Working with robotics also provides students with an opportunity to construct knowledge through activity and further develop numerous mathematical and scientific concepts. Children are able to work with computer technology outside the computer workstation; thus they will realize that control structures can be used to manipulate computer devices that function away from the desktop.

In this paper, we describe various phases of a pilot case study that integrated LEGO robotic technology into a mixed-year, optional technology classroom for middle-school students in Grades 7, 8 and 9. The classroom of study was situated in an urban school with a very small population of middle-school students (a total of 43 Grade 7, 8 and 9 students). Optional classes were offered Friday afternoons for 2.5 hours in a multi-year format.

For instructional, learning, and pragmatic purposes, the students in this study were placed together in small teams to design, construct, and program their robots. Data were collected in the form of student projects, reflective journals, observations, and video.

RELATIONSHIP TO EXISTING RESEARCH AND LITERATURE

The use of robotics in the classroom is based on earlier research work of Seymour Papert, the creator of the Logo programming language (Papert, 1980). Logo is designed for use by children and is based on Piaget's (1964) notion that abstract concepts can be learned through hands-on exploratory investigation.

Findings of the last two decades have supported Piaget's notion that people construct knowledge through activity (Case & Edelstein, 1993; Case & Khanna 1981; Halford, 1989; Siegler, 1994); however, these findings do not support Piaget's belief in universal logical structures as the foundation of the mind (Fisher & Immordino-Yang, 2002). Instead, they have shown that stages of skill development follow paths with a common structure but differ in time frame across task, individual, and culture. Therefore, the development of cognitive and behavioural abilities follows a trajectory that is highly variable (uneven) and context specific—with limited transference between domains.

The unevenness and order in variation of development in children's cognition and behaviour results in a "constructive web [whereby] knowledge building does *not* proceed across all areas of development synchronously in a linear, ladder-like progression" (Fischer & Immordino-Yang, 2002, p. 7). Rather, cognitive and behavioural skill development is said to be an independent process that occurs within a given task domain at an inconsistent rate. These skills, although developed independently, can often be combined during learning and problem solving.

One source of variation in skill development is related to the culture of social support in a child's learning environment. The level of support (increased or decreased), often referred to as *scaffolding*, can impact a child's ability to develop cognitive and behavioural skill sets. Vygotsky (1978) believed that the variability in skill development is directly linked to the support a child received from a more competent adult or peer. It is further suggested that concrete representations and artefacts can also operate as cognitive tools that mediate and scaffold action and skill development (Palincsar, 1998). Therefore the range of cognitive or behavioural skills a child develops is very often tied to the level of scaffolding the child encounters in the environment.

Logo to LEGO

The initial work with Logo learning in a constructivist environment formed the groundwork for research partnerships between the MIT Media Lab and LEGO Corporation (Martin, Mikhak, Resnick, Silverman & Berg, 2000), and subsequently with Tufts University and National Instruments (Portsmore, 1999; http://www.ni.com/company/education/

mindstorms.htm; www.ceeo.tufts.edu/). As a result of these partnerships, the ability for children to construct and program robots is making its way into school classrooms. One of Papert and Harel's (1991) major premises is that learners are most likely to generate new ideas when they are actively involved in problem solving that results in external representations (i.e., a Logo program to control the movement of a robotic turtle).

Constructivists believe that learners make their own meaning, thereby generating a unique set of conceptual representations in accordance with their personal experiences (Jonassen, Peck, & Wilson, 1999). Papert and Harel (1991) extend the theory of *constructivism* to encompass the more practical notion, *constructionism*. According to Papert, the two words differ profoundly. As Kafai and Resnick (1996) state, "one of the main tenets of *constructionism* is that learners actively construct and reconstruct knowledge out of their experiences in the world … it places special emphasis on knowledge construction that takes place when learners are engaged in building objects" (p.2). Constructionists approach knowledge formation with an emphasis on physical interactions with objects rather than the abstract formalizations. They believe that working on personally meaningful, context-specific projects, which require the manipulation of virtual or concrete objects, will assist students in the learning process (Carbonaro, 1997).

Robots, being physical objects, fit naturally within the constructionist perspective of learning. Students who engage in the design and construction of robots are actively engaged in their own learning, developing problem-solving skills, utilizing higher-order thinking skills, and often working in collaboration (Chambers & Carbonaro, 2003). In a LEGO/programming environment, students take ownership of their learning and meaning-making (Penner, 2001).

