ANT AND ROBOTS: THE ACTOR NETWORK APPROACH TO CHILDREN'S LEARNING ABOUT ROBOTICS

by

EUNJI CHO

(Under the Direction of Kyunghwa Lee)

ABSTRACT

This study explores a robotics class of 24 second graders in a Title 1 elementary school located in the southeastern United States. Drawing on Latour's Actor-Network-Theory and Bakhtin's notion of hybridity, the findings show that learning about robotics has heterogeneous associations with material, human, and quasi-material/quasi-human actors. Using case study, data were derived from filmed videos, video-cued interviews with children, interviews with two enrichment class teachers, children's activity logs, and children's pre- and post-instruction drawings and writings about robots.

This study identifies various actors that contributed to and constrained programming a robotic manipulative, a Bee-Bot. Bee-Bots are programmable floor robots encouraging children to program the robots by using directional commands, such as forward, backward, left, and right. The findings show that heterogeneous actors, including the use of activity logs, a bee shaped design and control system, use of simulation, abstract thinking, peer demonstrations, and teachers' comments were associated with programming in the Bee-Bot route activity. In addition, the processes of problem identification and robot building with Cubelets were examined in order to

understand how different roles of the children were negotiated and performed. Cubelets are magnetic robotic blocks enabling children to build their robots while learning about sensors and actuators. The findings show that problem identification and idea elaboration were intermingled with designing and building robots. Also, 24 participating children's pre- and post-instruction drawings and writings about robots were investigated in order to understand children's conceptualization of robots. Drawing on Bakhtin's notion of hybridity, the children's ideas about robots were hybridized through their experiences with robotic manipulatives, ideas from watching a video clip in the robotics class, and visual images from popular culture. Their drawings and writings showed that the functions and designs of robots became more personalized and sophisticated. The children's conceptualization of robots blurred the boundaries between humans and machines. The findings suggest that we need more studies which take into consideration the various actors and their heterogeneous associations involved in learning about robotics.

INDEX WORDS: Robotics class; Title 1 elementary school; Bee-Bots; Cubelets; Actor Network Theory; Material actor; Quasi-human and quasi-material actor; Programming; Problem identification; Robot building; Drawings and writings about robots; Case study

ANT AND ROBOTS: THE ACTOR NETWORK APPROACH TO CHILDREN'S LEARNING ABOUT ROBOTICS

by

EUNJI CHO

B.A. Kongju National University, South Korea, 2006

M.A. Kongju National University, South Korea, 2009

Ed.S. Northwestern State University, 2011

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2018

© 2018

EUNJI CHO

All Rights Reserved

ANT AND ROBOTS: THE ACTOR NETWORK APPROACH TO CHILDREN'S LEARNING ABOUT ROBOTICS

by

EUNJI CHO

Major Professor: Kyunghwa Lee
Committee: Cory Buxton
Joseph Tobin

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
May 2018

ACKNOWLEDGEMENTS

I would not have completed this dissertation without support and encouragement from a number of people around me. I would like to express my deepest appreciation to my advisor professor, Dr. Kyunghwa Lee. She has been a tremendous mentor to me, and her enthusiasm as a researcher and as a teacher educator have inspired and guided me throughout my doctoral study. I appreciate that I have closely worked with her in the research project that I was involved in for most of my time in this doctoral study. Without her guidance and persistent help I would not be at this point.

I would like to express my special gratitude to my committee members. Dr. Cory Buxton has encouraged me to link my ideas to science and the engineering education field. His diligent comments and patience greatly supported me in expanding my understanding in this study. I am genuinely grateful to Dr. Joseph Tobin. He inspired me to use several theoretical ideas, and these ideas allowed me to theorize the findings. He also encouraged me to pay close attention to the children's ideas and their own perspectives in their drawings about robots. A very special gratitude goes out to Dr. Chi Thai. His expertise in engineering graciously motivated me in terms of integrating robotics into early childhood education. He retired in 2015, but he has supported me all the way. My dissertation study could not have been completed without his endless help and patience.

I am grateful to the children and the teachers, who have participated in this study and provided me with motivation and emotional support during the research

implementation: the children showed never-ending curiosity and enthusiastic explorations, and the teachers willingly collaborated with me as a researcher. I am also grateful to the other research team members, Sung-eun Jung and Shara Cherniak, who have supported me and shared their warm hearts along the way.

I specially appreciate Rosemarie Goodrum, who had read my chapters and commented on my writing. She has always sent positive thoughts when I had a hard time in writing. Her questions made me clarify my abstract thinking. A special mention to Suyun Choi, Jaehee Kwon, Cindy Blair, Xioying Zhao because I would not have gotten through this journey without your kindhearted friendship and love. Special thanks to the Athens Korean Baptist Church community. I appreciate their prayers and that they took care of me and my family.

And finally, last but by no means least, I want to express my deepest love and thanks to my family. I sincerely appreciate that my parents and parents in law have supported and prayed for me. Without their endless love and sacrifice, I would not have succeeded in my doctoral study. Without my older brother and sister in law who took care of family matters in Korea, I would never have been able to concentrate on and complete my dissertation. I am deeply grateful for my husband who trusted me and supported me all through my study; I admire his patience and love for our family. My daughter, Jisu, has inspired me by sharing her thoughts and stories about her schooling. She has reminded me to pay close attention to what children think and talk about. I wish to acknowledge God's guidance to my study and life. I will move forward to another stage in my life, and I believe that His plan will guide me.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS iv

LIST OF TABLES viii

LIST OF FIGURES x

CHAPTER

1 INTRODUCTION 1

Review of Literature 6

Latour's Actor-Network-Theory 9

Methodology 12

Organization of the Dissertation 20

2 ACTORS IN BEE-BOT ROUTE ACTIVITIES 21

Latour's Notions of Material Actor and Heterogeneous Association 22

Context of the Bee-Bot Class 23

Findings 30

Discussions 51

3 CHILDREN'S ROLES IN PROBLEM-BASED ROBOT BUILDING ACTIVITIES 54

Reviewing Literature 55

The Study 59

Findings 64

Discussion 74

4 CHILDREN'S CONCEPTUALIZATION OF ROBOTS FROM THEIR DRAWINGS AND WRITINGS 78

Context of Robotics Class 78

Where Do the Young Children's Robot Images Come from? 83

Bakhtin's Notion of Hybridity 87

Findings from Children's Drawings of and Writings about Robots 90

Discussion 122

5 CONCLUSION 126

REFERENCES 133

APPENDIX

TRANSCRIPTION CONVENTIONS 150

LIST OF TABLES

Page

Table 1.1: Research Project Implementation Information 1

Table 1.2: Four Sessions and Activities in the Bee-Bot Class 15

Table 1.3: Data Sources 17

Table 2.1: Four Sessions and Activities in the Bee-Bot Class 26

Table 2.2: Actors that Contributed to or Constrained Programming 30

Table 2.3: The Participating Children's Preferences for Robotic Manipulatives 33

Table 2.4: Areas of Difficulty Observed from Children who Struggled in the Bee-Bot Route Activities 37

Table 2.5: Actors that Associated with Successful Programming 51

Table 3.1: Four Sessions and Activities in the Cubelets Class 60

Table 3.2: Each Group's Problem and Robot 62

Table 3.3: Grouping of the Children 64

Table 4.1: Six Findings the Children's Drawings of Robots 90

Table 4.2: Tamia's Pre- and Post-instruction Writings about Robots 91

Table 4.3: Kelsey's Pre- and Post-instruction Writings about Robots 100

Table 4.4: Emily's Pre- and Post-instruction Writings about Robots 102

Table 4.5: Josue's Pre- and Post-instruction Writings about Robots 104

Table 4.6: Issac's Pre- and Post-instruction Writings about Robots 106

Table 4.7: Craig's Pre- and Post-instruction Writings about Robots 108

Table 4.8: Sara's Pre- and Post-instruction Writings about Robots..... 112

Table 4.9: Nora's Pre- and Post-instruction Writings about Robots..... 114

Table 4.10: Cristian's Pre- and Post-instruction Writings about Robots 118

Table 4.11: Emma's Pre- and Post-instruction Writings about Robots..... 119

Table 4.12: Mark's Pre- and Post-instruction Writings about Robots 121

LIST OF FIGURES

Page

Figure 1.1: Luis's drawing of a robot and his attempt to build a fighting robot 4

Figure 1.2: A cleaning robot shown to the children as a robot building demonstration 5

Figure 1.3: Luis' robot *Helper* 5

Figure 1.4: Bee-Bots' front and back (command buttons) 14

Figure 1.5: Three basic Cubelets: a battery, a light sensor, and a speaker actor 15

Figure 1.6: A concept map from the process of analysis..... 19

Figure 2.1: Bee-Bot's front side and command buttons and Bee-Bot's jackets 24

Figure 2.2: Different routes 26

Figure 2.3: Written direction for the route activities..... 28

Figure 2.4: An engineer log for the route activities 29

Figure 2.5: Actors associated with the Bee-Bot route programming activities 31

Figure 2.6: Three actors that contributed to programming 32

Figure 2.7: Anne cuddled the Bee-Bot, pointed to Jerome, and said "It likes you." 35

Figure 2.8: An engineer log for a route activity..... 36

Figure 2.9: The Bee-Bot's command buttons: directions (left, right, forward, backward), clear, and pause..... 39

Figure 2.10: Four commands that required to move the Bee-Bot two steps forward and one step left 39

Figure 2.11: Embodied simulation of the Bee-Bot's movement with hands and wrists ... 40
Figure 2.12: Jorge's simulation ... 42
Figure 2.13: Comparing actors between the first and second group ... 43
Figure 3.1: Distance sensor activity, light sensor activity, and problem solving activity ... 59
Figure 3.2: A problem solving activity ... 61
Figure 3.3: An engineer log for problem identification and robot building ... 63
Figure 4.1: The engineer log used for pre- and post-instruction drawing and writing ... 79
Figure 4.2: A route, a grid, and a maze ... 80
Figure 4.3: Experiencing three basic Cubelets, a distance sensor, building a robot to solve a given problem, and solving a problem created by the children ... 81
Figure 4.4: Pre-instruction writing and drawing ... 82
Figure 4.5: A packaging robot, a farming robot, and a crab shaped robot from the video ... 82
Figure 4.6: Pre-instruction drawings of human body shaped robots ... 92
Figure 4.7: Pre-instruction drawings of non-human body shaped robots ... 93
Figure 4.8: Post-instruction drawings of human body shaped robots ... 94
Figure 4.9: Post-instruction drawings of non-human-shaped robots ... 95
Figure 4.10: A concept of a mobile operating system, an animation movie–Big Hero Six, and SpongeBob ... 96
Figure 4.11: Tamia' pre-instruction drawing ... 97
Figure 4.12: Tamia' post-instruction drawing ... 98
Figure 4.13: Kelsey's pre-instruction drawing ... 99
Figure 4.14: Kelsey's post-instruction drawing ... 99

Figure 4.15: Emily's pre-instruction drawing 101
Figure 4.16: Emily's post-instruction drawing 101
Figure 4.17: Josue's pre-instruction drawing 103
Figure 4.18: Josue's post-instruction drawing 103
Figure 4.19: Issac's pre-instruction drawing 104
Figure 4.20: Issac's post-instruction drawing 105
Figure 4.21: Craig's pre-instruction drawing 107
Figure 4.22: Craig's post-instruction drawing 107
Figure 4.23: Shara's explaining pre-instruction drawing and writing (Cubelet photo on the schedule board) 109
Figure 4.24: Kaity's pre-instruction drawing 110
Figure 4.25: Jorge's pre-instruction drawing 110
Figure 4.26: Sara's pre- and post-instruction drawing 111
Figure 4.27: Nora's pre-instruction drawing 113
Figure 4.28: Nora's post-instruction drawing 113
Figure 4.29: Anne's pre- and post-instruction drawing 115
Figure 4.30: Shelby's pre- and post-instruction drawing 115
Figure 4.31: Kaity's pre- and post-instruction drawing 116
Figure 4.32: Cristian's pre-instruction drawing 117
Figure 4.33: Cristian's post-instruction drawing 117
Figure 4.34: Emma's pre-instruction drawing 119
Figure 4.35: Emma's post-instruction drawing 119
Figure 4.36: Mark's pre-instruction drawing 120

Figure 4.37: Mark's post-instruction drawing 120

Figure 5.1: Actors associated with 2nd graders robotics class..... 128

Figure 5.2: Dr. Thai's sense-think-act paradigm of robots..... 130

CHAPTER 1

INTRODUCTION

> If action is limited a priori to what 'intentional', 'meaningful' humans do, it is hard to see how a hammer, a basket, a door closer, a cat, a rug, a mug, a list, or a tag could act. They might exist in the domain of 'material' 'causal' relations, but not in the 'reflexive' 'symbolic' domain of social relations. By contrast, if we stick to our decision to start from the controversies about actors and agencies, then *any thing* that does modify a state of affairs by making a difference is an actor—or, if it has not figuration yet, an actant. (Latour, 2005, p. 71)

Since January 2014, I have been involved in a research project, Early Childhood Robotics Education, led by Dr. Kyunghwa Lee (the principle investigator). The robotics research project was implemented in different spaces at different times over two years (see Table 1.1).

Table 1.1

Robotics project implementation information

	Period	Duration	Place
2014	January-May	13 days/ 2 hours/ once a week	A community-based children's club
	June 2nd-13th	10 days/ 2 hours/ every weekday	
	August-September	3 days/ 2 hours/ once a week	
2015	February-May	9 days/ 45 minutes/ once a week	A public elementary school
	June 8th-22nd	9 days/ 40 minutes/ every weekday	

In 2014, the research project was begun in a community-based learning space with children aged four through seven in the southeastern United States. This space was located in an African-American and Latino-family dominated community. After implementing the robotics class in the community-based learning space, we moved to a public elementary school for a robotics class with second graders in Spring and Summer 2015. The data for this dissertation study are from the research project implemented in a public elementary school in Spring 2015.

During the summer robotics camp in 2014, one moment stood out in my mind when I worked with Luis[1], a six-year-old Latino boy, in a Cubelet class. Cubelets are cube-shaped robotic blocks that allow children to explore different sensors and actuators. In the open house held at the conclusion of summer camp, Louis, who had been quite talkative and articulate during our robotics class, did not explain his robot's name and functions to guests invited to the open house. He reluctantly responded to questions posed by the guests, as described in Vignette 1.1 below:

Vignette 1.1

On the evening of June 13th, the last day of our summer robotics camp, guests gather at the library room of the community children's club to see the children's demonstration of their Cubelet robots. Luis stands at a rectangular table holding his robot, and I stand behind him.

Luis: (Looking at me) Can I show my mom what I did?

