Building Student Understanding and Interest in Science through Embodied Experiences with LEGO Robotics

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Abstract: The purpose of this study was to examine whether embodied experiences with LEGO robotics can build elementary school students' understanding of and interest in science learning. Previous studies have shown that many children do not enjoy learning about science; they often find it very difficult to learn (Johnstone, 1991; Millar, 1991). We developed a curriculum incorporating embodied experiences and LEGO robotics so that when students physically move their own bodies and then program robots to perform tasks related to science concepts including force and mass, speed and distance, and friction, learning develops from personal embodiment to embodiment through surrogate robots. We compared the understanding and interest of students with the embodied experience to those of children without the embodied experience. The results showed that students improved in their understanding overall, however, students with the embodied experience performed better in terms of their understanding of physical concepts as well as their interest in science learning.

Introduction

One of the major criticisms of the current paradigm of education and training is that students are often required to do what they are *told* to do. That is, they are expected to sit in class, be quiet, and memorize the facts conveyed to them by the teacher. Then they are asked to dictate this knowledge back on tests and quizzes, which prevents creativity and diversity (Reigeluth, 1996). Unfortunately, this is still what is happening in many classrooms today.

Innovative learning approaches and theories such as embodied cognition together with new technologies and media, however, have revolutionized the way students learn. Modern technologies and media have become powerful tools in supporting science learning. Students are now able to use technology as a medium in collaborating with other learners and support in developing learning strategies. Embodied cognition and technology such as LEGO robotics can help students understand and construct knowledge in a way that is meaningful to them.

LEGO Mindstorms NXT is a programmable robotics kit consisting of motors, connection cables, LEGO pieces, sensors, and the NXT Intelligent Brick. Some of the sensors include touch, sound, distance, light, and color, which act as the robot's hands, ears, eyes, etc. Students can build different types of "robots" and create commands on the LEGO Mindstorms NXT program. The LEGO Mindstorms NXT computer program utilizes icon-based programming in which students can drag and drop the "icon" on the screen. The finished program can then be downloaded to the NXT Intelligent Brick and the robot will perform various actions according to the program. Multiple programs can be downloaded to the Brick and it can run without being connected to the computer.

We developed a curriculum for fifth graders incorporating LEGO robotics with embodied experiences aimed to improve their understanding of physical science as well as increase their motivation and interest in science learning. We were interested in investigating the effects of LEGO robotics with an embodied approach on students' overall attitude and understanding.

Relevant Literature

In recent years, cognitive scientists began to examine how mind and body work together to form better understanding through embodied cognition in different contexts and settings. Grounded/embodied cognition is becoming increasingly important in cognitive research and theory. According to Barsalou (2008), we form multimodal representations that are based on the physical experiences we acquire through different sensory modalities, i.e visual, auditory, or haptic channels, as well as emotional conditions when we interact with the environment. These bodily experiences can also affect our memory (Dijkstra, Kaschak, & Zwaan, 2007). Glenberg (1997) claims:

> Suppose that memory and conceptualization work in the service of perception and action. In this case, conceptualization is the encoding of patterns of possible physical interaction with a three-dimensional world. These patterns are constrained by the structure of the environment, the structure of our bodies, and memory. Thus, how we perceive and conceive of the environment is determined by the types of bodies we have. Such a memory would not have associations. Instead, how concepts become related (and what it means to be related) is determined by how separate patterns of actions can be combined given the constraints of our bodies. (p. 1).

A recent study by Dijkstra, Kaschak, and Zwaan (2007) showed that body positions play a key role of memory recall. Dijkstra et al. (2007) examined how "body congruence" affects the retrieval of autobiographical memories in younger and older adults. Participants were asked to recall autobiographical events such as going to the dentist's office, playing sports, opening a door for someone, being at a concert and clapping their hands, waving at someone, placing their hand on their heart. They found that the response times were shorter when body postures during the retrieval were "congruent" to the ones that they had in the original events than when body postures were "incongruent." Participants were asked to recall the events two weeks after and they were better able to recall the events "for congruent-posture than for incongruent-posture memories" (Dijkstra et al., 2007).

In another study by Riskind (1983), he found that recall was better for both pleasant and unpleasant experiences where body positions and facial expressions were similar with the emotional state of these experiences. Memory retrieval will be improved when the conditions under which the event is retrieved are related to the conditions under which the event was initially stored (Thomson & Tulving, 1970). Furthermore, when people's perceptions from these channels are in agreement with their understandings of the knowledge, they will learn better and faster. Glenberg and Kaschak (2003) found in their study that people respond faster when their action responses are in agreement with their text responses.