Robotics, as an educational tool, allows students to learn in an active, constructionist environment, building physical objects and experiencing abstract concepts in intentionally meaningful ways. Research on the use of robotics in classrooms indicates that in addition to promoting problem-solving abilities and amplifying children's understanding of scientific, mathematical, and design concepts (Druin & Hendler, 2000; Bauerle & Gallagher, 2003; Wagner, 1998), there is evidence to suggest that children with diverse learning abilities can benefit from working with robotic technology (Rust & Kramer, 2002).

STUDY: METHODS, QUESTIONS, CONTEXT

The scope of the project was exploratory and dealt with research on the use of robotics. The objective was to conduct a pilot case study of children's knowledge development and problem-solving approaches to building and programming LEGO robots using new curriculum materials. This case study centred on the children's reactions and thoughts during their problem-solving processes. According to Gall, Gall, and Borg (2003), case study research can be viewed as an "in-depth study of instances of a phenomenon in its natural context and from the perspective of the participants involved in the phenomenon" (p. 436). In this exploratory study, the classroom setting provided the research context for examining the children's knowledge construction as they investigated the use of a novel technological phenomenon (LEGO robotics).

The bounded case (Stack, 2000) for this study consisted of a single, multi-year classroom of fourteen Grade 7, 8, and 9 students enrolled in a technology option. Ethics approval to conduct the pilot study was obtained from the Faculty of Education Research Ethics Board and Cooperative Activities Program, the local school districts' research project application. Students and their parents were given an information letter outlining the research and their options regarding participation; both students and parents were given letters of consent to sign and return. The school's vice principal, along with the teacher-researcher, verbally explained the research process to the students, including their option to not participate or to withdraw at any time without any repercussions in the context of the Career and Technology Studies (CTS) optional class.

The classroom teacher-researcher designed and taught this specific robotic option, with assistance from a second researcher and additional academic support. Though not specifically framed within action research methodology and epistemology, aspects of this study reflect characteristics of classroom action research, which “typically involves qualitative, interpretive modes of inquiry and data collection by teachers (often with help from academics) with a view to teachers’ making judgments about how to improve their own practice,” curriculum, and learning (Kemmis & McTaggart, 2000, p. 569). The second researcher (a highly experienced, award-winning teacher) was present each teaching day to collaborate in the research/teaching process with the teacher-researcher and to aid in data collection. The second researcher’s data collection responsibilities included the filming and compilation of all videotape data as well as recording anecdotal evidence of children’s verbal interactions, questions, and apparent struggles in the form of field notes and reflections. The classroom teacher-researcher and researcher met following each class to review and discuss the day’s activities, field notes, and reflections as well as to plan the next week’s activities. Planning took into account student difficulties and progress based on the review. The students were videotaped during various phases of the process of building and programming their robots. Data collection and analysis was an emergent process. For example, when it became obvious that videotaping was not a wholly viable solution in a busy classroom because of background noise and the dynamic nature of robot construction and programming, the teacher-researcher and researcher worked together to develop student reflective journals and an accompanying formative assessment process. The trustworthiness of the student reflective journal as a tool for helping the researchers interpret the effectiveness of robotic technology in supporting student learning as they developed knowledge and problem-solving skills was based on the expert knowledge and prior experience of the teacher-researcher and, especially, the researcher. The intent of the reflective journals was to explore student comments, thoughts, struggles, and ideas around the designing, building, and programming of their robots as they worked through the challenges. Additionally, students were asked to reflect on team dynamics and the group process. The teacher-researcher and researcher carried out a formative and ongoing assessment of student journals in order to be able to meet students’ needs and refine the pilot project as it progressed. The reflective journals also provided a rich source of qualitative data. Therefore, multiple methods were employed for data collection, consisting of videotape, anecdotal evidence in the form of field notes and teacher-researcher/researcher reflections, student work, and student reflective journals. Each data collection method was draw upon to explore the research questions, but especially the student reflective journals and teacher-researcher/researcher reflections.

The questions the study addressed were defined as follows:

- How can LEGO robotics be effectively integrated into technology and science components of the curriculum?
- What does an examination of students’ designing, building, and controlling of robots reveal to the teacher about the development of students’ knowledge and problem-solving skills?