I: Sure. Go ahead.

He turns the switch on, and the Cubelet robot makes beeping sounds and moves.

[1] All the names of the people in this dissertation are pseudonyms except the research team members' name.

The robot starts to move and pushes another robot. Luis smiles at his mom. Amber, one of our research team members for the summer camp, asks him, "What is the name of your robot, Luis?" Luis doesn't respond to this question. Luis moves his Cubelet robot to the other side of the table and tries to move it again. I place some Lego blocks in front of the robot to encourage him to demonstrate his robot.

I: (Trying to encourage Luis to engage in dialogue with the guests) Luis, let's introduce your robot.

Luis: (Not responding to my suggestion.)

I: (Asking him again) What is its name?

Luis: Helper.

I: (Explaining to the guest) His robot is [a] *helper*. (Asking Luis) How does it work?

Luis doesn't respond. One guest in the room observes his robot and says, "He can clean up."

This moment prompted me to think about how Luis's final artifact did not show his learning process from the robotics class. The difficulty Luis had with the verbal presentation during the open house encouraged me to reflect on what we had done during the last 10 days of summer camp. In order to understand Luis's learning process, I reviewed his drawings and his participation in the robotics camp by watching videos recorded from day 1 to day 10. What I realized was how Luis's process of creating a cleaning robot that he called "helper" during the open house had involved many different actors. As shown in Figure 1.1 presented below, on the first day of robotics summer

camp, Luis drew a human-shaped robot based on his imagination. On the 8th day of class, when I asked him to design and build his robot, Luis built a robot that he named "Assassin" similar to what he drew.

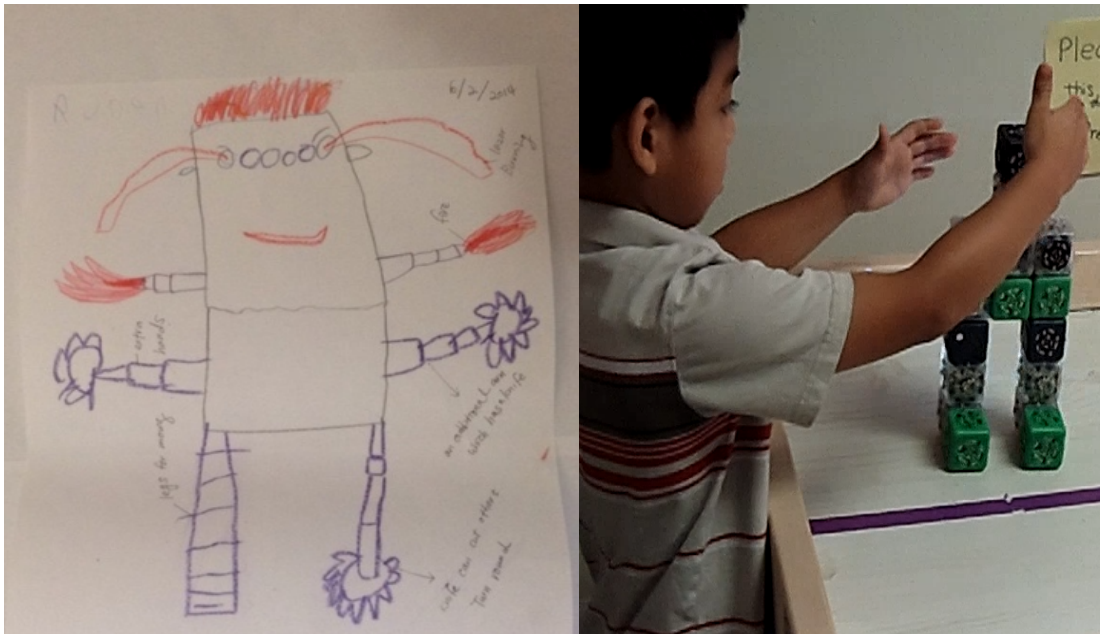


Figure 1.1 Luis's drawing of a robot (left) and his attempt to build a fighting robot (right)

However, Luis's Assassin robot was not stable because the cube-shaped magnetic blocks were not sturdy. He repeatedly tried and failed to build a durable robot. Luis worked with a partner, a six-year-old girl, Daniela, and they gave ideas to each other. For example, Daniela suggested putting a wheel on the back of the robot so it could move forward when the robot fell down.

Following Daniela's suggestion, Luis added wheels on the back of his fighting robot. When he placed the robot down on the floor, he was able to see that his robot was moving smoothly rather than breaking into several parts. On the 7th day, before Luis and Daniela began planning and building their own robots, I demonstrated the process of

building a robot by creating a cleaning robot (see Figure 1.2) with several Cubelets– including two light actors, wheels, and sensors.



Figure 1.2 A cleaning robot shown to the children as a robot building demonstration

Luis's "helper" robot (see Figure 1.3) that he built and showed during the open house emerged thanks to multiple actors (e.g., magnetic robotic manipulatives not cooperating with Luis on building a sturdy fighting robot, Daniela's suggestion for putting a wheel on the back, my demonstration of building a cleaning robot), which were combined with Luis's desire (e.g., building a fighting robot, putting wheels on the back of his robot, making his robot move).



Figure 1.3 Luis's robot *Helper*

My initial idea for my dissertation study was to investigate how a child, like Luis, would change his ideas when building a robot. Reviewing the process of Luis's robot building, I realized that his intention and intelligence were not the only elements involved in his robot construction. Luis's helper robot was developed through heterogeneous actors (Latour, 2005) involved in the whole process of robotics class. I became curious about *what kinds of change-makers are involved in a child's robot building*. The purpose of this dissertation study is to trace and identify the various actors associated with

children's learning about robotics in a second-grade classroom. The central research question for this study is: What actors are involved in children's learning about robotics in a second-grade classroom?

Review of Literature

Robots, Robotics and Engineering Education

Our image of a robot is often based on the image presented to us by mass media, such as movies and television. In the movies, a robot thinks and works by itself like a human. However, unlike a human, a robot depends on such essential components as computer programming to function as an autonomous system that can sense its environment and act on it to achieve some goals (Mataric, 2007). Mataric explained that robotics is the study of robots' autonomous and purposeful sensing and acting in the physical world. Robotics is an important part of engineering education.

Regarding the use of robotic manipulatives in education, previous research explained that robotics is helpful to teach engineering thinking. Moore, Glancy, Tank, Kersten, and Smith (2014) explained, "Engineering requires students to be independent, reflective, and metacognitive thinkers who understand that prior experience and learning from failure can ultimately lead to better solutions" (p. 5). Engineers seek out new knowledge/solutions when problems arise (Moore et al., 2014). More specifically, researchers have argued that engineering education teaches students how to design solutions to problems and to optimize the decision for the best solution (Nugent, Barker, 2010; Rogers & Portsmore, 2004). Eguchi (2014) explained, "Educational robotics is effective for project-based learning where STEM [science, technology, engineering, and mathematics], coding, computer thinking and engineering skills are all integrated in one

project" (p. 4). Castledine and Chambers's (2011) study revealed that children's problem solving skills learned in a robotics class influence their daily lives, so children apply their problem solving strategies to other contexts.

Some researchers have found that robotic manipulatives allow children to learn through the hands-on application of STEM concepts (Bers, 2010; Petre & Price, 2004). For example, Rockland, Bloom, Carpinelli, Burr-Alexander, Hirsch, and Kimmel (2010) insisted that robotics brings opportunities to use engineering in science instruction because scientific concepts, such as motion of objects, forces, and energy, are embedded in robot construction. Bers (2010) explained that using robotic manipulatives provides opportunities for young children to learn about mechanics, sensors, motors, programming, and the digital domain. Horn, Crouser, and Bers (2012) argued that robotics activities encourage children not only to learn about robotics concepts but also to acquire logical thinking skills, which are not encountered in other educational experiences.

Engineering is well suited for learning about several science concepts, such as motion (K-3rd grade) and force (e.g., push and pull in 2nd grade), as well as other concepts in various disciplines, including literacy and mathematics (Eguchi, 2014; Mataric, 2004; Petre & Price, 2004). Katehi, Pearson, and Feder (2009) mentioned that engineering education needs to incorporate knowledge and practice from mathematics, science, and technology.

Gaps in the Previous Literature of Early Childhood Robotics Education

Previous research (e.g., Bers, 2010; Kazakoff, Sullivan & Bers, 2013; McDonald & Howell, 2012) on robotics education, which framed children as passive recipients of

learning activities, tended to emphasize the one-way influence of robotic manipulatives on children's learning. Consequently, robotics education research is needed to explore the bidirectional or multi-dimensional relationships among the multiple actors (e.g., robotic manipulatives, learners' attitudes and actions, teachers' instructional strategies) to see how they afford and limit one another in robotics class.

In addition, theories used in the existing studies were limited. Most of the previous research in the field of early childhood robotics education was rooted in constructivism, which posits that learners construct their knowledge out of their experiences. Constructivists have focused on children's cognitive competence and reasoning in developing new knowledge through either adaptation and assimilation (Piaget, 1973) or social interactions (Vygotsky, 1978). The previous research based on constructivism tended to focus on comparing the effectiveness of individual learning with that of working with peers or parents (e.g., Beals & Bers, 2006; Levy & Mioduser, 2008).

Another theoretical framework that has been widely used in the field of early childhood robotics education is constructionism (Papert, 1980). Papert and Harel (1991) explained constructionism in two ways: One version of the explanation is the notion of bricolage, and the other version referred to the idea of "closeness to objects." According to Papert and Harel, "Bricolage takes its starting point in strategies for the organization of work: The painter-programmer is guided by the work as it proceeds rather than staying with a pre-established plan" (para. 14). Thus, the concept of bricolage was "to serve as a source of ideas and model for improving the skill of making–and fixing and improving–mental constructions" (Papert, 1993, p. 144). In addition, Papert and Harel explained that the notion of "closeness to objects" is related to the fact that "some people prefer ways of

thinking that keep them close to physical things, while others use abstract and formal means to distance themselves from concrete material" (para. 14). Papert (1993) thought that as children observe and touch objects, they develop subtler ideas about them– learning by making. The idea of constructionism was used (e.g., Bers, Flannery, Kazakoff, and Sullivan, 2014; Stager, 2001) by focusing on building knowledge through constructions (i.e., seeing how children build their own robots as a meaningful project).

In the previous studies using both constructivism and constructionism, robotic manipulatives were treated as passive media with which humans interact to generate knowledge. Using the lens of Latour's (2005) Actor-Network-Theory (ANT), in this study I consider both materials and humans "actors that contribute to and make changes in children's learning in robotics class.

Latour's Actor-Network-Theory

Bruno Latour has developed his ideas about Actor-Network Theory (ANT) based on the premise of irreductions, and he resists, for example, reducing people to categories that can explain only one aspect, such as Christians, Catholics, Westerners, engineers, etc. (Harman, 2009). According to Latour (1988), "Nothing can be reduced to anything else, nothing can be deduced from anything else, everything may be allied to everything else … we mutually define ourselves" (p. 163). Through the principle of irreductions, Latour (2005) emphasized that the world is made up of actors or actants. According to ANT, "Atoms and molecules are actants, as are children, raindrops, bullet trains, politicians, and numerals," and whether they are living things or not, "all entities are on exactly the same ontological footing" (Harman, 2009, p. 14).

ANT emerged in the 1980s out of criticism of more traditional sociology, which tended to disregard the role of the material in the constitution of social reality (Latour, 2005). Latour criticized the term *social*, arguing that the term cannot comment on the inevitable social dimension of what people are doing in society.

> There is no social dimension of any sort, no social context, no distinct domain of reality to which the label social or society could be attributed; that no social force is available to explain the residual features other domains cannot account for. (Latour, 2005, p. 4)

Latour (2005) explained that only human's intentional behavior has been highlighted in our society, while we cannot avoid considering materiality's impacts in our daily lives. From the perspective of ANT, nonhumans have agency to act by themselves and speak to networks of humans and nonhumans, all mediating one another's activity (Latour, 2005). According to ANT, the properties of technologies in learning situations cannot be ignored or considered transparent since both they and the humans that use them mediate each other (Hillman, 2012; Latour, 2007; Law, 2002; Shaffer & Clinton, 2006). Latour (2005) insisted that objects are never assembled together to form other things, and it is difficult to determine their value or power by thinking about social values that won't allow us to really evaluate objects. Rather, Latour asserted that "their action is no doubt much more varied, their influence more ubiquitous, their effect much more ambiguous, their presence much more distributed than these narrow repertoires" (p. 85). Latour called it "multiplicity," which he claimed could be proved by "a close look at what objects really do in the texts of the writers alluded to above: they deploy many other ways

for objects to act than the ones granted to them by their author's own philosophy of matter" (p. 85).

According to Latour (2005), materials have been there, but they have not been conceptualized as having agency because they are non-organic. He claimed, "Material does make a difference under trials and so these implements, according to our definition, are actors, or more precisely, *participants* in the course of action waiting to be given a figuration" (p. 71). Viewing materials as "participants" helps me understand the roles of materials in a robotics class as agents. However, the term "act" here does not necessarily mean a visible movement; many non-organic things exist, and existence itself can be counted for acting. An act calls for a user's reactions. Children in a robotics class interact with each robotic manipulative's specific design, including colors, movements, and working systems.

Although ANT emphasizes that a nonhuman has agency, this is not an attempt to divide humans and nonhumans. Rather, ANT allows me to move beyond the human and non-human binary. Latour (2005) criticized the fact that materials have been marginalized because actions are limited a priori to the intentional, meaningful actions of humans. He explained, "the continuity of any course of action will rarely consist of human-to-human connections or of object-object connections, but will probably zigzag from one to the other" (p.75). Thus, Latour employs the word *collective* instead of *society* because the latter will be reserved only for the assembly of already gathered entities in terms of existing social groups/categories that sociologists have made of social stuff. However, as he explains, a "collective will designate the project of

assembling new entities not yet gathered together and which clearly appear as being not made of social stuff" (p. 75).

Methodology

Case Study

This qualitative case study is designed to explore the heterogeneous actors involved in a 2nd grade robotics class. An explorative case study (Yin, 2009) is characterized as the collection of data and subsequent search for patterns in the data. Merriam (1998) defined a case study as "a thing, a single entity, a unit around which there are boundaries [a researcher] can fence in what [s/he is] going to study" (p. 27). She described three characteristics of case study: particularistic, descriptive, and heuristic. Particularistic means that "case studies focus on a particular situation, event, program, or phenomenon," and in this case "the case itself is important for what it reveals about the phenomenon and for what it might represent" (p. 29). Descriptive means that "the end product of a case study is a rich, 'thick' description of the phenomenon under study" (p. 29). Heuristic means that "case studies illuminate the reader's understanding of the phenomenon under study. They can bring about the discovery of new meaning, extend the reader's experience, or confirm what is known" (p.30). According to these authors, case study has been used to enhance the understanding of a phenomenon or an event based on thick description and rich data.