In addition, previous studies using fMRI have found that mirror neuron areas play a critical role in the reenactment of sensory-motor representations during conceptual processing of actions stimulated by printed words (Aziz-Zadeh et. al., 2006). Fadiga, Craighero, and Olivier (2005) found using transcranial magnetic stimulation that the muscles used when participants watched another individual act were the same as those used in the observed action, indicating we would go through same perceptual simulation process when we observe another individual acting.

Though embodied cognition has been implemented in many different forms (e.g. direct-manipulation animation and haptic channel (Chan & Black, 2006), haptic feedback and physics learning, social cognition and relationships (Semin & Cacioppo, 2007), domain knowledge with experts and embodiment (Beilock & Holt, 2007), sentence comprehension (Black, Turner, & Bower, 1979; Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004; Zwaan & Taylor, 2006), and emotion and affect (Clore & Schnall, 2008; Barrett & Lindquist, 2008; Winkielman, Niedenthal, & Oberman, 2008), we choose to adopt instructional embodiment, and more specifically direct and imagined embodiments, as our grounding theory in providing students with embodiment experiences. Direct and imagined embodiments have shown strong evidences in helping students' programming skill by physically and mentally enact the functions and behaviors in the video games they have designed (Fadjo, Lu, & Black, 2009). By using direct and imagined embodiments, students are left with a strong impression on the effectiveness of embodied experience.

Neathery (1997) have shown that performance on science assessments and student attitudes toward science are positively related. This suggests that student motivation and interest are critical aspects for student learning in science and lead them to pursue careers in science-related field (George, 2006). Eccles and Wigfield (2002) have found that "interest is more strongly related to indicators of deep-level learning than to surface-level learning" (p.7).

Furthermore, agents are strong instructive tool that can take on many different forms, and different forms of agent can help learning in different ways. An agent "collects or receives sensory information concerning its external environment and takes actions within the dynamically changing environment" (Hagras & Sobh, 2002, p.1). Pedagogical agent provides instant and complete information when needed (Thaiupathump, Bourne, and Campbell, 1999). Teachable agent helps students understand the system of concepts by constructing a concept map for their avatars (Schwartz et al., 2007). Reflective agent helps students learn by specifying propositional, functional, and procedural knowledge to the avatar (Bai & Black, 2005). By choosing an appropriate agent, students can learn different concepts quicker and better.

We used robotic agents in this study because physical concepts can be best demonstrated by having a robotic agent perform different designed activities. LEGO robotics offers students the environment and opportunity to observe abstract concepts through the use of tangible, hands-on objects (Druin & Hendler, 2000).

Participants

Our participants consisted of twenty-seven fifth graders from two urban public elementary schools in New York City, with 12 girls and 15 boys. The data for 4 students were not included in our analysis because they did not complete the program due to lack of attendance and one was removed from the class due to disruption.

According to the results from our surveys, most of the students displayed some interests in learning science but had low confidence in doing so. The students were randomly assigned to either: control or experimental group, with 11 students in the control group and 12 in the experimental group. Seven of our students spoke very little English. Teachers were available in translating the materials to the students.

Materials

Participant's prior knowledge was measured with a 12-question pretest on the three physical concepts: force and mass, speed and distance, and friction. The posttest measured learning outcomes using the same 12 items arranged in a different order. All the participants also filled out a survey with 10 questions on their confidence, interest, and motivation about science learning and LEGO robotics at the beginning of our program. We also included 3 questions asking them whether they have had prior experience working with LEGO robotics; however, they were not counted as part of students' interest and confidence towards science learning. At the end of the program, students were given the same survey questions.

Procedure

The intervention took place once a week, with ten sessions total for each school. The duration for each session was approximately two hours. During the first two sessions of our program, we introduced the LEGO Mindstorms robot to our participants. Students were asked to build a basic LEGO NXT Mindstorm robot with another student according to the instructions in the manual. They also had the opportunity to create simple NXT programs so that they would become more familiar with programming in NXT Mindstorm. An example of a beginner NXT program would be to make the robot move forward for a certain amount of time they have designated. We also gave students the pretest and survey to complete.

In the next session, we used a demo robot to introduce NXT sensors to our students and asked them to build a Tribot that included four sensors: touch, light, distance, and sound. Following demonstration, students were given adequate amount of time to finish building the Tribot with help from teachers. Students were then asked to participate in a "bowling competition," which was a series of hands-on activities we had designed for them to work on the rest of the program. Through the activities, students would investigate, learn, and apply the three physical concepts.