The fourteen students (four Grade 7, five Grade 8, and five Grade 9) were asked to sort themselves into groups. Each group was required to have one Grade 7 student, one Grade 8 student and one Grade 9 student. While these students were very comfortable collaborating with their peers, the mixed-grade grouping was a relatively new experience for them. However, students knew each other well (this is a very small, community-centred school) and did not appear to have difficulty with the mixed-grade group structure. From a learner-centred, social-constructivist perspective, Bonk and Cunningham (1998) support collaborative learning, suggesting “instruction should provide opportunities for embedding learning in authentic tasks leading to participation in a community of practice” (p. 26). Students worked collaboratively as members of a design and programming team, within a technology community. Additionally, groups are recommended for working through the activities using the *Mindstorms for Schools ™ Team Challenge Kit* (LEGO, 1999a), and were necessary due to equipment and space limitations. Five robotic kits were available for instruction. This resulted in four colour-coded groups (blue, green, red, and yellow) of three students each and one group (colour-coded black) that consisted of only two students, one in Grade 8 and the other in Grade 9. The teacher emphasized the need for good team dynamics and cooperation; students were encouraged to participate and support one another and were given direction when needed. This type of teacher support for successful group work is recommended by Johnson and Johnson (1989/1990). Individual group members were asked to choose the roles they would assume from the following: Team Manager, Communication Specialist, and Materials/Information Specialist. All team members were expected to contribute equally to design, building, and programming tasks. The specialized roles, that is, Team Manager, and so on, remained relatively stable throughout the course of instruction though they became secondary to building and programming concerns.

LEGO robot kits come with typical LEGO pieces that allow simple construction methods to be easily incorporated into a multitude of designs. The kit used for this study was versatile and allowed the students to create two types of robots, an *Acrobot*, and a *Vehicle*. These components included gears, axles, wheels, pulleys, motors, and sensors (light and touch); the core element of all robot creations is the LEGO programmable yellow brick, also referred to as the Robot Command Explorer (RCX) (See Figure 1). The RCX is a microcomputer powered by batteries, and is equipped with input and output ports to allow for environmental influences such as light, touch, and axle rotation to control various types of motors or lights. Programs are written in an iconic-based language called ROBOLAB and then downloaded from a desktop computer via infrared transmitter to the RCX thereby enabling the robot to behave autonomously.

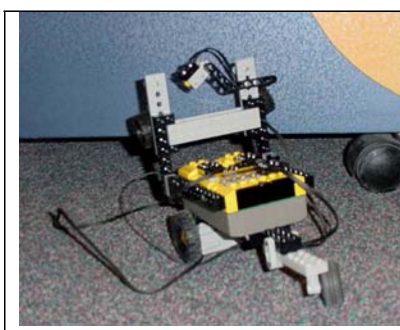
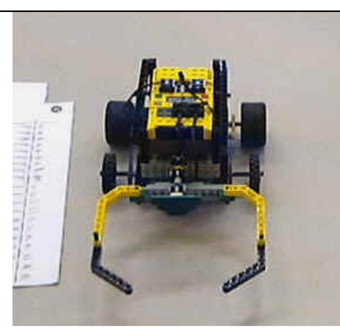
		
Acrobot	Parts used for vehicle	Vehicle

Figure 1: LEGO robots and a typical set of parts

Study Chronology

The outcomes are grouped in four general phases. Each phase summarizes the case study chronologically across ten consecutive weekly classes. Each class consisted of 2.5-hour blocks of time for a total teaching/observational time of 25 hours.

Phase one. The groups were asked to read a short passage from *Robotic systems: A guide to understanding the robots around us* (LEGO, 1998). Each of the five groups was assigned a different topic to read, summarize, and present to the rest of the class. Topics included robot control, form, behaviour, reliability, and implementation. Students then discussed the characteristics of robots, identifying them in everyday life. This exercise set the context of the project and allowed the teacher and students to investigate a number of pragmatic reasons for building robots.

Each team then completed an introductory Acrobot building activity (LEGO, 1999b). Students were taken through the steps of putting batteries in the RCX, building a robot, equipping it with two touch sensors and one light sensor, decorating the robot, then finally using the RCX built-in default program set.

In order to provide students the needed direction to successfully complete and monitor their performance, reflective journals were instituted. Students reflected on the roles of the various team members, problems encountered during the day with possible solutions and outcomes noted, as well as group dynamics and time management. The intention of the journaling was to provide students with important scaffolding and support for their learning. Following are example excerpts from student journals:

> *Black Team*: We began learning the basics of robotics. We discussed body, control and behaviour. Our group learned how robots work and what different types of robots there are. We assembled the Acrobot robot up to step 11. The Acrobot was a basic robot that allowed us to learn how to use the braking system and the light sensor system.
>
> *Yellow Team*: Our second problem was putting on the infrared sensor. At first, we put it above the tire which doesn't work because the tire is too dark for it to move. We moved the sensor forward and closer to the ground. The solution worked successfully.
>
> *Blue Team*: The robot didn't run in the hall with the light sensors. We tried running it in the class where it's bright, then in the hall. We found out that it is very sensitive.