Especially, case study has been used in educational research to explore the processes and dynamics of practice (Merriam, 1988). Merriam explained that from the perspective of the qualitative research paradigm, a case study is the most suitable method for collecting and analyzing data in the natural setting of research. In this dissertation

study, all the robotics activities were implemented in a classroom setting, and the children's and teachers' natural actions and conversations were recorded and analyzed.

In this study, I examined each robotics activity as a unit of analysis to understand the meaning of a particular experience as well as to discover any common patterns that might lead to a conceptual understanding. Finding such meanings and patterns was achieved by reviewing and analyzing multiple data sources, such as video records, engineer logs (i.e., children's weekly written records of their activities), activity plans, and the children's writings and drawings, which are further explained in the section on data collection.

Participants and Settings

In Spring 2015, the robotics class was implemented in collaboration with a Title 1 public elementary school. The robotics education program was offered to 24 second-graders (12 boys and 12 girls), including 11 European-American, eight Latino-American, three multi-racial and two African-American children, during an enrichment class time after the regular daily schedules in their home rooms. At the time of implementation, five children were 7-years-old, and 19 children were 8-years-old. According to the two teachers leading the enrichment class, Ms. White and Ms. Bridges, these students were selected from different second-grade classrooms based on their academic achievement, in particular, for having met grade-level standards, and five of them were identified as gifted.

Robotics Activities and Tools

Our research team designed and taught 30-45 minute classes once a week for nine weeks in Spring 2015. We divided the 24 participating children into two groups: one

group started with the Bee-Bots class, while the other group started with the Cubelet class. After completing all four sessions in each class, the two groups switched their classes. As a result, each group had different sequences of robotics activities. During the transition period, the children watched a video clip of different kinds of robots, including a surgery robot, a packaging robot in a factory, a farming robot, a submarine detecting robot, and a vacuum robot. In showing these robots, we wanted children to develop a sense of the robots which are around us and used in daily life. In the final session (week 9), we conducted a semi-structured interview with each group as a form of reflection on the robotics classes.

Bee-Bots and activities. A Bee-Bot (© Terrapin Software, https://www.terrapinlogo.com) is a programmable floor robot that is controlled by command buttons, including right (→), left (↑), forward (↑),backward (↓), clear, pause, and go (Figure 1.4).

I discuss Bee-Bots' commands and functions in more detail in Chapter 2. For the robotics class, the Bee-Bot activities were designed for the children to develop the basic programming skills.



Figure 1.4 Bee-Bot's front and back (command buttons- clockwise forward, right, pause, backward, clear, left, go)

For the Bee-Bot class, four different sessions were provided. The detailed weekly activities will be presented in Chapter 2. For the first session, children were encouraged to draw and write about a robot. Then, they learned about basic functions of a Bee-Bot. During the second session, various route and grid boards were offered to children to

program a Bee-Bot by using command buttons. In the third session, different sizes (e.g., 2x3, 3x4, 6x6) of grid boards with tasks were provided to the children to program a Bee-Bot. In the fourth session, a maze board was offered to the children to practice their programming skills. In the Bee-Bot class the children in pairs shared the Bee-Bot, and the pairs were changed each week to help each child work with a partner to reach each week's activity goal. Engineer logs were provided to each child for each activity.

Cubelets and activities. Cubelets (© Modular Robotics, https://www.modrobotics.com/cubelets/) are preprogrammed magnetic blocks that promote children's learning about sensors, actuators, and their causal relationships. To make Cubelets work, three basic Cubelets are needed, including a sensor, a battery, and an actuator. Cubelets have different types of sensors (e.g., light, distance, temperature) and actuators (e.g., light, sound, rotation, movement) for children's exploration. Figure 1.5 shows a battery (left), a light sensor, and a speaker actor as an example of the three basic Cubelets.



Figure 1.5 Three basic Cubelets: a battery (left), a light sensor (middle), and a speaker actor (right)

For the Cubelet class, four different sessions were provided. Detailed descriptions of the activities for Cubelet class are presented in Chapter 3.

Data Collection

In this study, both Bee-Bot and Cubelets classes were video recorded by using four cameras per class in order to capture multiple individual and group activities. Video-recording was helpful to watch and analyze the data repeatedly. In early childhood educational research, many researchers (Correa-Chavez, Rogoff, & Arauz, 2005; Mejia-Arauz, Rogoff, Dexter, & Najafi, 2007; Parks & Schmeichel, 2014; Tobin & Hsueh, 2007) have used video-recording to capture children's verbal and non-verbal actions and interactions. In some psychological studies, video has been used to record children's engagement with materials during activities for basic reasoning skills (Gopnik, Sobel, Schultz, & Glymour, 2001; Kushnir & Gopnik, 2007). In our robotics project, we used the video to carefully observe how the participating children use the robotic manipulatives and their bodies, how they interact with peers and teachers, and how the robotic manipulatives respond to and change through interactions with the children.

In each Bee-Bot and Cubelets weekly session, four cameras recorded an average of two hours per week. Using a total of eight cameras, we generated approximately 35 hours of video-recorded observation data (2.2 hours /week x 8 sessions x 2 classes) from the two robotics classes. In addition, the participating children used individual activity logs for six weekly sessions while completing group activity logs for two sessions. The children also had pre- and post-instructional drawings and writings about a robot. We used the children's weekly activity logs as well as their drawings and writings about a robot as our data.

In the ninth session of the robotics class, interviews and surveys were implemented with the children. For the interviews with children, we adopted "video-

cued interviews" (Tobin, Hsueh, & Karasawa, 2009) by using still images of the children from the videos to remind them of what kinds of activities they were engaged in the two robotics classes. After watching the slides of their photos, the children responded to the question, "Choose the robot you like best between Bee-Bots and Cubelets. Why do you like it best?" The next question for children involved comparing Bee-Bots and Cubelets with the other objects, such as "How are Bee-Bots similar to and different from other moving toys, such as toy cars?" and "How are Cubelets similar to and different from other blocks?" Through those questions, the children showed their understanding about the two different robotic manipulatives' functions. Each group interview took approximately 30 minutes with the children.

Table 1.3

Data Sources

	Data Sources	Collected Data
Video-recorded observation data	Activity observation	35 hours
	Interview with teachers	2 hours
	Interview with children	1 hour (30 minutes x 2 groups)
Activity logs	Drawings and writings about a robot	2 times: pre- and post-instruction drawings and writings
	Engineer logs	6 sessions: individual logs 2 sessions: group logs

After finishing the robotics classes, we also conducted a video-cued interview with the two enrichment class teachers for two hours to ask them about the participating children's engagement in the robotics classes. The teachers also shared their thoughts about the two robotic manipulatives, instructional activities, and other materials such as engineer logs. During the interviews with the teachers, we were able to get additional

information about the children so that we could better understand their performances in the robotics class. Table 1.3 presents data sources of this dissertation study.

The Researcher's Role

My role as a researcher was different from the traditional participant observer in qualitative research. In this study, the research team members included Dr. Kyunghwa Lee, Shara Cherniak, Sung-eun Jung, and I, and we designed and offered the robotics class. While two additional graduate student colleagues took turns to help video-record the Bee-Bot class activities, I video-recorded the Cubelet class activities. Our research team discussed the activities and the children's performances after each session ended, and those discussions led us to revise the next activities and the pairing and grouping of the children.

Data Analysis

Using microanalysis (Graue & Walsh, 1998), I carefully looked at the video-recorded observation data, the activity logs, and the participating children's drawings and writings about robots. Graue and Walsh explained that "microanalysis requires greater accuracy than more conventional forms of analysis," and "the level of accuracy required will depend on one's purpose" (p. 136). To enhance the level of accuracy, I transcribed weekly videos and drew a concept map or cartography mapping (see Figure 1.6). Use of visual mapping was helpful "to think metaphorically about patterns that are emerging in field texts to arrive at a more conceptual understanding about what is occurring. This process can suddenly illuminate connections that have remained elusive" (Butler-Kisber, 2010, p. 38). Visual mapping was useful for following my thought process, and I

repeatedly revisited the drawn maps to see whether there was an undiscovered connection that could be revealed later.



Figure 1.6 A concept map from the process of data analysis

Qualitative research data analysis starts from field work. Butler-Kisber (2010) explained that a qualitative data analysis is "going on from the outset—based on what the researcher brings with her to the inquiry, what she paid attention to and selects out of what she is hearing, seeing, and recording, and how the field texts are constructed" (p. 30). According to Butler-Kisber's constant comparison method, I analyzed the data through "categorizing, or the comparing and contrasting of units and categories of field texts, to produce conceptual understandings of experiences and/ or phenomena" (p. 47).

Organization of the Dissertation

Drawing on Latour's (2005) ANT, this dissertation study aims to explore a variety of actors that contributed to 2nd graders' performance in the robotics activities in a public elementary school. This dissertation consists of five chapters: Chapter 1 introduces the purpose and procedures of the research project. Chapter 2 examines a Bee-Bot's route activity in order to examine various actors that contributed to and constrained the participating children's successful programming. Chapter 3 focuses on a Cubelets activity, which encouraged the participating children to identify problems on their own and design robots to solve their problems. In particular, I try to understand how the children negotiated and performed different roles in their small groups. Chapter 4 investigates the participating children's pre- and post-instruction drawings of and writings about robots in order to understand their conceptualization of robots, sources of the children's images of robots, and whether there are any changes after the robotics class. In Chapter 5, I conclude the study with implications for general early childhood research and practice as well as early childhood robotics education.

CHAPTER 2

ACTORS IN BEE-BOT ROUTE ACTIVITIES

This chapter investigates the heterogeneous actors associated with a Bee-Bot programming activity in order to identify various actors that contributed to or constrained the participating children's successful programming. The route activities were the first programming trial that the participating children attempted in order to get the Bee-Bot to its final destination. Tracing actors involved in programming, I focused on the process rather than the results of the route activities in order to see what new insights we could gain.

The way robotics is currently introduced in education has not been diversified (Rusk, Resnick, Berg, & Pezalla-Granlund, 2008). Exploring a wider range of possible applications has the potential to engage children with a broader range of interests (Benitti, 2012). Robotic education research needs to change the paradigm that sees robotic manipulatives as passive media for children's development of concepts and skills relevant to science, technology, engineering, and mathematics (STEM).

In the previous studies, analyzing the use of robotic manipulatives has focused on how the robotic manipulatives increase cognitive competence, including sequencing, computational thinking, and programming ability (Bers & Portsmore, 2005; Chun-Wang et al. 2011; Levy & Mioduser, 2008; Strawhackers & Bers, 2015). Mitnik, Nussbaum, and Soto (2008) explained that robotics research in the previous studies had mainly

focused on teaching subjects related to the robotics field, such as robot programming, robot construction, or mechatronics. However, Mitnik et al. tried to apply robotics into education to use the real world situations of a robot to teach non-robotic related subjects, such as math and physics, and they also provided a robot with a proper level of autonomy to guide and mediate in the development of the educational activity.

Latour's Notions of Material Actor and Heterogeneous Association

I used Bruno Latour's (2005) Actor-Network-Theory (ANT)[2] to frame this chapter. By using ANT, I looked at the actors associated with learning instead of focusing on the impact of robotic manipulatives on children's cognitive competence (e.g., sequencing, abstract thinking). As explained in Chapter 1, according to Latour, "*any thing* that does modify a state of affairs by making a difference is an actor—or, if it has not figuration yet, an actant" (p. 71). ANT allowed me to consider all possible actors whether they were an object, a person, or in-between. ANT helped me think about children, robotic manipulatives, designed activities, and other instructional props (e.g., engineer logs, written instructions) as having agency.

Latour (2005) denied the notion of homogeneous social forces in a course of action. He explained that, "any course of action will thread a trajectory through completely foreign modes of existence that have been brought together by such heterogeneity" (p. 75). In order to understand actors that contribute to successful programming or failure in route activities, I try to show heterogeneous actors and their associations. Although I understand these actors are interrelated, to clarify, I attempted to

[2] I discussed Actor-Network-Theory in Chapter 1

separate the actors into each category (e.g., human, material, quasi-human/quasi-material) and explain how they contribute to or constrain successful programming.

Latour (2005) recommended tracing objects as a way of discovering unexpected ideas and actors. Tracing objects allows us to realize how they are interconnected. According to Latour, discovering unexpected ideas and actors means that tracing objects allows us to discover actors that we had never taken into consideration before. Latour argued: "In order to absorb the third source of uncertainty, we should be ready to inquire about the agency of all sorts of objects. But since objects have such poor and constructed roles in most of the social sciences, it's very difficult to extend their original activity to other types of materials" (p. 76). Using Latour's idea of tracing objects, I traced objects in our robotics class in order to find undiscovered ideas and actors which were associated with a Bee-Bot programming activity.

Context of the Bee-Bot Class

Bee-Bots

Bee-Bots were designed by a company, Terrapin (https://www.bee-bot.us), for the purpose of instructing young children to learn sequencing, estimation, and problem-solving. Bee-Bots have vivid colors with yellow and black stripes, buttons, and a bee-shaped design. A Bee-Bot has four directional buttons of right (→), left (←), forward (↑), and backward (↓) and additional functional buttons (e.g., go, pause, and reset) on the top of its body (see Figure 2.1). The Bee-Bot's eyes light up when it moves a step in any direction. The Bee-Bot also has a detachable white cover (see Figure 2.1), which can be used for additional decoration or for another purpose (e.g., to customize the names of

each command button) by using markers or stickers. Bee-Bots store up to a maximum of 40 commands per trial.



Figure 2.1 Bee-Bot's front side and command buttons (left) and Bee-Bot's jackets (right)

Bee-Bots were used for young children to program a Bee-Bot and recognize whether their programming was accurate. Highfield (2010) explained that a floor robot, a Bee-Bot, was selected and used for its simple, robust interface, so when children programmed the Bee-Bot, they could then observe its movements. She explained that children could "see their program in action and decide if their plan has worked as expected" (p. 23). Bee-Bots require unique competency. Children need abstract thinking in using the Bee-Bot. For instance, to successfully program the Bee-Bot, children should be able to see the Bee-Bot's movement and control it by using a set of command buttons. Highfield, Mulligan, and Hedberg (2008) explained that this potential and the non-screen-based programming enabled a variety of problem-solving strategies. According to the Next Generation Science Standards (2013), sequencing and debugging skills in programming, abstraction of commands or symbols, and repeated loops are critical to computational thinking. The Bee-Bot promotes these skills and concepts.