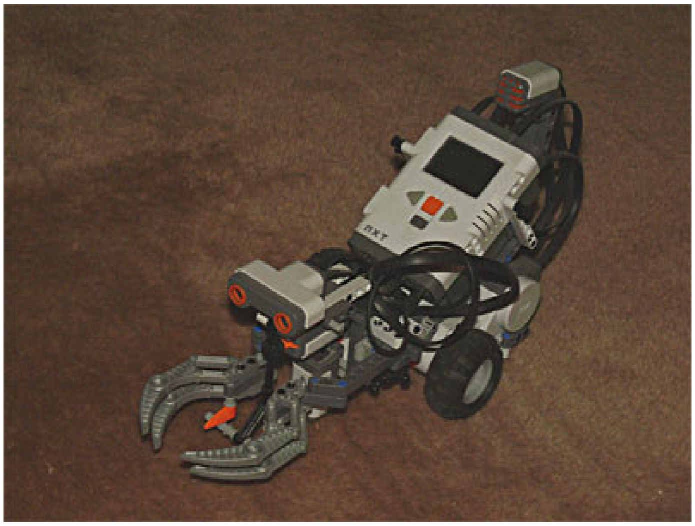

Figure 1: Tribot

In part one of the bowling activity, students were asked to program the robot so that it would move at a designated power level and stop until it hits a ball. The ball would roll for a certain distance. Students were asked to measure the distance of the ball and record it on their worksheet. In the second round, students increased the power level in their program and performed the same activity. They were asked to observe what would happen to the distance when the power level was increased. In part two of the activity, another ball of a different mass was used and students again measured the distance and compared that with the first type of ball they used. Students were required to answer related questions on their worksheet. They observed the relationship between force and mass. Eventually, they found that the greater the force placed on an object, the greater the change in motion. Furthermore, the more massive an object is, the less effect a given force will have upon the motion of the object ("Force and Motion," 2009). In part two of the activity, students tested the identical program of pushing the two types of balls with different power levels but this time on another type of surface: the rug. They observed the effect of friction on the motion of the balls and what kind of difference it would have on the distance.

During the activities, students in the experimental group were asked to imagine themselves as the robots and moved their own bodies according to the instructions given for the challenges. They then programmed the robots to perform related movements. While they were programming the robots, they were also encouraged to imagine the robots' movements. Therefore, in part one of the activity, students in the experimental group held the ball in their hands, rolled the ball with a certain force, and then observed what happened. In the second round, they held the other type of ball in their hands and physically felt the difference between the two types of balls used. They would see and feel the difference between the mass of the two objects used. In part two of the activity, students rolled the two types of spheres on the rug, just like what their robots would do. They then observed the effect of friction on the motion of the objects. On the other hand, students in the control group were asked to sit in their chairs while receiving instruction regarding the bowling competition and programming the robots. After they finished programming the robots, they were asked to test their program out with their robots. After treatment, students in each group were given a posttest with questions that we had created based on the science concepts introduced in the activities.

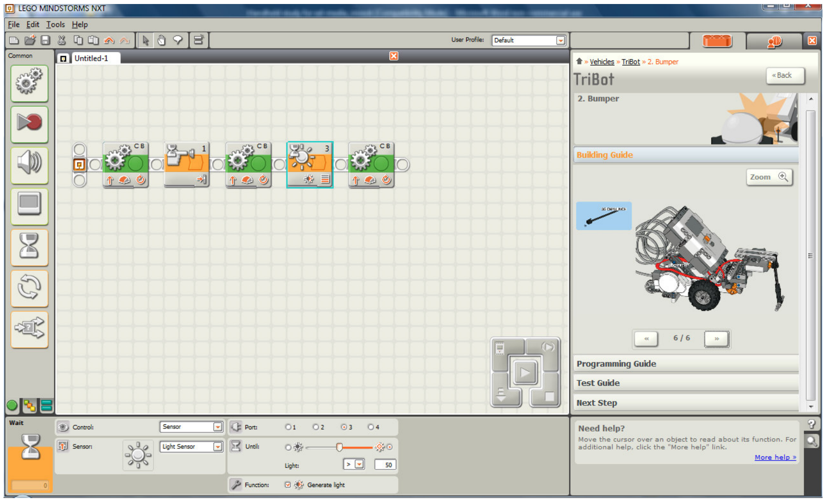

Figure 2: Sample program of a Tribot using light and touch sensors

Results

We used SPSS 17.0 to analyze the data, trying to find out:
1) Whether our curriculum had an overall effect on both groups;
2) Whether there was significant difference between pretest and posttest scores for each of the two groups;
3) Whether the increase in gain scores was higher for the experimental group;
4) Whether our curriculum increased students' interest and confidence in science learning;
5) Whether both groups increased their interest and confidence in science learning;
6) Whether the increase in interest and confidence was higher for the experimental group.