This phase of the project was essential for students, the teacher and the researcher for a number of reasons. First, it allowed all parties to familiarize themselves with the equipment and typical construction tasks. More explicitly, it allowed particular skills to develop which could later be integrated to form more complex skills, perhaps with some regression and relearning of skills (Fischer & Immordino-Yang, 2002). Second, it generated problem-solving activities that pushed the students to formulate solutions and reflect on them through the process of journaling. Third, it enabled the teacher and researcher to adapt their instructional and observation strategies to more effectively describe the students' actions. Finally, it helped to define the situational environment (group, classroom, activity, observation) in which the learning and problem solving took place. Problem-solving activities are usually tied to the same environments in which problems are encountered (Brown, Collins & Duguid, 1989). In this instance, the students had no prior experience in understanding the process of constructing robotic devices. Phase one provided a necessary introductory level to build on for future design and programming challenges. Additionally, though the students had a wide range of collaborative skills developed across a wide range of domains, the role-specific nature of the team environment was, at times, fairly demanding of the students and their abilities to work collaboratively.

Phase two. The second major problem-solving activity was the design and development of a computer program to control a robot's behaviour. Although some students had used a limited set of HTML commands to produce Web pages, most were complete novices to any form of programming. ROBOLAB is an icon-structured, object-based, programming environment. The capabilities of the ROBOLAB environment are extensive and allow for development of fairly sophisticated programs (Chambers & Carbonaro, 2003). The LEGO ROBOLAB CD contains an excellent set of introductory exercises that are easily understood and executed. These exercises demonstrate how to set up the infrared transmitter and download the firmware from the desktop computer to the RCX. Various programming commands were then introduced to control inputs/outputs on the RCX such as power levels for motors, and light and touch sensor levels. Students were challenged to make their Acrobot go in the opposite direction, or to make it spin. The following excerpt from a student journal illustrates initial programming/construction difficulties as well as how more support can lead to a jump in optimal performance (Fischer & Immordino-Yang, 2002):

> *Blue Team*: We wired our second engine into Socket C, but programmed for B. We didn't realize [the problem] at first so we tried reprogramming. The robot performed as before as we still hadn't realized the problem. We had trouble with the wiring. Then we were taught how to do it properly. We finally were able to wire properly and it worked.

Flowcharting was introduced to the students to help them organize their programs on paper (pseudocode) before doing their work on the computer. The students were introduced to four simple symbols, an *oval* for starting and stopping, a *square* for individual process steps, a *diamond* for conditional decisions (e.g., YES or NO), and *lines* for program flow. Students were encouraged to think that a program must loop repeatedly until all the conditions have been satisfied. Students then created flowcharts and were asked to consider if flowcharting would help them program their robot. Figure 2 shows examples of flowcharts drawn by the students.

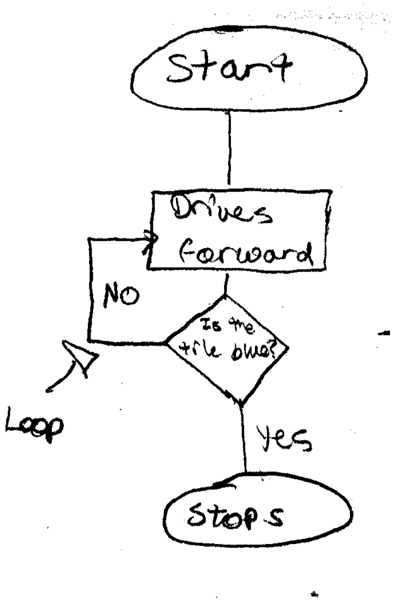
With respect to the value of flowcharting, the students were initially very supportive of the process as reflected in the following comments:

> *Black Team*: We do think that flowcharting will help us to program our robot. It gives an outline to study before programming the robot. It lines up your ideas and acts as a reference for the rest of the program.

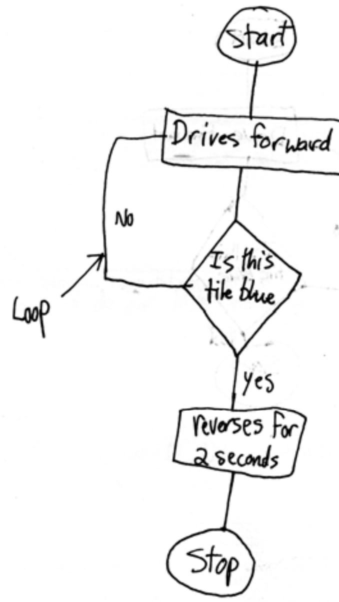
> *Yellow Team*: [It] helps us plan ahead for the flowchart on the actual computer program. It is easier to write it all down on paper and then transfer that exactly on to the program than to make it all from scratch on the program [computer]. When you write down things, it flows more clearly through your head rather than just clicking a few buttons.