Janka (2008) explained that Bee-Bots were beneficial for kindergartners when they were introduced to teach "control elements" (i.e., programming by using command buttons). In her study, the participating children in her study were actively engaged when

they had roles as story-writers in open-ended stories. In a study, Highfield et al. (2008) determined that a five-year-old boy struggled to discover the Bee-Bot's working system by using four command buttons. Highfield et al. argued that the five-year-old boy developed program-solving strategies through experimentation. Through the process, he experienced "transformational geometry (linear motion and rotation)" and one of the programming skills of "assigning an initial (incorrect) meaning and then re-assigning a correct meaning to the arrow symbols" (p. 174). The results from these previous studies revealed that the programming process of young children (5-6 years old) included trying to understand the directional command buttons to program Bee-Bots. In this chapter, I show the learning processes, including the participating children's understanding of the directional command buttons, in Bee-Bot activities that are closely associated with programming.

The Route Activity

In this chapter, I focus on the route activity in order to find the actors which contributed to and constrained the participating children's programming. I explored the route activity because this was the first attempt the participating children made to learn about Bee-Bot programming so that I was able to identify how the children initially interacted with materials. The route activity was implemented in the second session of the Bee-Bot class (see Table 2.1).

In the route activity, our research team offered various routes to each group to help them explore the different commands and functions of a Bee-Bot. Each route had three to seven steps and zero to four turns (see Figure 2.2).

Table 2.1

Four Sessions and Activities in the Bee-Bot Class

class	session		activities	materials
Bee-Bot	1.	What is a robot?	1) drawing and writing about a robot 2) exploring functions of a Bee- Bot	engineer log-1, pencils and crayons, a rule board, a question board, Bee-Bots, chart paper, written directions
	2.	Programming	1) programming a Bee-Bot on a route 2) programming a Bee-Bot on a grid 3) moving like a Bee-Bot	engineer log-2, pencils, route boards, grid boards, Bee-Bots, written directions
	3.	Finding and correcting errors in programming	1) revising and correcting programming 2) programming a Bee-Bot on a grid 3) programming a Bee-Bot with a task on a grid	engineer log-3, pencils, grid boards (with tasks), Bee-Bots
	4.	Programming with different tasks	1) programming a Bee-Bot with a task on a grid 2) programming a Bee-Bot on a maze	engineer log-4, pencils, grid boards (with tasks), a maze board, Bee-Bots

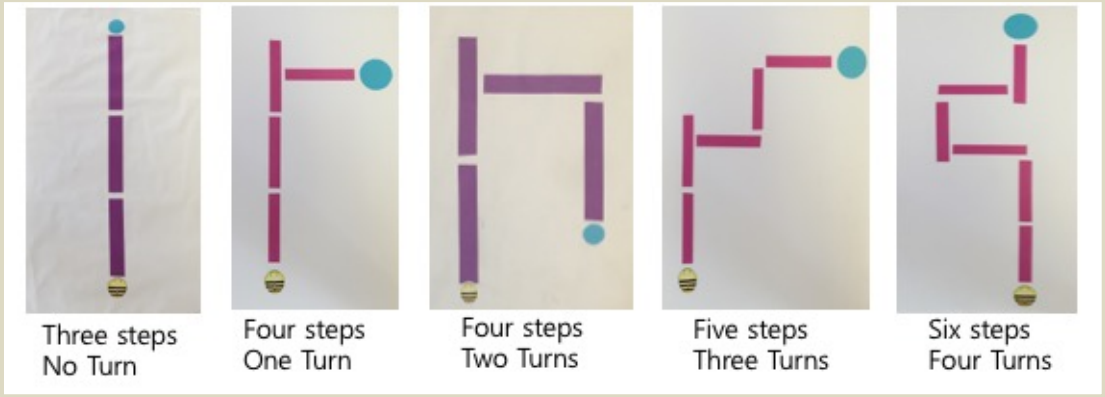


Figure 2.2 Different routes

Based on the number of turns, we determined the levels of challenges and provided the children with different levels of routes from Level 1 to Level 4.

In the written instruction that we gave to the participating children during the Bee-Bot class, we emphasized the basic sequence of two commands: "Always start your programming with 'Clear' (reset) and end it with 'Go' (start)." The children in pairs or in small groups of three worked on the same route by sharing a Bee-Bot, and the pairs and the small groups were changed in each session. After the first session, Dr. Lee and Sung-eun, one of our research team members who led the Bee-Bot class, grouped the children based on their performance from the first session. Each group was mixed with children having different levels based on their implementation in the previous activity. The grouping with different performance levels was helpful for the children to learn from one another. In the last two sessions, we gave the children four different grid boards to encourage them to create their own routes and program their Bee-Bots accordingly. During the last session, three children (Kaity, Cristian, and Horacio), who completed programming on both routes and grids, also had an opportunity to program their Bee-Bot on a large, complex maze designed by our research team.

The route activity was led by three adults, including Dr. Lee, Sung-eun, and Ms. White, one of the enrichment class teachers. Sung-eun briefly explained the route activity at the beginning of the second session and allowed the children to read the written directions, laminated and set up at each table (see Figure 2.3). The participating children also had individual engineer logs (see Figure 2.4) which were designed for them to draw the route and record their programming commands in arrows. Specifically, our research team used the engineer log to help the children find their errors in their programming by checking their written commands.

Can you program your Bee-Bot to follow a route?

1. Choose a **route**.

2. **Draw** the shape of your route on your Engineer Log.

3. **Program** your Bee-Bot to make it arrive in the final destination by following the route.
   * **Remember**
   : The 3 basic sequence of commands
   : Always start your programming with "Clear" and end it with "Go".

4. When programming your BeeBot, think:
   - *Which direction does your BeeBot have to go?*
   - *How many commands do you need to give your BeeBot?*

5. **Record** the commands on your Engineer Log.

6. If your Bee-Bot does not move along the route, **find errors** in your programming and fix them.
   * *Try again until your BeeBot successfully arrive in the final destination.*

7. You can choose **another route** or another lab only after completing one route successfully.

Figure 2.3 Written directions for the route activity

Data Sources and Data Analysis

For this chapter, I focused on the data collected with 24 children during the second session of the Bee-Bot class. In particular, I used 3 hours and 26 minutes of video recordings from this session. The children in pairs or small groups worked on the floor, and they were captured by four different video cameras. I conducted microanalysis of video data (Graue & Walsh, 1998). I transcribed each group's activity and recognized actors that were associated with programming. In order to discover patterns, I represented each group's activity in a concept map by drawing actors and networks.

Cycle 2 - Week 3 – Engineer Challenge #1- **Revisit to Programing on the Routes**

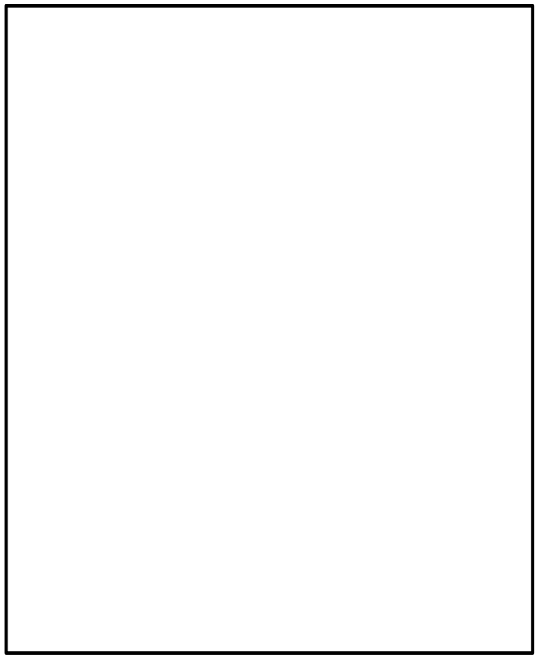
Question to Investigate:

Can you program your Bee-Bot to follow a route?

Date:

Names:

Q1. Draw the shape of your route below.



Q2. Record the commands you need to program your Bee-Bot to move along your chosen route.

** Record them by using symbols (e.g., ← ↑ ↓ → Go X)*

** If you find errors, mark where need to correct them.*

1st trial

X Clear							

2nd trial

X Clear							

3rd trial

X Clear							

Figure 2.4 An engineer log for the route activities

Findings

In this chapter, I attempted to trace multiple actors that contributed to or constrained programming and to identify their heterogeneous associations in the Bee-Bot route activity. Through the data analysis, I discovered seven contributing and two constraining actors (see Table 2.2). Actors that contributed to programming included the bee-shaped design and control system, the use of simulation, the use of abstract thinking, the use of engineer logs, comments by adults, peer demonstrations, and prior experience with robotic manipulatives. The actors that constrained programming were the participating children's failure to push the reset button and confusion with the turn button.

Table 2.2

Actors that Contributed to or Constrained Programming

Contributing actors	Constraining actors
Bee-shaped design and control system	Failure to push the reset button
Use of simulation	Confusion with the turn button
Use of abstract thinking	
Use of engineer log	
Comments by adults	
Peer demonstrations	
Prior experience with robotics	

I grouped these actors that contributed to or constrained successful programming into another tier by drawing on Latour's (2005) notions of material, human, and quasi-human/quasi-material actors. I regrouped the material actors with the Bee-Bots' bee-shaped design and control system, failure to push the reset button, confusion with the turn button, and the use of engineer log; the human actors with comments by adults, peer

demonstrations, and use of abstract thinking; and the quasi-human/quasi-material actors with the use of simulation and prior experience with robotics. Figure 2.5 shows these actors and their associations with one another, and I explain them in the subsequent sections.

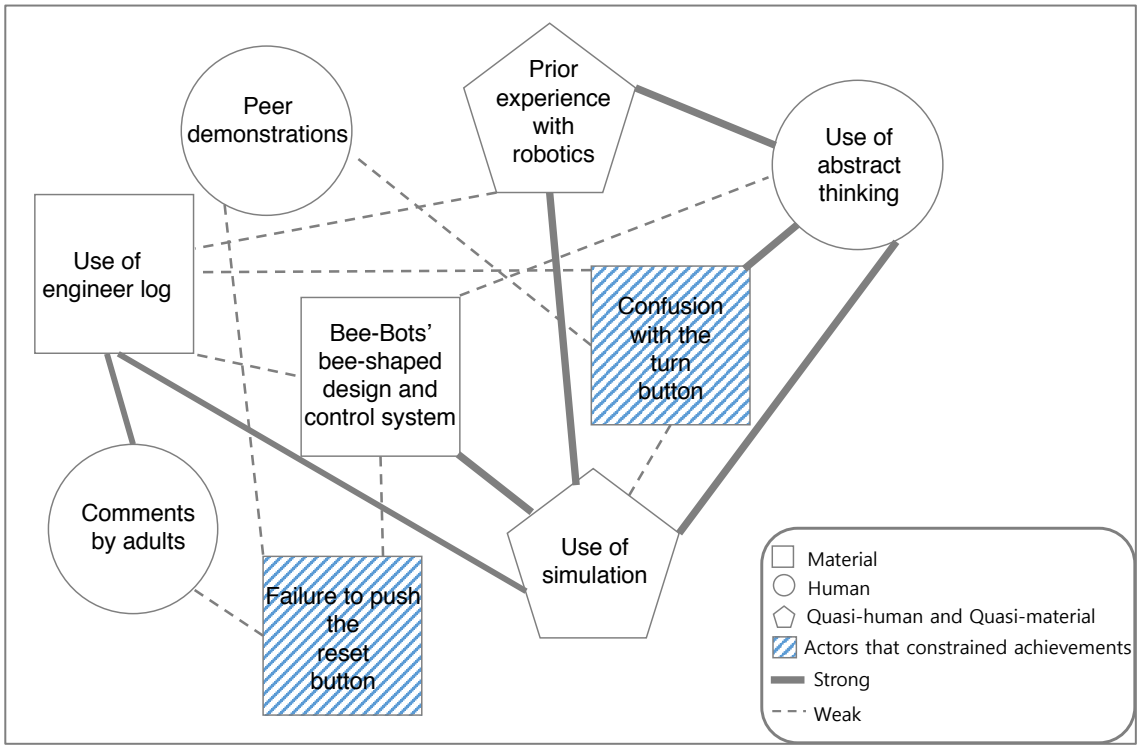


Figure 2.5 Actors associated with the Bee-Bot route programming activity

A total of 19 (79%) out of 24 children succeeded in programming the Bee-Bot on routes. As shown in Figure 2.6, I identified three actors, including the use of simulation (9 children, 39%), abstract thinking and spatial perception (8 children, 35%), and the use of engineer logs (5 children, 26%), which strongly contributed to programming. I consider the use of engineer logs as a material actor, abstract thinking as a human actor, and use of simulation as a quasi-human and quasi-material actor, which are in-between human and material. I discuss each of the three actors in the following section.

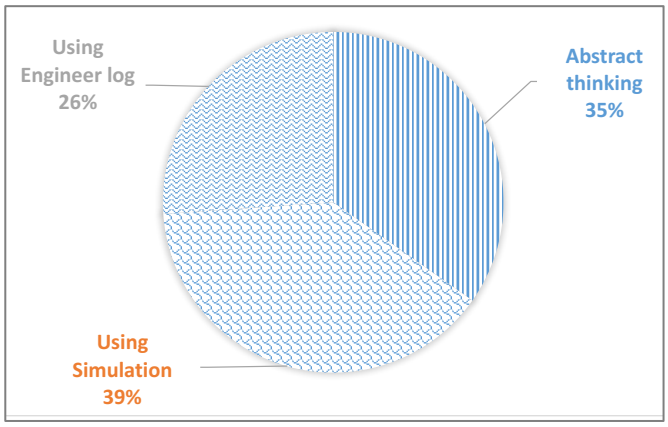


Figure 2.6 Three actors contributing to programming

Material Actors Contributing to and Constraining Children's Programming

Drawing on Latour's (2005) ANT, I consider materials having agency and making changes in interrelated actors and their associations. Particularly, materials and people who use the materials are strongly associated with one another. In the Bee-Bot's route programming activity, I noticed that the Bee-Bot's bee-shaped design and control system led to the participating children's programming, while its turn and reset buttons challenged the children's programming.

Bee-Bots' bee-shaped design and control system leading to repeated trials. The participating children voluntarily repeated their trials in programming the Bee-Bot. Some children expressed their excitement in exploring this bee-shaped moving manipulative. When asked which one of the two manipulatives, the Bee-Bot or Cubelets, they preferred, 11 out of 24 picked the Bee-Bot, eight chose both, and five chose the Cubelets. Those children who selected the Bee-Bot provided the reasons, presented in Table 2.3. The children responded that they liked the Bee-Bot because it was bee-shaped and it was like a toy to play with. The bee-shaped outfit and command buttons seemed to attract the children. In particular, four out of the 11 children, who preferred the Bee-Bot, liked the manipulative due to their sense of having control. I think that one of the reasons

why the children voluntarily repeated programming the Bee-Bot might be that they were intrigued by the Bee-Bot's bee-shaped design.

