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Strategies used by elementary schoolchildren solving robotics-based complex tasks: innovative potential of technology

Samuel Blanchard[a], Viktor Freiman[a] *, Nicole Lirrete-Pitre[a]

[a]*Université de Moncton, Moncton, New Brunswick, Canada*

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Abstract

Robotics is being introduced in many schools as an innovative learning environment enhancing and building higher order thinking skills and abilities to help schoolchildren solve complex problems. As part of the New Brunswick Canadian Innovation Learning Funds program, we conducted a case study on robotics-based learning at one local elementary school with two groups of 11-12 year old students. We conducted several in-class observations and interviews. Two teams were asked to solve one robotics-based task and to think aloud explaining what they were doing and why. We discuss our findings suggesting the emergence of situational awareness and critical thinking in students.

Keywords: Robotics; critical thinking, strategies; technology, problem-based learning

1. Context and problem statement

The French minority population in New Brunswick, Canada faces many challenges related to the lack of human and material resources, demographic decline and survival of language and culture. A quest for a better education that began in the early 1990's with a curriculum reform has been supported by international studies in mathematical, scientific and reading literacy. These studies show that 15-year old New-Brunswickers are trailing their peers from other Canadian provinces in all three subjects (Bussière, et al., 2001, Freiman & Lirette-Pitre, 2007). Countries recording low performance in PISA are searching for answers in order to identify the structural problematic in order to improve the achievement of students with objectives to allow students to be active and well educated citizens of a 21st century global world. A lack of critical thinking skills is one of the frequently mentioned factors for such low scores. In an effort of changing teaching-learning approaches in order to better educate our students, many teachers and school administrators feel a need to work together with researchers and the community with the objective of finding and experimenting innovative ways of teaching and learning, which is one of the reasons used by the provincial government to launch the Innovative Learning Fund in 2007. This fund supports teachers in their quest for good practices that can subsequently be shared with and replicated in other schools (MENB, 2007).

The project we analyze in this article called RoboMaTIC is an example of such initiatives.

* Viktor Freiman. Tel.:1 506 858 4437; fax:1506 858 4317
E-mail address: freimanv@umoncton.ca

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The teachers from one rural elementary (K-8) school used LEGO Mindstorm© robots and laptops with their students. Additional time was allocated for professional development allowing teachers to learn how to teach in such an environment and to elaborate robotics-based learning scenarios. The research team CASMI (www.umoncton.ca/casmi) from the Université de Moncton was invited to collaborate on implementation of these scenarios with Grade 5-6 Middle School children over two school years. The main objective of the study was to look at problem solving strategies used by students in order to program robots according to series of challenges. While collecting samples of students' work, we wanted to investigate the situations in which higher order thinking skills would emerge and develop during a problem solving process in a robotic-based environment.

2. Theoretical framwork

Jonassen, Howland, Marra, and Crismond (2008) developed a model meaningful learning as active (manipulative/observant), constructive (articulative/reflective), intentional (goal-directed/regulatory), authentic (complex/contextual), and cooperative (collaborative/conversational). Authors claim that if schools are to foster meaningful learning, then the ways we use technologies in school must change from technology-as-teacher to technology-as-partner in learning. Being inspired by these ideas, we connect them to the context of authentic, problem-based and collaborative learning enabled by robotics activities that were developed according to our integrative model of learning. It is based on notions of constructionism, problem-based learning and socially and affectively rich environments that meet the needs of the Net generation of students that have grown up in a digital and technology-enhanced world.

The use of robotics in the classroom is, by its nature, an exciting technological breakthrough and relatively unused in classrooms today (Williams, Ma, Prejean, & Ford, 2007). Robotics research has shown a positive effect on science and technology motivation in classrooms (Barker & Ansorge, 2007; Carbonaro, Rex, & Chambers, 2004; Gura, 2007; Nourbakhsh, et al., 2005). In addition, several authors have mentioned a positive effect of robotic-based learning on the level of collaboration between students on problem solving and critical thinking skills in children (Petre & Price, 2004), the ability to use inquiry skills in classroom (Williams, et al., 2007), and on the learning of a programming language (Nourbakhsh, et al., 2005) while being an excellent interdisciplinary agent (Rogers & Portsmore, 2004).

In order to identify learning outcomes in robotics-based experiences of young children, it's important to recast them as active learners developing a wide variety of thinking skills, making them researchers and producers of new knowledge while fostering emergence meaning making skills (Gura, 2007). It can be achieved with an open-based pedagogy like *problem-based learning* (Barell, 2007). The authenticity of such learning is seen by Ormrod (2008) as being catalysis of transferable skills and knowledge, as well as the support of acquiring a life-long learning experience. According to our vision, robotics-based learning using probem-based tasks can not only enchance the development of important cognitive and metocognitive skills and abilities but can also be an important factor for developing critical thinking in today's young learners.