> *Green Team*: Flowcharting will help program our robot because it will help us arrange our ideas before we start programming our robots on the computer. Potential problems will be noticed before we start programming on the computer. We will decide what

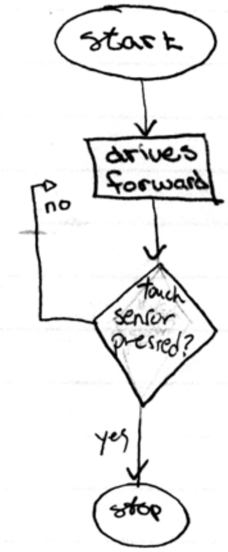
exactly we have to do. It will help us understand what the robot will be doing before we begin.



Flowchart 1: Your robot drives forward until it sees a dark blue tile and then stops.
Green Team



Flowchart 2: Your robot drives forward until it sees a dark blue line. It then reverses for 2 seconds and stops.
Yellow Team



Flowchart 3: Your robot drives forward until it bumps into an object or a wall. It then stops.
Red Team

Figure 2: Sample flowcharts produced by some of the teams

Additionally, these student excerpts indicate discontinuities in optimal (supported) performance. The flowcharting exercise enabled students to make dramatic leaps in their programming capability thereby providing a concrete scaffolding mechanism (Fischer & Immordino-Yang, 2002).

The teacher-researcher and researcher discussed logical extensions to the flowcharting process, tying the act of flowcharting to the programming sequence. Student comments were analysed in light of their use of flowcharting as an aid in understanding programming difficulties, for example:

> *Blue Team*: Today, I was unable to make the robot respond to the programming fork. It didn't react to depression of the touch sensor. I tried many different programming techniques, even resorting to starting from scratch…twice. I also attempted simplifying as well as complication. The robot continued to not respond as if mocking[sp] me.
>
> *Yellow Team*: Our group did not know how to use the loop button correctly, and then we did not know how to make it loop 5 times. We decided to ask [Name] how to work it, and how we can make it loop 5 times. After we asked [Name] looping worked as many times as we wanted it to work.

In the above examples, the students did not return to their flowcharts to aid in problem solving. Instead, it would seem the students regressed in component skill level as more complex tasks were undertaken. The class required more extensive work on the use of flowcharts. They also needed a better understanding of how to map their flowchart design to ROBOLAB program code. For example, the teacher could have drawn a flowchart for a simple program algorithm on the whiteboard, with the class then working together to build the program on the computer. This would have helped students tie the abstract process of flowcharting to the process of using the ROBOLAB programming icons to represent events, and subsequently to the concrete process of testing the program and observing the results. One simple flowcharting change that did aid in student transfer of flowchart to programming occurred when the teacher began flowcharting horizontally on the whiteboard. The ROBOLAB program code places the icons in a horizontal frame. Consequently, by turning the flowcharting from the vertical to the horizontal, students were able to visually make the connection between the written flowchart on the whiteboard and the program on the computer screen.

Only one team (Black) used flowcharting to refine their problem solving during the final programming activity (see Phase four discussion below), exemplifying the differences in level across students. The level of detail and analysis captured in this flowchart was well beyond what either the teacher-researcher or researcher expected based on the students' level of experience (see Figure 3). The planning associated with the development of such a flowchart indicates a high level of critical and reflective thinking skills for this domain. Reflective thinking of this nature requires extensive deliberation and involves inferential reasoning. As Jonassen (2000) points out, "a common criticism of constructivist approaches to learning is that learners are so active that they do not have time think about what they are doing" (p. 13). In this case, the complex steps involved in collaborative problem solving and the construction of the flowchart suggests a sophisticated level of reflective thinking.

Phase three. During this phase the students focused on making robotic vehicles. Teams were randomly assigned a chassis to build from the *Subassembly Constructopedia* (LEGO, 1999c), a book that outlines various chassis designs. Students were asked to describe the strengths and weaknesses of the particular chassis' designs with respect to speed, manoeuvrability, power, durability, and specific advantages; they also took digital photographs of their completed chassis (see Figure 4). This was a very specifically designed form of scaffolding that drew detailed attention to particular design issues. This phase of the project required that students engage in a detailed interaction with components of the LEGO kit. They also developed an awareness of the relationship between gears, gear design, force, friction, and ratios. Such concepts are often made more accessible when placed in context of designing with LEGO (Martin, 1995).