Table 2.3

The Participating Children's Preferences for Robotic Manipulatives

Response from the children who preferred the **Bee-Bot**	• Because it can [go] anywhere you want and you can *control* it. • Because you get to *control* them. • Bee-Bots are my favorite because you get to *control* them. • Because I like to *control* it. • Because I like to *program stuff* and I like to press buttons, because it is fun. • I like the Bee-Bot because I *don't have to build* it. • It is a *bee*. • I like *a toy* to play with. • Because they're so *cool looking* and there's only *one type*. • I like the Bee-Bot because they can *move lots of ways*. • It is really *easy*.
Response from the children who chose both the **Bee-Bot** and **Cubelets**	• I like both of them because both of them are very fun to work with. We don't have to build none of them. Why do we not have the colorful Cubelets? • Because they were both very fun. • They are so cutttttteeee!!!! • They are both very interesting!!! • They both can move and make sound. • They're both fun.

Janka (2008) explained that the Bee-Bot design was attractive for young children in kindergarten classrooms:

> This toy [Bee-Bots] is adapted to a child user – the toy has a shape of a yellow bee with black stripes. (This design is not fixed. It can be slightly modified by the use of special plastic shells, on which a child can stick paper antennae, woolen wings, etc.) The toy has a small connector for a toy carriage or other moving devices in its rear part. (p. 114)

This insect shape manipulative seemed to encourage the children to imagine that the robot is alive with its functions of moving around and making sounds. Vignette 2.1

shows how some children used imaginative play and pretended that the Bee-Bot was alive and that the manipulative could detect with its sensor when they explored the Bee-Bot's functions and working system.

Vignette 2.1: Video transcripts from the Bee-Bot session 1

Anne, Felipe, and Jerome sit in a circle on the green tiled floor, and their engineer logs are in front of them. While they read their engineer log, Ms. White brings pencils. One of our research team member, Sung-eun, says, "If you are ready, I will bring a Bee-Bot." Anne, Felipe, and Jerome look at the written direction board to learn about the Bee-Bots' command buttons. Sung-eun puts a Bee-Bot on the floor and says, "Here is your Bee-Bot. You have to share it." Anne immediately pushes the "go" button, and it did not respond. Anne pushes two forward buttons without the go button, and it does not move. Felipe pushes the go button, and it starts to move and blink. Anne immediately crawls along with the Bee-Bot as it moves and says, "Oh, Oh, Oh, Oh!" while she excitedly taps her left hand on the floor. She presses the forward button three times with the go button. The Bee-Bot again starts to move. She crawls nearer to it and says, "It (is) walking. Walking!" Jerome says, "going and stopping." Anne picks up the Bee-Bot and turns it to the other side where Jerome and Felipe sit. She presses the forward buttons again. As the Bee-Bot moves toward Jerome, Anne points to him and says, "It likes you."

This vignette shows how Anne explored the functions of the Bee-Bot. She seemed to understand that the Bee-Bot detected Jerome and turned to him (see Figure 2.7). The manipulative's familiar shape, its movements, its blinking eyes, and its sounds seemed to

help the children feel less threatened by the unfamiliar robotics activities, such as programming and debugging, while developing a sense of control and persistence in their trials.

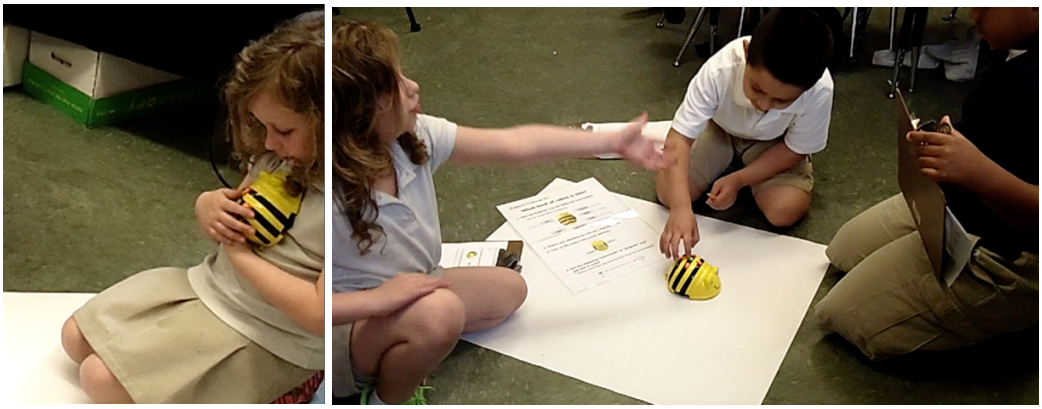


Figure 2.7 Anne cuddles the Bee-Bot (left), points to Jerome, and says, "It likes you."

During the interview, Ms. White talked about the Bee-Bot's potential: "It looks like a toy. The children might think they can get it at a store" (Interview, 5-15-2015). She saw a Bee-Bot as an accessible and attractive toy for young children to learn programming.

The use of engineer logs. Documentation of programming has been emphasized in engineering education (De Jong et al., 2010; Lethbridge, Singer, & Forward, 2003; Litzinger, Lattuca, Hadgraft, & Newstetter, 2011) because it has helped children find errors and correct them for successful programming. Our research team designed engineer logs to guide the participating children to understand each activity goal, to provide them with directions for each activity, and to help them record their weekly work, including programming.

Five out of 19 children, who succeeded in the Bee-Bot programming, accomplished this achievement mainly by using the engineer logs for their trials. Using the engineer logs was different from using worksheets in the classroom. Worksheets in

general have right and wrong answers, but the engineer logs were designed to both guide and document the process of the children's work in our robotics classes.

As shown in Figure 2.8, first, the children drew a route to figure out how many steps their Bee-Bot needed for programming. Next, they wrote each directional command in a separately given space. The written commands helped the children press corresponding command buttons while finding and revising errors.

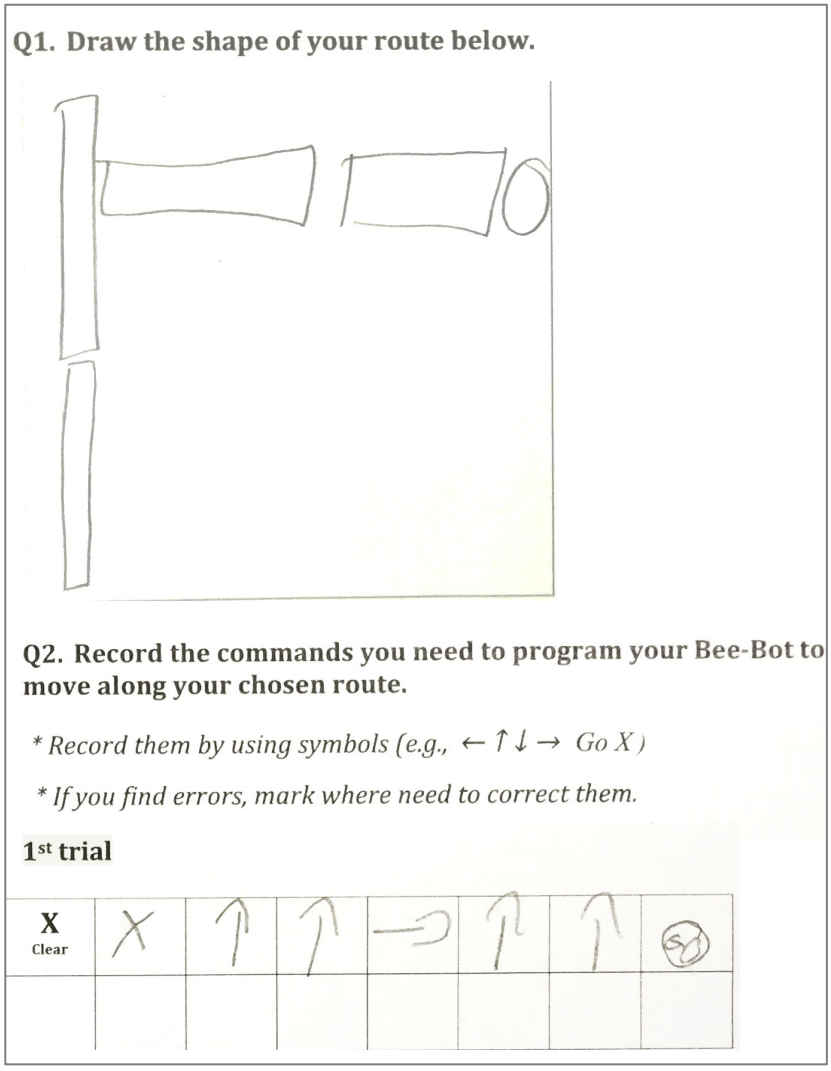


Figure 2.8 An engineer log for a route activity

However, even the children who used engineer logs for their successful programming, still needed guidance from the adults. For example, four children (Emma,

Josh, Craig and Eliana) in the first group used their engineer logs while working with Dr. Lee. Felipe in the second group used his engineer log to accurately program his Bee-Bot when he worked with Ms. White. From these findings, I see that using an engineer log was effective for programming, but the adult encouragement was critical to the children's use of their engineer logs. I also found that once the children learned how to use their engineer logs, they increasingly utilized their logs when programming complex routes later.

In addition, I looked at the material actors that constrained the children's programming in the route activity. Table 2.4 shows five children from both the first and second groups, who struggled with programming activities and their areas of difficulty that I observed.

Table 2.4

Areas of Difficulty Observed from Children who Struggled in the Bee-Bot Route Activities

Group	Name	Areas of Difficulty
1st group	Sara	✓ Confused about right and left (turn) command buttons ✓ Did not use a reset button ✓ Used an engineer log but it did not help her to understand turn buttons
	Hector	✓ Discouraged from several failed trials ✓ Showed little interest in learning about the Bee-Bot programming ✓ Had difficulty in understanding the reset button and the right/left command buttons
	Josue	✓ Partner (Alicia) dominated the Bee-Bot ✓ Did not have enough chances to explore and learn about the Bee-Bot's working system
	Madison	✓ Confused about right and left command buttons ✓ Did not use a reset button
2nd group	Ashley	✓ Explored whether a Bee-Bot had a sensor like Cubelets because her previous experience was with Cubelets ✓ Treated the Bee-Bot as an animate being ✓ Had difficulty in understanding the reset button and the right/left command buttons

One of the repeated errors that four (Hector, Josue, Chloe, and Ashley) of the five children made was related to forgetting about pressing the clear button, which resets the Bee-Bot. Another frequent error these children made was connected to their confusion about the left/right turn buttons. The actors were connected to the Bee-Bot's function with command buttons and a reset button.

Failure to push the reset button. The fundamental programming sequence starts with pressing a reset button to delete previously entered commands. The children often forgot about this step, so they pressed the command buttons without pushing the clear button which led to incomplete programming. The participating children in their initial trials struggled to understand this essential step, but with several trials and observation, most understood it except for four children in the first group and one child in the second group, as presented in Table 2.4. For example, Eliana, who was successful in programming the Bee-Bot early on, immediately figured out that the clear button should be pressed before entering her new commands. Whereas, Hector, who could not complete the programming activity, did not seem to understand how the sequence (i.e., clear-directional commands-go) was crucial to programming. Another girl, Madison, was not aware of the function of the clear button. She did not ask the teachers or her peers to help her. Instead, she just repeated pushing her command buttons without first pressing the reset button. All five children did not press the reset function and/or had little chance to practice it because a partner dominated the Bee-Bot.

Confusion about the turn buttons. On the Bee-Bot, the directional command buttons are marked with arrows. To program the Bee-Bot, the children needed to know how the right and left command buttons worked because these buttons make a Bee-Bot

rotate only 90 degrees left or right (see Figure 2.9). While the forward and backward buttons move a Bee-Bot one step forward or backward, the left or right buttons do not move in those directions, but just turn left or right 90 degrees. This function confused the children when they tried to program the Bee-Bot on routes.

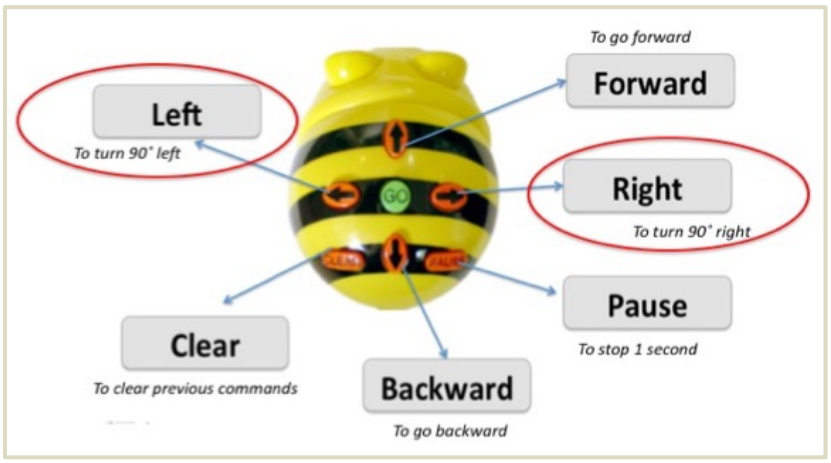


Figure 2.9 The Bee-Bot's command buttons: directions (left, right, forward, backward), clear, and pause

For example, Figure 2.10 shows the Bee-Bot's route (the photo on the left) and a sequence of correct commands (the photo on the right) recorded in Felipe's engineer log. As marked in the red rectangle in the photo on the left side, when a Bee-Bot moves forward twice and turns left, four command buttons—forward, forward, left, and forward—should be pressed.

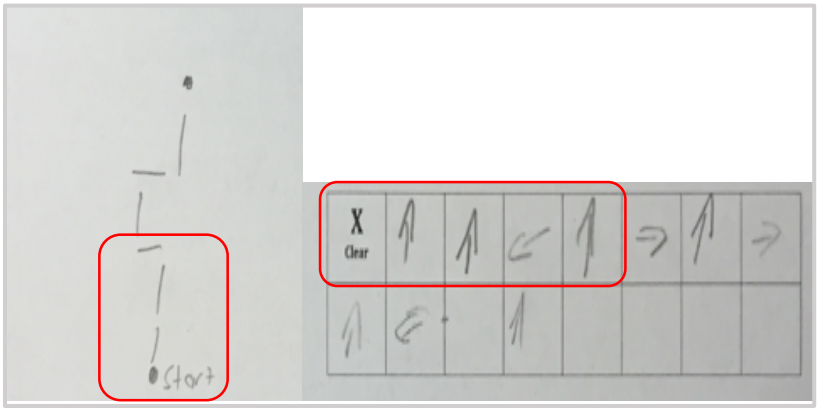


Figure 2.10 Four commands that required to move the Bee-Bot two steps forward and one step left

Without a clear understanding of the function of left and right command buttons, the goal of the route activity could not be achieved. However, the right and left command buttons were confusing, as 16 out of 24 children struggled with these command buttons when they initially programmed their Bee-Bots.