In our previous work (Blanchard, 2009), we analyzed literature decsribing a phenomenon of new 21st century learners forming a so called Net Generation. When teachers address the diversity of needs of these learners, they aim to create healthy and creative inclusive environments where students can reach their unique potential. Researchers suggest several pedagogical principles that shoul be respected in building such envrionments that give students freedom of choice. Allow expressing their personality using a variety of digital communication tools, create opportunities to develop critical judgment and cyberethics, foster integrity and openness, is interactive and motivating, prompts collaboration and socialization, and finally provides a rapid information and feed-back. We found that robotics-based learning may create environments that resepect the before mentioned principles.

Higher-order thinking, like problem solving, creative thinking and critical thinking are part of 21st century skills required in today's society (Sendag & Odabasi, 2009). What is critical thinking and how can it be fostered and developed by teachers? Paul & Elder (2007) consider critical thinking as "the processes of analyzing and assessing *thinking* with an objective of improving it". Critical thinking involves analysis, synthesis, interpretation, evaluation and noticing assumptions in their everyday lives regarding their relationships with others and the environment (Sendag & Odabasi, 2009). More specifically, critical thinking is a constructivist analysis process which demands students to examine what is going on in their direct and indirect environment (Sendag & Odabasi, 2009), which is also known as situational awareness.

Endsley (1995a) conceptualized the most common theoretical framework of situational awareness in *dynamic systems*. According to the author, situational awareness is defined by as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995b, p.36). This theory is mainly used to analyze complex settings that may require handling emergency situations like in aviation. We believe that this theory can help explain how people act in any kind of environments involving complex problem solving. Although alone, situational awareness cannot guarantee successful decision making, it does however support the necessary input processes and variables (e.g., cue recognition, situation assessment, and prediction) upon which good decisions are based (Artman, 2000).

We postulate that the use of a robotic-based environment can also be characterized by the use of situational learning described above. Pupils need to become aware of the role of variables in the robotic programming environment and make appropriate decisions based on their knowledge of the behavior of those variables according to the parameters chosen. They can afterwards make use of the problem-solving strategies to help them keep their decision-making process under control. The analysis of research data collected within our case study examines in-depth the use of strategies by the students and their evolution in the problem-based environment towards the emergence of critical thinking patterns and analysis of obstacles of their growth.

3. Methodology

Two groups of Grade 5 (group A) and 6 (group B) students (N=45) participated in our project. Teachers received one-day training with an expert in implementation of robotics in schools. They developed five pedagogical scenarios to be implemented in the grade 5 and 6 classes: (1) Classification of pieces, (2) Robot construction, (3) Advancing robot on one meter with RoboLab© programming tool, (4) 360-turn task, (5) Reaching three targets.

During the academic school year 2007-08, the scenarios 1 through 4 were conducted with both group A and B and the following year, the scenario 5 was conducted with the students of group A (who advanced to the Grade 6). Unfortunately, the robotic program was not part of the Grade 7 curriculum; consequently the group B didn't take part in scenario 5. However, robotic inquiry was made available as part of an extra-curricular weekly session called "arts-sports". Several students from group A and B took part in these working sessions in order to further their work with robotics. Students were working in small groups of 3-4. To collect data, we used classroom observations, video recording, and school blogs written by participants. In order to investigate in-depth emergent patterns of situational awareness and decision-making, we proposed a specially designed task of programming robots called "*Alerte au Métro*" to two teams (one from group A, and one from group B), who were selected by the school administration with regards to the students involvement in the robotics program (in-class and extra-curricular).

The problem was presented to the two Team A and Team B individually as follows:

We recently found a suspicious box in one the main control rooms of the metro station. We need your help! Using your programming abilities, we ask your team of experts to verify the safety of the suspicious box. As we don't want to harm any humans in this task, it is very important that the robot goes to the box without exterior help.

The teams were asked to program the Robot in order to make the robot move from point 1 to point 2 while moving around three sides of a rectangular fence to make it enter the surrounded area in order to inspect the suspicious object. In addition, this task had to be completed in the shortest time laps possible (the limit was set at 45 minutes). The figure bellow was recreated on the floor of the class so the students could try their programs. The two teams were asked to realize this task making comments and explaining what they were doing and why. The work was recorded with a video camera and transcribed afterwards. While a detailed analysis of all collected data is underway and due to the limited space for this proposal, we focus this present analysis on transcribed video-recording while looking at how children develop strategies to overcome obstacles in the process of problem-solving while utilizing situational awareness from their collective work.