This phase of the project was extended for the five Grade 8 students involved in the robotic CTS option through integration in the Grade 8 science curriculum. The students worked with the science teacher to further solidify their understanding of gear design and forces. They examined their robot constructions based on their previous studies in science in terms of the following key concepts: a) design and function, b) transmission of force and motion, c) simple machines, and d) mechanical advantage, speed ratios, and force ratios (Alberta Education, 2003, p. 43). Through discussion, demonstrations, and written reflections, the students described and explained the forces, gear ratios, speed and power advantages, and capabilities of their individual robot designs. We believe the students' scientific conceptual understandings were deepened and solidified through manipulation and observation of the gears, motion, and forces at work within each of the different robot designs. These conclusions are based on observational, written, and anecdotal evidence as well as comments from the science teacher. However, this phase of the pilot study was limited in time and scope, consequently further research is needed to support this conclusion.

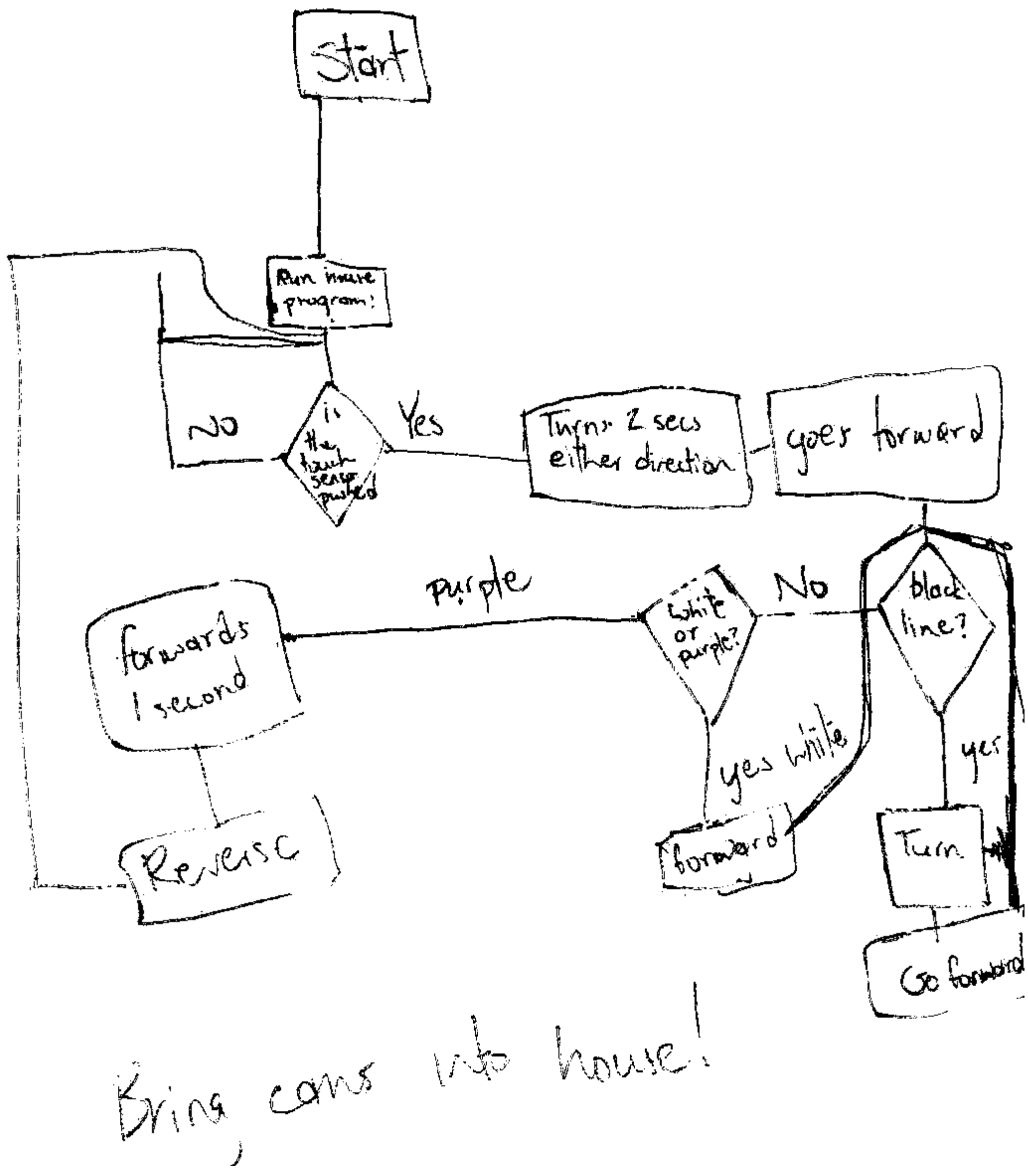
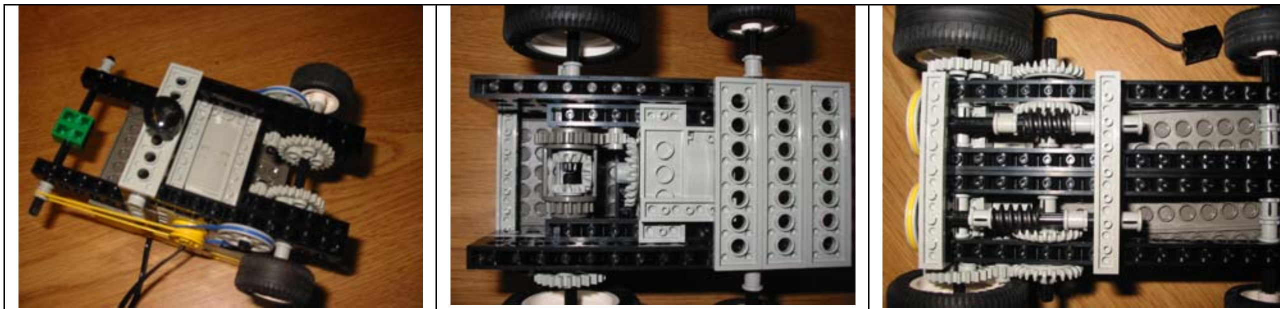