In addition, there is a strong relationship between using a clear button and understanding the turn (left/right) buttons. When the children first attempted their programming, they did not have a clear idea about the right and left turn buttons so they made an error. In their following trials without pressing the clear button, the children realized that their Bee-Bots moved in the same direction as they initially programmed. So, they needed to reset the Bee-Bot. After resetting their programming, the children explored how the right and left command buttons worked. However, if they failed in recognizing the importance of using a reset button, they also struggled with figuring out the functions of the right and left command buttons. The children who could not program their Bee-Bots on the routes had difficulty in properly using both the reset command and the left/right turn buttons. For example, Sara did not succeed in her route activity until the end of the Bee-Bot class. Because she struggled to remember pressing the clear button, she couldn't even advance to press the right and left turn buttons.

Quasi-Human and Quasi-Material Actors Contributing to Successful Programming

In the children's initial trials, 16 out of 24 children had difficulty with the Bee-Bot's direction changes. When the Bee-Bot made a turn, the directional command buttons needed to be pressed from the Bee-Bot's shifted position, but the children tended to program the Bee-Bot from their perspectives. Nine (two from the first group and seven from the second group) out of 19 children who succeeded in the route activities

used simulation during their programming.

Embodied simulation for the understanding of directional changes. The simulations showed two different patterns. One pattern used body parts, including a wrist, a hand, a finger, or an arm, to simulate the Bee-Bot's movements. Our research team calls these strategies "embodied simulation" (Cho, Lee, Cherniak, & Jung, 2017). For instance, as presented in Figure 2.11, the children started to use parts of their bodies, such as their hands (first and second photos) and wrists (third and fourth photos), to figure out the directions to program their Bee-Bots.

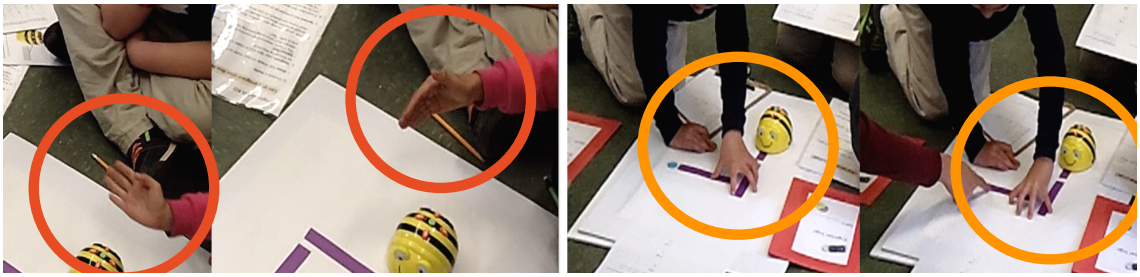


Figure 2.11 Embodied simulation of the Bee-Bot's movement with hands and wrists

In vignette 2.2, Jorge, explained a right (turn) command button for his partner, Felipe, who had difficulty in grasping right and left command buttons. Jorge simulated the Bee-Bot's movement by using his hand to help Felipe.

> Vignette 2.2: Felipe and Jorge's programming in the Bee-Bot session 2
>
> After Felipe and Jorge explore the first route, they have a second route that needs a total of eight command buttons (↑↑→↑←↑→↑) to have their Bee-Bot get to the final destination. Felipe tries to program the Bee-Bot and fails. Felipe now moves his Bee-Bot one step at a time on the route by using his right hand and then pushes a command button. Not recognizing the error in his programming, he says, "Okay, I got it." He smiles. Felipe moves the Bee-Bot back to the starting point and presses the start button. The Bee-Bot starts to move–forward, forward,

and turn right–and the Bee-Bot again turns left instead of moving forward. Felipe frowns, "What's…?" Jorge giggles and carefully watches Felipe's trial while the Bee-Bot moves two steps forward and stops after rotating (turning right and again turning left) at the first turning point. Felipe brings the Bee-Bot back to the starting point and says, "I think I did [it] like this." Felipe presses two forwards and moves the Bee-Bot to the first turning point. He again presses the right (turn) command once and moves the Bee-Bot one step forward to the right side without pressing a forward command button. Jorge carefully watches this and says, "No. No." He immediately moves the Bee-Bot back to the turning point and says, "Look." Felipe says, "Oh!" and takes the Bee-Bot from Jorge's hand. Jorge says, "You pressed it anyway, it just *turns*," while he moves his left hand to the turning point and twists his wrist to *simulate* the Bee-Bot (see Figure 2.12). Felipe brings the Bee-Bot back to the starting point again. He moves the Bee-Bot one step at a time and begins to press a right turn or a left turn followed by a forward command at each turning point. Felipe brings it to the starting point and presses the go button. The Bee-Bot goes smoothly over the route and gets to the final destination. Felipe claps, using his two wrists.

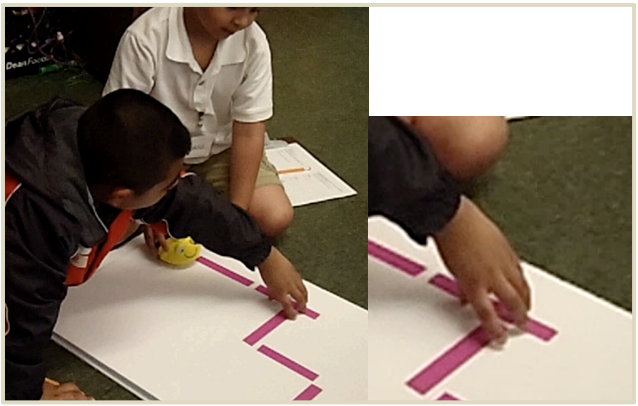


Figure 2.12 Jorge's simulation

The other pattern of simulation was observed when Felipe moved his Bee-Bot one step at a time while simultaneously pressing the correct command button. As shown in the vignette presented above, Felipe was confused at first. Then, he began to use this simultaneous move and press strategy to program his Bee-Bot.

Prior experience with robotics. Through my analysis, I noticed that the children's performance in the Bee-Bot route activity showed differences between two groups. In the first group, eight children (out of 12) succeeded in the route activity, and this group had the Bee-Bot class first before moving to the Cubelet class. In the second group's trials, 11 children (out of 12) successfully programmed the Bee-Bot, and they experienced the Cubelet class before coming to the Bee-Bot class. As shown in Figure 2.13, the second group of children tended to use abstract thinking skills and simulation more frequently, while using engineer logs less often than their first group counterparts.

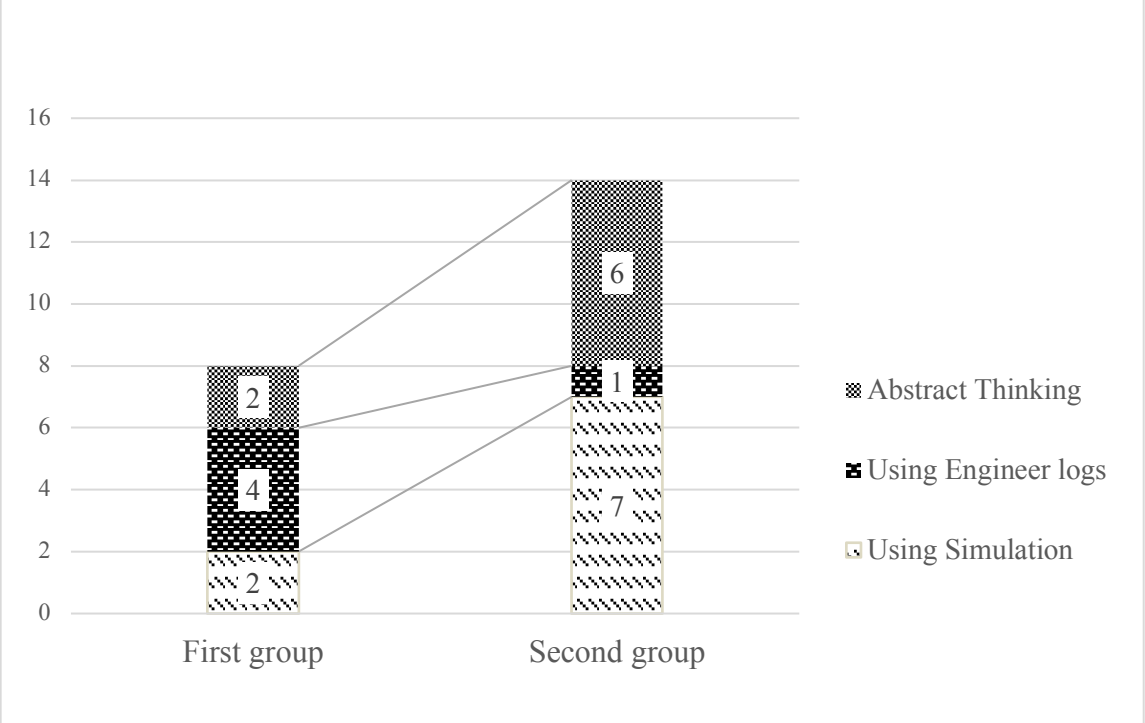


Figure 2.13 Comparing actors for programming between the first and second group

The number of children who used the engineer logs decreased for the second group. I was not able to find a convincing reason for this tendency. However, I suspect that the increasing abstract thinking skills and simulation strategies might have led the students to rely less on their engineer logs for successful programming.

Human Actors Contributing to Successful Programming

Abstract thinking. Some children used abstract thinking to figure out the Bee-Bot's working system without relying on additional resources or strategies, including the aforementioned simulation. Eight children (two from the first group and six from the second group) immediately noticed the Bee-Bot's working system by observing its movements, which, I think, might be related to abstract thinking and the spatial perception. Spatial perception helped the children to imagine their Bee-Bots' movements so that when a Bee-Bot made a turn or multiple turns, children with a better spatial perception seemed to be able to simulate the Bee-Bots' movements on an abstract level and press the right command buttons from the Bee-Bots' point of view.

Eight children out of 24 clearly showed a better sense of abstract thinking and spatial perception than their peers. According to the two enrichment class teachers, four of these children were identified as gifted. Some of these children seemed to use only their cognitive thinking skills when programming the Bee-Bot. For example, as described in the vignette presented below, Cristian and Issac mainly used their abstract thinking and spatial perception to program their Bee-Bots:

Vignette 2.3 Cristian and Jayden's programming in the Bee-Bot session 1

Cristian is sitting on the floor, and a route (forward-forward-turn right-forward-forward), a written direction board, and his engineer log are placed in front of

him. He looks at the written direction and his engineer log. Cristian picks up the Bee-Bot and brings it to the starting point on the route. His partner Jayden looks at the written direction and lets Cristian draw the route first in his engineer log. Jayden presses the command buttons, but the Bee-Bot does not show a response because it is turned off. Jayden turns it on and tries but hesitates to push the command buttons. Cristian presses the forward and the go buttons. Immediately, the Bee-Bot moves one step forward with beeping sounds and blinking lights, and it stops. Cristian again presses the go button, and it moves one more step forward and stops. At the point where the Bee-Bot needs to turn right, Jayden again hesitates to press the buttons. Cristian presses the clear button and brings it to the starting point. Cristian presses two forwards and two right turn buttons (*Note*: The correct programming requires two forward buttons, one right, and two forward buttons). The Bee-Bot stops at the turning point after turning 180 degrees instead of turning 90 degrees and moving forward. Cristian notices this, brings the Bee-Bot back to the starting point, and presses the five correct command buttons. The Bee-Bot successfully arrives at the final destination on the route.

As shown, when Cristian's Bee-Bot stopped at a turning point, he immediately recognized that a right command button made the Bee-Bot turn 90 degrees in that direction without moving forward. After making this error, he reset the Bee-Bot and started to press the command buttons again. Cristian seemed able to think abstractly and remember the sequence of commands that his Bee-Bot needed.

In the case of Kaity, she appeared to improvise her strategic skills while still using abstract thinking skills. She figured out how the Bee-Bot worked by reviewing the written instructions provided by our research team, reading her engineer log, and listening to the teachers' explanations. As presented in the following vignette, she first read the written instructions and the directions in her engineer log. Then, she voluntarily asked Sung-eun to come and check what she had done.

Vignette 2.4 Kaity's programming in Bee-Bot session 1

This is the first session of the Bee-Bot class with the second group of children. Kaity is sitting on the green tiled floor with her partner, Jayden, having a full size poster sheet, a written direction board, and an engineer log in front of her. She carefully reads the written directions which explain how to control a Bee-Bot by using the directional command buttons. Waiting for the Bee-Bot, Kaity quickly looks through her engineer log. She also looks at Sung-eun, one of our research team members, who says to the class, "Are you ready? If you are ready, I will bring the Bee-Bot." Kaity raises one hand to show that she is ready. Ms. White brings a pencil for Kaity and Jayden. They write their names on their engineer logs. Sung-eun brings the Bee-Bot and puts it on the poster sheet. Kaity picks the Bee-Bot up and looks at the bottom of it. She turns the switches on, one for power and the other for sound. She puts the Bee-Bot back on the paper and presses two forward buttons followed by the go button. The Bee-Bot moves two steps forward with beeping sounds and blinking lights. Then, she presses the clear button to reset the program. She puts the Bee-Bot beside her and starts to write on the engineer log. When she completes her engineer log, she goes to

Sung-eun and brings Sung-eun to her place. Sung-eun checks Kaity's engineer log and then draws a route, forward-forward-turn right-forward, on the poster paper with a pencil. Kaity presses two forward and two turn buttons. Her Bee-Bot moves two steps forward and turns 180 degrees without moving forward. She immediately brings the Bee-Bot back to the starting point and presses two forward steps, a right turn, and one forward step with the go button. The Bee-Bot smoothly goes through the route. While Sung-eun observes her, Kaity programs her Bee-Bot again, pressing two forward steps, a right turn, and another forward step followed by the go button. Again, the Bee-Bot successfully goes through the route.