We tested whether our curriculum had an overall effect in both control and experimental groups. We found that the posttest scores were higher than the pretest scores across both control and experimental groups. The mean pretest score was 3.870 (SD=2.603) and the mean posttest score was 8.478 (SD=2.150). The mean difference was -4.609 (SD=1.883). The posttest was significantly higher than the pretest across both groups ($t=-11.740$, $df=22$, $p<.01$). Therefore, these results suggested that learning physical concepts with LEGO robotics seemed to have an effect on the students' learning.

We also found that both the control and experimental groups had higher posttest scores than pretest scores. The mean pretest score was 3.636 (SD=2.461) and the mean posttest score was 7.318 (SD=2.294) for the control group. There was significant difference between the pretest score and the posttest score in the control group ($t=-8.945$, $df=10$, $p<.01$). For the experimental group, the mean pretest score was 4.083 (SD=2.819) and the mean posttest score was 9.542 (SD=1.373). There was also significant difference between the pretest score and posttest score in the experimental group ($t=-9.767$, $df=11$, $p<.01$).

We looked at differences of pretests and posttests across groups. The Levene's test indicated that the assumption of homogeneity of variance had not been violated (for pretest, $F=.105$, $p=.750$; for posttest, $F=4.133$, $p=.055$). We found that there was no difference ($t=-.403$, $df=21$, $p=.691$) between control and experimental groups in pretest scores. However, there was significant difference ($t=-2.850$, $df=21$, $p<.05$) between the two groups in posttest scores.

We took another approach and looked at the change from the pretest and posttest scores. The question of interest was whether the improvement in scores from pretest to posttest was greater for the group with the embodied experience than it was for the group without the embodied experience. We computed the difference between the pretest and posttest scores for each participant (Gain) and then analyzed those differences in a one-way ANOVA using treatment as the only factor. If the treatment main effect was significant, then the change from pretest to posttest was not the same in the two groups. We found that the increase in gain scores was higher for participants in the embodied condition (M=5.458) than for those in the control condition (M=3.682), and this difference in gain scores between the two groups was significant, $F(1, 21) = 6.354$, $p=.020<.05$.

Next, we investigated whether our curriculum had an effect on students' interest and confidence in science learning for both groups. We found that the interest and confidence in science learning had increased for both groups (before, M=24.739, SD=6.433; after, M=36.696, SD=6.138). We found that this increase was significant (t=-11.761, df=22, p<.01). Therefore, these results suggested that learning physical concepts with LEGO robotics seemed to have an effect on the students' interest and confidence in science.

We also found that both the control and experimental groups increased their interest and confidence in science learning after finishing our program. The mean survey score at the beginning of the program was 23.000 (SD=5.950) and the mean survey score at the end of the program was 33.273 (SD=6.943) for the control group. The increase of interest in the control group was significant (t=-8.358, df=10, p<.01). For the experimental group, the mean pre-survey score was 26.333 (SD=6.692) and the mean post-survey score was 39.833 (SD=3.010). This increase in interest and confidence was significant (t=-9.000, df=11, p<.01). Therefore, both groups showed a significant increase and confidence in interest for science learning.

In addition, we wanted to see whether the increase in interest and confidence for science learning was greater for the group with the embodied experience than it was for the group without the embodied experience. We found that the increase in interest and confidence for science learning was higher for participants in the embodied condition (M=13.500) than for those in the control condition (M=10.273), although this difference in gain scores between the two groups was not significant, F(1, 21)=2.710, p=.115>.05.

Limitations

Despite the positive findings from this study, there are several limitations we would like to discuss. First, the sample size of this study was small, therefore, larger sample size would give us more reliable results. Furthermore, since some of our participants spoke very little English, several different teachers from the school had to translate the materials, therefore, we could not ensure that all of our participants received the same kind of information. In addition, due to time limitation and the age of our participants, we made our pretest and posttest short and did not include any open-ended questions. This may have prevented us from detecting any valuable insights that might have been available to us. For future studies, interviews of our participants should be added.

Conclusion

The results we found from this study provide evidence that students with the embodied experience have higher gain scores than the students in the control group. In addition, students with the embodied experience have higher interest and confidence in learning science with LEGO robotics than students without the embodied experience. This suggests that embodiment can be used to enhance the learning experience with LEGO robotics for elementary school students as well as increase their interest and confidence in science learning. We believe that the results from the experiment can help educators in designing science curriculum and instructional materials for elementary school students.

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