Figure 3: Flowchart for final project by the black team



Two wheel chassis	Differential gear	Gear train with worm gear

Figure 4: Sample chassis design undercarriages

Phase four. In this final phase, students were given the option of refining or redesigning their robot vehicles constructed in the previous phase in order to complete the programming challenges. Four of the five groups completely redesigned their robot vehicles; the fifth group made minor modifications to their chassis design. Once the vehicle robots attained a functional physical form they were ready to be programmed. The objective was for the students to develop strategies (plans) in the form of computer programs that could allow the robots to execute certain tasks. Each group worked independently and non-competitively on the progressively more difficult programming challenges; the groups' final programming achievements varied though each group's success was acknowledged and applauded. Students were first asked to program their robots to move soda-pop cans outside a clearly defined area (a 90 cm diameter circle outlined in black on a white background). Once this programming challenge was successfully met, they were challenged further—to start their robot outside the defined area, enter, and then, again, remove the soda-pop cans. This challenge level was successfully met by all groups. The next level—to turn the robot around in the 'house' (a black-outlined square situated outside but adjacent to the circle) and then proceed into the circle and remove the soda-pop cans—was successfully completed by three of the five groups. The final challenge—identical to the previous challenge with the added task of returning the soda-pop cans back to the 'house'—was not successfully completed by any of the groups, although one group (Black) came very close. Unfortunately, time ran out.

By no means are the events, as presented in the four project phases described here, able to encapsulate the richness of the learning environment experienced by the students. Nevertheless, the observations reported from this study do provide valuable insights with regard to our key questions. In the next section, we discuss the results in terms of the research questions and relevant literature.

DISCUSSION OF THE RESULTS

The first question, 'How can LEGO robotics be successfully integrated into the technology and science components of the curriculum?' is directly answerable by the overall achievements embodied in the students' work. The curriculum used represents only one of many that could have been employed; however, it does indicate that technology integration—using robotics—can produce challenging learning activities. The curriculum design effectively and powerfully scaffolded student learning through sequential staging of supported challenges and activities. The progressive design of the programming interface and ability of the robotic artefact to respond according to programming algorithms and design factors aided in scaffolding student learning. This notion of “scaffolding embedded in technological tools and activity structures” (Davis & Miyake, 2004, p. 266) is supported by prior research (cf. Palincsar, 1998; Reiser, 2004; Wyeth, Venz, & Wyeth, 2004). Additionally, the collaborative and peer-supported learning environment enabled the students to develop individual expertise that they could then share with their group members and fellow classmates, providing another scaffolding medium.

Other curriculum decisions enabled effective integration of robotic technology; the incorporation of flowcharting, an activity structure which scaffolds student learning in programming and algorithmic decision-making, is an example of a valuable instructional approach. Students indicated flowcharting to be an effective method to help them organize their ideas. Unfortunately, only one team was able to extend the use of flowcharting to help them organize and understand more complex problems. This is not surprising given how skills develop (Fischer & Immordino-Yang, 2002). However, it is important the teacher recognise that differences in cognitive skill development occur across groups and is able to accommodate those differences. The curriculum developed by the teacher-researcher attempted to do so; however, classroom time constraints prohibited adequate practice and refinement of flowcharting skills. That being said, the team’s efforts to utilize flowcharting during problem solving indicated a significant level of critical thinking.