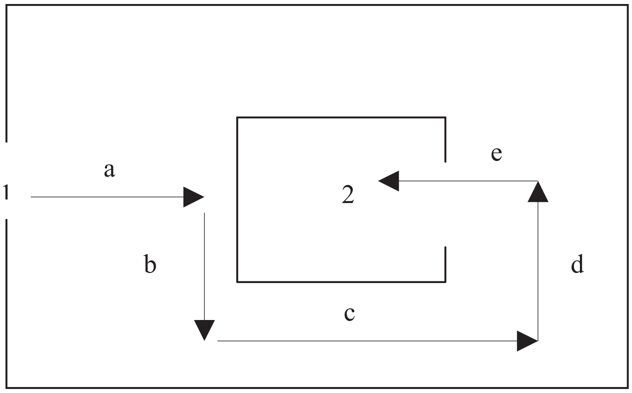

Figure 1 –Floor plan for the *Alerte au Métro* task

4. Results and discussion

The two teams of students who were asked to resolve the problem *Alerte au metro* did it in a different manner. In order to solve the problem, students had to decide what trajectory to take in order to bring the robot from the starting spot (1) to the final destination (2). Both teams decided to use the same path by splitting it in five segments (a, b, c, d and e) described in Figure 1. This path was to be transcribed in program code using RoboLab© commands. Each segment required the robot to advance a certain distance and then to make a proper turn. In order to make sure that the robot advanced the right distance or turn into a right angle, they had to give values to two RoboLab© parameters: the first controlling the number of wheel rotations allowing the robot to advance and the second to control the wheel movement (which one will move and in what direction). The first parameter can be expressed in three different ways: number of seconds, number of rotations or number of rotational degrees. One team (A) decided to use seconds to advance and degrees for the turns. The second team (B) used only seconds for both – advancement and turns. The second parameter permits the blockage or steering (similar to a car's steering power) of one or multiple wheels for better turns and was expressed in % used by the students in this study. For an example, if a student expresses a 75% turn to the right, it means the cursor is three quarters the way (from center to far right). Different percentages in conjunction with a wheel rotation determined the turn angle made by the robot. One team (A) used a blockage method, where they blocked the use of one wheel and turned with the use of the other wheel (i.e. to turn right, they would block the right wheel and turn exclusively with the left wheel making for a smooth turn to the right). In contrast, Team B used different percentages and wheel rotations during the problem-solving task in order to achieve their angles. We will now analyze different patterns of decision-making that emerge from each team's work while helping to explicit observed problem solving abilities, strategies and situational awareness.

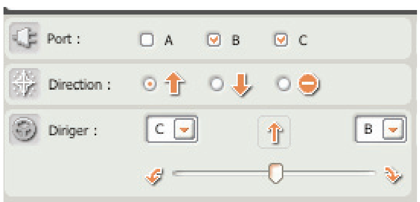

Figure 2 –RoboLab©

Team A (Grade 6). While the team started to work on the task, they immediately began with a thorough discussion about the strategies that may be used to achieve their goal. Some members of the team offered to use mathematics to calculate the number of rotations of the wheels and then use angles that they already used in previous tasks. Other members argued that using mathematics would take a lot of time and they suggested going by trial and error. They started with estimation of the number of seconds ('If I put like 2 seconds, let's see on how many centimeters the robot will move and we will take it as reference unit'). When they put 180 degrees on the computer – they already knew that it would lead them to obtain 90 degrees of the robot's rotation. Then they started to play with the number seconds verifying each time if the robots moves. They repeated the same procedure for each of the segments a-f. Every time they realized the robot does not move in the right direction or at the right distance, they adjusted the parameters. By choosing the new value they were trying to analyze the error and make better choices*: [After applying a program] It's not enough. The robot is going too far. We need to double the rotation. No, we need to add more then double. We will try and see*. After certain amount of trials-and-errors, they succeeded to complete the task, which was reaching the specific target with precision.

As we mentioned previously, this team had more in-class learning experience with robotics-based tasks and seemed to have encountered fewer difficulties managing the environment and the problem proposed to them. The use of the trial-and-error strategy helped them to do better estimations while moving through the process of programming. Their comments allow us to see the application of this strategy in a more explicit way: *We are going to try this, and if it doesn't work, we will change it for something else. C*onversations between students give us more insight into their choice of the strategy as we mentioned above. In fact, they were aware that a better strategy could be used applying more precise mathematical tools like rulers and protractors that would result in more precise values of robot variables that could be transcribed in RoboLab©. This strategy was not fully developed because it was determined by the students that it would take too much time to analyze and concretize: *No, look. I have another idea. I think it would be easier, but longer. We would need to calculate with a ruler the length of the trajectory from there to here.*

It was apparent that this group was comfortable with the task given their previous experience with robotics in a more formal teaching and learning environment. Students had previous knowledge in terms of clues and techniques they should use in order to solve the task more successfully. The extra year proved fruitful in decision-making and strategy use in order to solve complex tasks. Consequently, they were not matched with a chaotic environment needed for more complex cognitive and metacognitive strategies mentioned previously and needed by the other team resulting in little use of critical thinking abilities. Ultimately, the team successfully solved the problem without any apparent problems: *The teacher explained to us, and she told us that if you want to make a 90-degree rotation, we had to double what we would normally put it. Like if I wanted to turn 90 degrees, we have to put 180 in the program*

The following section analyzes different patterns of decision-making that emerge from the team's B work while helping to explicit observed problem solving abilities and strategies.