For Kaity, not only observing the Bee-Bot's movements but also using additional instructional materials (e.g., the written instruction, an engineer log) and the teacher's confirmation were helpful for her programming. Interestingly, Kaity kept her eyes on Sung-eun. It might have been her strategy to communicate closely with the adult about the tasks so that she had a better understanding of them. Thus, in the case of Kaity, her abstract thinking and sequencing skills combined with her strategies, including carefully reading both the written instruction and her engineer log and checking with the teacher, contributed to her programming of the Bee-Bot.

Comments by adults. As mentioned earlier, in the route activity three adults–Dr. Lee, Sung-eun, and Ms. White–often provided each child or each group with feedback. These adults worked with 12 children for each session. Although I didn't quantify the comments given to each child or group, the majority of the children received comments from the adults. In each session Sung-eun explained the activity to the whole group

before they began to work in pairs or in small groups. Arranging the activity materials, the adults talked with the children. Specifically, the three teachers reminded the children to reset their previous programming (e.g., "You need to press the clear button first") or to document their work in their engineer logs (e.g., "Draw your route in your engineer log and count how many steps your Bee-Bot needs to move"). In addition, each adult reminded the children to read the written instructions provided at their tables. Vignette 2.5 shows how Ms. White taught Felipe to think about programming his Bee-Bot by using his engineer log.

Vignette 2.5 Felipe and Jorge's programming in Bee-Bot session 1

Felipe and Jorge are sitting side by side on the green tiled floor with two clipboards, two pencils, a route board, and two engineer log sheets. The two boys are working on the route that needs a total of five command buttons (forward, forward, turn left, forward, and forward). They read the directions written in their engineer logs and copy the route in their logs.… Felipe cautiously starts his first programming with the Bee-Bot, and soon afterwards his Bee-Bot stops at the point where its head *turns left*. Felipe says, "Oh!" He grabs his Bee-Bot immediately. Jorge carefully observes how Felipe programs the Bee-Bot. When Felipe grabs the Bee-Bot and brings it to the starting point, Ms. White tells him, "*Okay. Stop and think what you did.*" Felipe puts the Bee-Bot on the route board and looks at his engineer log. Ms. White again says, "Write what you did [in your engineer log]." The teacher points to the place in the engineer log where the children record their command button arrows. Felipe writes his written commands in his engineer log, and Jorge copies Felipe's written commands for

his engineer log. Ms. White tells Jorge, "You don't need to copy him. You can make yours." Jorge erases his written commands and tries to program the Bee-Bot by himself. Jorge presses the two forward command buttons, and Felipe immediately intervenes and presses the clear button. While Jorge looks at the route and thinks, Felipe asks Jorge, "How many commands do you need?" Without responding to Felipe, Jorge presses the command buttons: forward, forward, left (turn), forward, and forward. Jorge's Bee-Bot goes successfully through the route to the destination at once. Jorge giggles. Felipe exclaims, "Oh!" and Ms. White suggests again, "*Copy them [commands that you pressed] in your engineer log*." Felipe points at his written commands (↑↑←) to solicit the teacher's suggestion, "What [should] I do here?" Ms. White points at his written commands and tells him, "You need to change it. One is not right." Felipe does not understand what she means. Ms. White explains, "What happens if you only have these three group (commands)?" She points to the route and asks, "How many commands do you need?" Felipe says, "I am going to need two forward (buttons) and one right and . . ." He mumbled some words. Jorge immediately responds, "Five! Five! Five!" Ms. White confirms what Jorge said, "Right." Felipe points to the route by using his pencil and says, "One forward and another forward." Ms. White follows him, "Yes!" Felipe again starts to press the command buttons–forward, forward, (turn) left, and forward. The Bee-Bot moves two steps forward and turns left with a beeping sound. However, the Bee-Bot stops after moving only one step forward. Felipe says, "Oh, oh." Ms. White tells him, "Okay, how many forwards do you need [after you turn left]"

Felipe responds, “Two,” and Ms. White confirms, “Yes, two forwards.” While Felipe edits his written commands in his engineer log.

Sometimes an adult sat with a small group of children to see if they needed advice for their programming. When the children repeatedly made errors, the adult’s timely comments were most effective. As described in vignette 2.5, when Felipe and Jorge failed to program the Bee-Bot, Ms. White asked them to stop their repeated trials and think about how to find errors in their programming by using their engineer logs. After several trials, Felipe still struggled with figuring out how to program a Bee-Bot in order to make it turn right or left and move forward. Ms. White used Felipe’s engineer log to provide guidance for him. Her comment was critical and timely because Felipe might have given up due to his repeated failures.

Learning from peers’ trials. I noticed that some children tended to mimic their partner’s or groupmates’ trials when using the command buttons (e.g., a clear button, right/left turning buttons). At times, they also copied their partner’s commands written in the engineer logs. Interestingly, when each member performed at similar levels, the group work was not necessarily helpful to solve problems. Instead, if one of them had an advanced understanding, the heterogeneous ability grouping contributed to solving the problem faced by the group. This does not necessarily mean that the children who had a better understanding helped their peers; rather, the children were able to learn from both successful programming and mistakes from one another. Grouping was an actor associated with the children’s performance (Lleras & Rangel, 2008; Smutny, Walker, & Meckstroth, 2000).

Discussion

The goal of this chapter was to identify heterogeneous actors associated with the participating children's successful programming in the Bee-Bot route activity. The results revealed that seven actors contributed to successful programming while two actors constrained the children's programming (see Table 2.2). Drawing on Latour's (2005) ANT, I regrouped the contributing and constraining actors into material, human, and quasi-human/quasi-material actors. Material actors included the Bee-Bot's bee-shaped design and control system and use of engineer logs which contributed to programing; the reset button and the turn left/right turn buttons challenged the children's programing. Quasi-human and quasi-material actors consisted of the use of simulation, and prior experience with robotics. Human actors included the use of abstract thinking, the adult's comments, and peer demonstrations, which led to the children's programing. From these findings, I learned that associations of some of these actors were stronger (e.g., use of engineer log–comments by adults, use of simulation–use of abstract thinking–prior experience with robotics) than relationships among other actors (see Figure 2.5).

Table 2.5

Actors Associated with Programming

Material actors	Quasi-human and quasi-material actors	Human actors
Bee-Bots' bee-shaped design and control system	Use of simulation	Use of abstract thinking
Use of engineer log	Prior experience with robotics	Comments by adults
Confusion with the turn button		Peers demonstrations
Failure to push the reset button		

Based on these findings, I have gained the following insights. First, tracing actors by using Latour's (2005) ANT helps us appreciate material and quasi-human/quasi-material actors, which are associated with children's learning and performance. In particular, grouping material and quasi-human/quasi-material actors encouraged me to recognize that teaching and learning cannot be fully understood just by considering human actors. Instead, we need to pay attention to the importance of understanding that the material actors and actors situated in-between human and material were interwoven in teaching and learning.

Second, previous studies (Chun-Wang et al. 2011; Levy and Mioduser, 2008; Strawhackers & Bers, 2015) examined the use of robotic manipulatives by considering a single factor (e.g., sequencing, computational thinking, or programming ability) rather than examining the associations of multiple elements. In those studies, robotic manipulatives are treated as passive media, which are used to teach children about specific concepts or skills. Using ANT (Latour, 2005) encourages us to appreciate the relationships or associations among actors. Fenwick and Edwards (2010) stated that ANT leads us to focus on the individual nodes holding the networks or relationships together and on examining how the connections came about and what sustains them. For instance, the use of engineer logs is closely related to the adult comments, as the children attempted to use the engineer logs mostly when their teacher guided them to use the logs. Thus, the use of engineer logs cannot be treated as an independent variable influencing children's performance.

I acknowledge the limitation of my analysis used for this chapter. Highlighting the role of material and quasi-human/ quasi-material actors in children's learning and

distinguishing between contributing and constraining actors are contradictory to the principle of Latour's (2005) ANT. From Latour's perspective, heterogeneous actors, including human actors, material actors, and quasi-human/quasi-material actors, are closely associated with each other in learning about robotics. Therefore, separating one of the actors or grouping several actors from the network is challenging and does not fully describe what is involved in children's learning. In this chapter I intended to highlight the agency of material, human, and quasi-human/quasi-material actors and their heterogeneous associations. In order to show their heterogeneous associations, I could not avoid separating (e.g., contributing and constraining) and combining them as a process throughout this paper. Even if my intention was to move beyond the human centered perspective, it was challenging to avoid it. These limitations confirm the importance of tracing all heterogeneous actors associated with children's learning without attempting to separate them.

CHAPTER 3

CHILDREN'S ROLES IN PROBLEM-BASED ROBOT BUILDING ACTIVITIES

This chapter investigates the process of designing and building a robot to understand how the participating children performed various roles (e.g., a recorder, a builder, and an idea generator) in a problem-solving robotic activity. This engineering design activity was offered to the second group of 12 children during the last Cubelet session.[3] This activity was provided to the children in order to understand what problems they were able to generate and how they applied the functions of Cubelets to their problem-solving.

In this activity, the participating children worked in pairs or in small groups of two to three. Our research team encouraged each group to choose one person as a recorder, who would document their design process in the engineer log. Except for the recorder, we did not specify what roles the remaining group members should play. Thus, the children were able to flexibly create, choose and perform roles necessary to define a problem as well as to design and build a robot solving their group problem. The central questions for this chapter include: 1) How do the children in each small group negotiate with and perform different roles? 2) How do their different roles contribute to identifying a problem and to designing and building a robot?

[3] Detailed information about participants is presented in the research methods section.

Reviewing Literature

Engineering Design as an Instructional Model

Integrating engineering into science education has been emphasized by the Next Generation Science Standards ([NGSS], 2013). According to NGSS (2013), the term *engineering* does not necessarily mean a subject area; rather, it can be applied to designing learning activities or learning models in education. In the field of technology education, there are increasing needs to integrate an engineering-design-based approach to instruction (Denson, Kelley, & Wicklein, 2009).

To promote children's competence in problem-solving, engineering design has been integrated into curriculum, standards, and classroom practices in science and technology education (Daugherty & Custer, 2012). Engineering design has been emphasized for content knowledge and pedagogies (National Research Council, 2013). NGSS (2013) explained that engineering design could be used for problem solving, which includes defining problems that people want to solve, generating multiple solutions, testing solutions, and optimizing solutions. NGSS divided the levels of engineering design into K-2, 3-5, and 6-8 grades and argued that, for young children in kindergarten through 2nd grade, engineering design allows them to identify problems around them and use tools and materials to solve the problems.

Daugherty (2012) conducted a focus group with 15 experts in STEM to explore how to infuse engineering concepts into an instructional design process. His study showed that engineering in the K-12 environment means a "way of thinking," and engineering practices assist "habits of mind" (p. 7). The participating expert group explained that inquiry and design are tools and that students should learn how to decide

which tool is needed in problem solving. The experts shared that "engineering could offer design contexts for a problem based approach to instruction" (p. 7).

Performing Roles in STEM Learning

Few studies have investigated how children (4-8 years old) perform various roles in problem solving activities. I expanded the literature review by focusing on gender and STEM learning in order to get a glimpse of what has been studied in relation to children's role performance.

Gender gaps in STEM learning. In STEM education, gender gaps in a learner's interest and motivation were studied among kindergartners (6-7 years old) (Patrick, Mantzicopoulos, & Samarapungavan, 2008) and in pre-kindergartners to second graders (4-7 years old) (McKenney & Voogt, 2010). Studies revealed that STEM curriculum for girls was not effectively designed and implemented. Heybach and Pickup (2017) critiqued that curricula for girls in STEM are marketed to girls and women by including feminine design (e.g., colored pink) without altering anything substantial in scientific practices. According to Betz and Sekaquaptewa (2012), role models in math and science are demotivating to young girls in general and to girls who are already not interested in STEM in particular.

As a way of broadening participation, Buxton (2006) argued that an authentic science inquiry model should tap into the strengths of a youth-centered model which is grounded in student-generated inquiry. Eisenhart (2001) emphasized that educators should consider the potential power of middle-school girls' culture in order to provide opportunities for them to enhance skills and competences in science and technology. There is little research examining learning in STEM, which focuses on how girls or other

underrepresented groups of children in primary grades (K-2nd) perform. My dissertation study closes this gap by examining how boys and girls in a second-grade classroom participated in the problem-solving activity.

Gender stereotypes. Gender stereotypes influence women's performance and their self-concepts of future careers relevant to STEM (Steffens & Jelenec, 2011). In the subject of mathematics, for example, when gender stereotypes were salient in a situation, math performance outcomes declined for females regardless of their level of performance (Keller, 2002; Smith & White, 2002).

Gender stereotypes have dominated science and mathematics education. In Jones and Myhill's (2004), the participating students (six elementary students, three middle students, and one high school student) revealed their stereotypical beliefs, including how girls behave better and are more compliant than boys. The students described girls as doing hard work, while perceiving boys as born with better abstract thinking and thus having more strategies for science and mathematics. Kessels (2015) summarized research on stereotypes about STEM and girls by using empirical data of 135 9th graders' self-presentations. The author argued that there is a mismatch between stereotypes about STEM learning and girls' self concepts. In the study, males tended to choose their career options related to STEM after having positive feedback on physics, whereas females did not choose STEM-related careers even after receiving highly positive feedback on their physics ability. In this chapter, second graders role negotiation in robot construction shows whether gender is associated with the robot building process. If gender is one of the influencing actors, this chapter will show how it is associated with activity.

No gender difference. Despite many studies that examined and revealed gender differences, McKenney and Voogt (2010) found no gender difference in children's competence in using computers. Studying 167 pre-K through 2nd graders through one-on-one interviews, these authors revealed that boys' attitudes towards computers were more positive than the attitudes of girls. Nonetheless, these differences in attitudes did not lead to gender differences in these children's school computer use. In addition, no gender differences were found in the ability level of performing various computer activities.

Master, Cheryan, Moscatelli, and Meltzoff (2017) examined 96 6-year-old children's gender stereotypes about STEM fields and tested an intervention to promote girls' motivation for STEM. Their study revealed that girls who experienced programming showed a higher technology interest and self-efficacy and did not show a significant gender gap relative to boys' interest and self-efficacy. When the children revealed gender stereotypes (i.e., boys are better than girls at robotics), the authors implemented intervention sessions for the girls to see if the intervention made a difference. Master et al. explained that gender differences in young children's motivation of using technology are influenced from specific experiences because the girls from the treatment group showed a large increase in interest and self-efficacy.

As shown, although many studies have examined gender gaps and gender stereotypes in STEM learning, few studies have focused on how children negotiate with and perform certain roles in the STEM learning process. This study closes the gap in the existing studies by exploring how boys and girls negotiate their roles and contribute to

generating problems, designing and building robots, revising ideas, and recording their problem identification and problem solving process.