The partial integration of robotic technology in the Grade 8 science curriculum, specifically Unit D: Mechanical Systems (Alberta Education, 2003), was included in order to explicitly capitalize on the science concepts embedded in the technology; science concepts concerning “design and function,” “transmission of force and motion,” “simple machines,” and “mechanical advantage, speed ratios and force ratios” (Alberta Education, p. 43). However, though this study’s limitations did not allow for a thorough exploration of these ideas, research by Norton (2004) demonstrates the applicability of “Lego artifacts as a tool for the learning of mathematics and science concepts through technology practice” (p. 1). His research points to the need for appropriate and explicit scaffolding when integrating robotic technology in the science curriculum.

The second question, ‘What does an examination of students’ designing, building, and controlling of robots reveal to the teacher about the development of students’ knowledge and problem-solving skills?’ was also addressed. The problem-solving methods embodied in robot construction cannot be easily defined in terms of algorithms. Nor would it be easy for each student to specify an optimal problem-solving pathway for robot construction and programming. Instead, robot construction and programming present an open-ended problem space whereby “practice in such problems raises levels of confidence and generates a willingness to take risks in seeking solutions” (Reid & Yang, 2002, p. 94).

Students constructed new knowledge and refined their thinking skills with regard to various scientific, mathematical, programming, and design concepts. They did this by self-assessing the computer programs they wrote and through examining and analysing the robot creations they built. The autonomous capabilities of the robotic vehicles allowed the students to make connections between their chosen strategies—programming as well as design solutions—and resulting actions/responses of the robots. This was a recursive and reflective process; students made programming or design decisions, watched the robots in action, made refinements or alterations in their programming or design constructions, and then repeated the process until a viable solution was found for the problem. This exemplifies reflection *in* action (Ertmer & Newby, 1996). Ertmer and Newby highlight the importance of reflection in the learning process:

> As a powerful link between thought and action, reflection can supply information about outcomes and the effectiveness of selected strategies, thus making it possible for a learner to gain *strategy* knowledge from specific learning activities. … In an actual learning situation, reflection allows learners to consider plans made prior to engaging in a task, the assessments and adjustments while they work, and the revisions made afterwards. (p. 14)

Furthermore, the reflective logbook provided an additional, concrete opportunity for students to reflect on their learning and problem-solving choices. Ertmer and Newby describe this process as reflection *for* action; "employing reflective thinking skills to evaluate the results of one's own learning efforts" (p. 18). Incorporating a reflective and metacognitive dimension to learning and teaching can empower learners and build confidence in novel learning situations using computer technology (Phelps, Ellis, & Hase, 2001). The role and importance of reflection *in* and *for* action in the learning process and for developing learner confidence is evident in the following excerpt from the green team: "The robotics option is a perfect blend of education and fun. We write journals to prove that we are learning something. We get to build the robot from scratch, program it, and then watch our creation in action."

CONCLUSION

This pilot research study focused on the integration of LEGO robotic technology into a mixed grades (seven, eight, and nine) classroom. Students worked in small collaborative groups, in a constructionist learning environment, on robot building and programming projects. Our case study was framed in an action research context focusing on how LEGO robotics can be integrated into the curriculum, and the development of students' knowledge and problem-solving skills through the designing, building, and controlling of robots. Students were required to record and reflect on their learning activities. The teacher-researcher and researcher recorded their observations of classroom interactions and students' problem-solving behaviours. The data collected revealed that learning and problem solving can be supported and enhanced when this type of robotic technology is used in the classroom—particularly when flowchart techniques are used by the teacher to scaffold student learning during the solving of programming problems. That being said, students moved through a vast learning/problem-solving space in diverse ways and their conceptual understanding often fluctuated when asked to articulate and design incrementally more complex computer programs. For example, most children had difficulty in generalizing the use of scaffolding techniques they had learned for simpler programming problems to more complicated problems. Further research on the use of flowcharting as a scaffolding medium would help teachers understand how to more effectively incorporate this instructional technique.

Earlier studies, similar to the one described in this paper, have previously been conducted in research institutions and major universities (Martin, 1996; Miglino, Lund, & Cardaci, 1999). With advances in technology, the field of robotics is beginning to make its way of out research labs and into the K to 12 classroom (cf. Bers, Ponte, Juelich, Viera, & Schenker, 2002; Goldman, Eguchi, & Sklar, 2004; Norton, 2004). The opportunity to use robotics to stimulate learning and problem-solving offers children the possibility of realizing that computer technology extends beyond the reach of their desktops. As a student in Grade seven so eloquently stated, *"Never give up! There are many ways to solve a problem."*

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