Team B (Grade 7). Like Team A, Team B started to solve the problem with a short discussion about the strategies that may be used to achieve their goal. They quickly decided to work with estimation and reference units. They then started to program the robot using the RoboLab© parameters in order to complete segment A while focusing on obtaining their initial reference: *One tile is equal to one second in robot program*. The series of actions this team performed during the problem-solving task can be divided in two different stages. During the first stage, students were able to achieve some success after a brief use of an estimation strategy mentioned earlier and trial and error. Namely, they succeeded to move the robot around the right side of the fence and to bring it closer to the final destination (point 2). However, they correctly judged that the distance between the arrival point of the robot and the point 2 was too big to ensure that the goal is attained: *we need to be more precise in order to arrive at the specific target.* Therefore, the second stage is when the team decided to look on how to improve their program by re-examining previous movements and decisions: *The previous turn, here, needs to be higher, 0.7 seconds instead of 0.5.* This re-examination proved to be unsuccessful, as the robot never again came close to the final mark.

In order to justify their failed attempt to solve the problem, the team tried to identify reasons why error after error occurred. First, they hypothetically presumed that there was a physical problem with the robot. Second, they realized that their estimations were imprecise and that they eventually needed more precision in their choices of values in order to attain their goals. Lastly, they suggested that the use of more complex robotics tools like sensors would aid the achievement of the problem.

It was evident that the students where aware there was a problem with their RoboLab© program or/and the robot itself, but an analysis of their conversation couldn't pin point a strategy evolution needed to obtain their goal. The analysis clearly exemplified repeated failures brought on by an ill decision-making process while choosing the proper variable values. In order to do so, the students needed a certain level of "strategy flexibility" (Elia, Heuvel-Panhuizen, & Kolovou, 2009) in conjunction with situation awareness of the environment in which they were presented. This flexibility is very important and helps induce success in problem-solving situations (Elia & al., 2009). This chaotic environment of repeated failures is by nature an environment where critical thinking and problem-solving skills are highly needed to obtain a more metacognitive view of the situation (Elia & al., 2009). This analysis helps students define new plans of action and strategies in order to solve the problem. Despite being confronted with this rich environment, redirected actions were observed using the same cognitive strategy, which was composed of estimation and trial-and-error. A metacognitive process in order to assure the proper strategy evolution seems not to be achieved during this problem-solving process. Despite repeated failures, the team clearly communicated that precision was the key in resolving this problem. They were aware that their strategy wasn't satisfactory but could not modify it in the given time.

5. Conclusion

A robotic-based learning approach is very promising because of its instant/constructive feedback during a problem-solving situation. These kinds of problems have shown positive results in achieving high competencies in several problem-solving transversal skills (Barell, 2007) such as critical thinking and situational awareness. Students can readjust their strategy according to their situational awareness competencies, making the problem-solving situation a more complex and constructive task.

Our analysis confirms the potential of robotic-based learning in a complex and chaotic environment needed for the use of problem-solving skills and critical thinking. A robotic-based task would require students to coordinate movements of the robot and virtual commands of their programming system, which is known to be a meticulous endeavor. By its nature, such synchronization between Lego Mindstorm© robots and the RoboLab© software is constantly soliciting complex combinations of high-level cognitive and meta-cognitive thinking abilities such as situational awareness and decision-making strategies.

A chaotic environment is essential for the emergence of situational awareness and decision-making resulting in a full-scale critical thinking analysis. We learned from the work of two teams, two different spectrums of task achievability while using the same trial-and-error strategy. While one team used explicitly the previous classroom experience and applied procedures that were taught, the other ream tried to build its own strategy to overcome obstacles but fell shortly into an unsolved trail-error-trial loop, therefore their use of situational awareness and decision-making process were compromised. While the direct impact of our finding is limited to one case, it suggests more research into the development of better critical thinking to enhance a smoother strategy evolution throughout the task. Our findings also point at the importance for teachers to develop scenarios in which students are faced with an environment and a task within their proximal zone of development and critical thinking abilities. While trial and error remains the most often used strategy within this complex task, students may eventually develop and use more effective cognitive and meta-cognitive tools as they find themselves in a supportive and risk-free learning environment.

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