The Study

Contexts

As explained earlier, in our robotics project we had two classes, including a Bee-Bot class and a Cubelet class, and each class had four sessions. In this chapter I focus on the fourth session of the Cubelet class. Four sessions of the Cubelet class are described in Table 3.1. In the first session, the participating children learned about three basic Cubelets, including a distance sensor, a light actor, and a battery. In the second session, the children explored different sensors, including a distance sensor and a light sensor (see Figure 3.1), through experimentation with various actuators called actors (e.g., a drive actor, a light actor, a bargraph actor, and a sound actor).

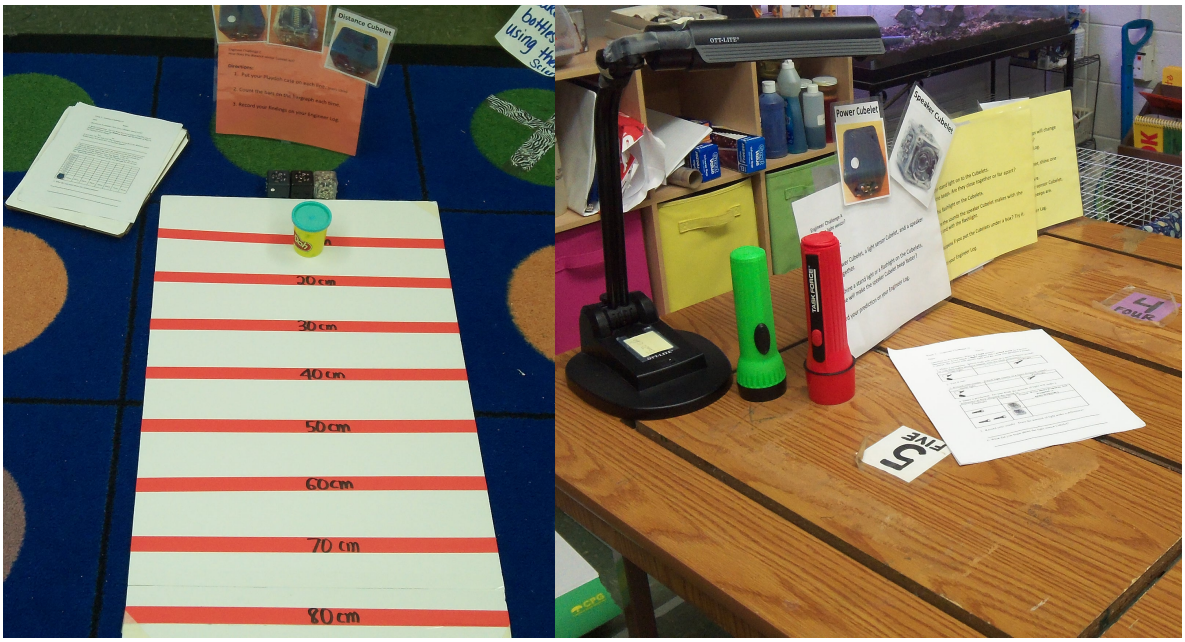


Figure 3.1 A distance sensor activity (left), a light sensor activity (right)

Table 3.1

Four Sessions and Activities in the Cubelet Class

class	session	activities	materials
Cubelet	1. What is a Cubelet?	1) Learning about three basic Cubelets (battery-sensor-actor)	Engineer log 1, pencils, Cubelets (a battery, an object detector sensor, a light actor), written directions, a question board
	2. Sensor	1) Learning about a light sensor 2) Experimenting a distance sensor	Engineer log 2, pencils, Cubelets (a battery, light and distance sensors, light and speaker actors), written directions, a question board, desk and flash lights, cellophane, activity foam boards
	3. Building a robot	Building a Cubelet robot that solves a problem given by the research team	Engineer log 3, pencils, Cubelets (a battery, light and distance sensors, light/speaker/bargraph/ rotate/drive actors), activity foam boards
	4. Building a robot with tasks	Building a Cubelet robot that solves a problem identified the group	Engineer log 4, pencils, Cubelets (a battery, light and distance sensors, light/speaker/drive actors), activity foam boards

In the third session, the children built robots to solve two problems our research team provided for them. The problems presented to the children are as follows:

(1) A post officer cannot push heavy items because his back is badly injured. Please build a robot to help the post officer push heavy boxes (wood blocks) (see the left photo of Figure 3.2).

(2) Animals that live in areas where people live tend to cross the road at night and, unfortunately, many of them get hit by cars. Please build a robot that can warn animals that a car is nearby detecting a car's headlights (see the right photo of Figure 3.2).

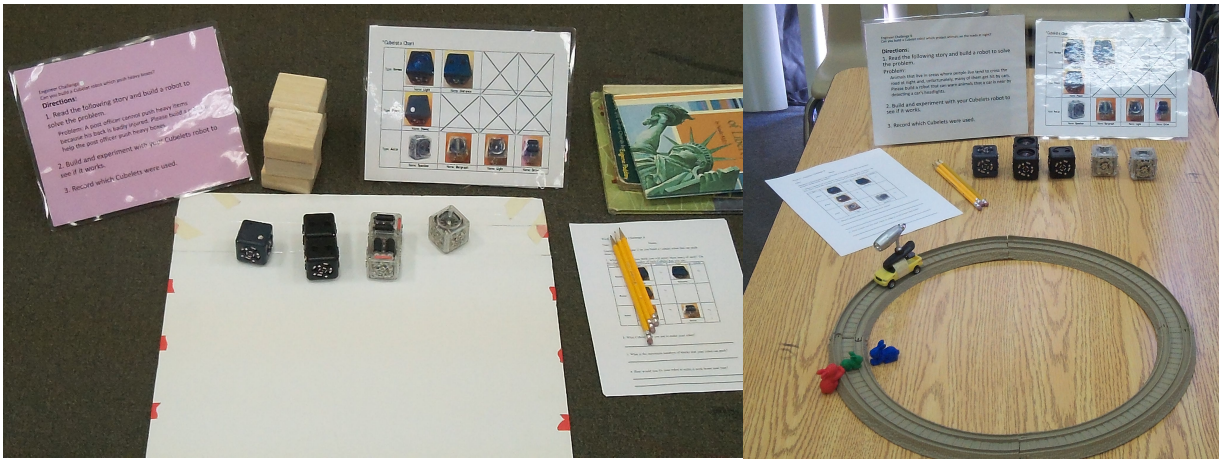


Figure 3.2 A problem solving activity

For this task, the children were asked to choose a sensor and two or more actors to build a robot. We offered these pre-designed problems to the children as scaffolding before requiring them to identify and solve their own problems. In the fourth session, each small group was asked to identify and define its own problem and build a Cubelet robot to solve the problem. In the third and fourth sessions, the children were expected to apply what they had learned about the functions of different sensors and actors to their design of a robot. Table 3.2 presents the problem identified by each group and the robot built to solve each group's problem.

Due to the limited number of Cubelets that our research team had, we distributed a specific set of Cubelets to each group. Each set included one battery, two sensors and three to four different actors. When the children asked, additional actor Cubelets were offered. Each group had an engineer log (see Figure 3.3) to plan and record their process. In the engineer log, the children were asked to record sensors and actors used for their group robot design. In each group, one recorder took charge of documenting the process in the engineer log.

Table 3.2

Each Group's Problem and Robot Design

	Group 1 (Caleb, Isaac and Emma)	Group 2 (Josue, Hector and Craig)	Group 3 (Madison and Josh)	Group 4 (Sara, Nora and Eliana)
Problem Identified	Waking up in the morning	Bullying	Debris on the road	Mailman broke his leg and his truck broke down
Solution Generated	Robot alarm clock which has a light and can move closer as needed	Robot that detects a bully	Robot bulldozer	Robot that drives mailman around to deliver the mail
Cubelets Used	Distance sensor, light sensor, drive actor, sound actor, light actor, and battery Cubelets	Distance sensor, light actor, sound actor, drive actor, bargraph actor, and battery Cubelets	Distance sensor, light sensor, drive actor, light actor, bargraph actor, and battery Cubelets	Distance sensor, drive actor, sound actor, and battery Cubelets

Note: Several children asked for additional Cubelets, so each group had different numbers of the manipulatives.

Data Sources and Data Analysis

As explained earlier, we divided the class into two groups with 12 children per group. Each group spent four weeks with one type of the robotic manipulatives before switching the materials. The first group of 12 children needed extra time to complete the first three sessions of the Cubelet class; thus, they did not have a chance to identify their own problems and build robots to solve their problems. As a result, we were able to implement the activity designed for the fourth session only with the second group of 12 children. For this chapter, I focused on the data collected with these 12 children in the second group. In particular, I used 2 hours and 15 minutes of videos recorded during the fourth session of the Cubelet class implemented with the second group of children.

Question to Investigate: **Can you build a Cubelet robot that can solve a problem?**

1. **Read the following directions.**
   Your group needs to complete planning and building your robot within 25 minutes. You can build your robot by using the Cubelets given to your group.

2. **Design your robot.**
   (1) What problem will your robot solve?

   _____

   (2) Which of these sensors will your robot need? Circle.

   Light Sensor Distance Sensor

   (3) Which of these actors will your robot need? How many? Circle the number.

Type	Name	Number	Name	Number
Actor	Light	0 1	Bargraph	0 1
			Drive	0 1

   (4) What will your robot look like? Draw your robot.

3. **Build a robot to solve the problem & Record your results.**

   (1) Build and experiment with your Cubelets robot to see if it works.

   (2) Which sensor did you actually use? Circle.

   Light Sensor Distance Sensor

   (3) Which actors did you actually use? How many? Circle.

Type	Name	Number	Name	Number
Actor	Light	0 1	Bargraph	0 1
			Drive	0 1

   (4) How well did your robot work? Check.

   ( ) Very well ( ) Well ( ) Not well

   (5) Which part of your robot would you like to change to make it work better?

   _____

Figure 3. 3 An engineer log for problem identification and robot building

Two small groups worked at the tables and two groups worked on the floor, and these groups were captured by four different video cameras. Data was analyzed by

microanalysis of video data (Graue & Walsh, 1998) and constant comparison inquiry (Butler-Kisber, 2010). Each group activity was transcribed. Transcribed data was analyzed in order to understand how children's roles were negotiated and performed in each group. Findings were coded and categorized through constant comparison inquiry.

Findings

The 12 children from the second group worked in small groups of two to three. The majority of activities in the robotic class except for pre- and post-instruction drawings and writings were designed for small groups or pairs. As presented in Table 3.3, this problem identification and solving activity was designed by two different groupings: mixed gender and same gender. These groupings were planned by our research team based on the children's implementation and gender. In the mixed gender groups, two boys and a girl were in group A, and a girl and a boy were in Group B. In the same gender groups, three girls were in group C, and three boys were in group D.

Table 3.3

Grouping of the Children

Gender	Group	Participant
Mixed-gender	Group A	Caleb (m), Issac (m), Emma (f)
	Group B	Madison (f), Josh (m)
Same-gender	Group C	Sara, Nora, Eliana (all female)
	Group D	Craig, Hector, Josue (all male)

Note: (m) signifies a male and (f) signifies a female.

A Recorder as a Collaborator and an Idea Generator in the Mixed-Gender Group

The children in the mixed-gender group and the same-gender group showed different patterns of role taking and performing in their robot design and building

process. On the surface, in the two mixed-gender groups, the boys tended to be the robot builders whereas the girl performed the role of the recorder. I paid particular attention to the girls in the mixed-gender groups to understand how they performed their roles. In Vignette 3.1 presented below, Emma with two boys (Caleb and Issac) participated in generating and defining the group problem:

Vignette 3.1 Caleb, Issac, and Emma's Robot building in the Cubelet class

Isaac, Caleb, and Emma stand around the rectangular, wooden table. Emma holds a pencil, and the engineer log is located in front of Emma. Isaac picks up a drive actor and keeps touching the wheels. Caleb grabs three Cubelets (a battery, a light sensor, a light actor) given to the group and looks at each side of the manipulatives. Caleb puts the Cubelets back on the table, but he keeps touching them with his left hand while reading written directions in the engineer log for the day. He then asks, "So what should our problem be?" Isaac immediately responds, "I don't know." Then, holding up the drive Cubelet, he says, "I can't reach high places," and he makes a sound, "Shu-Shuuuuu." Receiving no response from his teammates, he dismisses that idea with a shake of his head, "No." He says something (inaudible) to Emma, and she hits Isaac's arm as if to let him know she doesn't like the idea. Isaac mumbles and says, "No. Just for stories." Emma again hits Issac's arm. Issac looks at the camera and smiles. Holding a drive Cubelet, Isaac looks at Emma and says, "I need a robot to make me wake up in the morning." Emma turns her head to Caleb to see how he responds. Putting two Cubelets together, Caleb responds, "Oh, I got it. I got it. I got it. I got it." Emma quickly moves closer to the table and picks a light actor

Cubelet, while Caleb grabs all the other Cubelets. Caleb puts a drive actor, a battery, and a distance sensor in a line. Emma stretches her hand to Caleb's construction of the Cubelets, then she stops at some point. Emma looks at Caleb's Cubelets construction. Caleb looks at Emma and says, "We can make it move." Isaac gets excited, "Make, make it move. Oh, we can make it move. Move into my nightstand."

In this vignette, Caleb and Issac shared ideas (e.g., waking up in the morning, making their robot move) about their problem and robot design. Both boys attempted to confirm their ideas with Emma, and she used non-verbal gestures (e.g., hitting Issac's arm, turning her head to Caleb as if she was asking his opinion, making eye contact with Caleb) to express her disapproval or agreement.

In the following vignette, Emma's engagement increased. She carefully listened to the two boys' conversation about the need to add a speaker Cubelet.

Vignette 3.2 Caleb, Issac, and Emma's Robot building in the Cubelet class

When Caleb attaches four Cubelets (a battery, a distance sensor, a drive actor, and a light sensor), Isaac grabs a pencil and says, "Wait! *We need a speaker* [Cubelet]." Isaac looks at the Cubelets and asks, "*Do we have a speaker*?" He walks over to the teachers. Emma quickly takes Caleb's construction of the Cubelets robot and detaches them one by one. She carefully looks at each Cubelet. Caleb takes the Cubelets robot back. Emma picks up the other two Cubelets from the desk, looks at them, holds a light sensor, and mistakenly says, "This is the speaker." Caleb corrects her, "It's a sensor." Emma responds, "Are you sure?" Caleb and Issac walk to Ms. Bridges, while Emma manipulates three

Cubelets and finally puts them in a vertical shape. The Cubelets construction lights up. Caleb comes back and sees the lights on the Cubelets.

In Vignette 3.2, Emma wanted to contribute to building the robot, so she tried to help find a speaker. Her engagement became more active than the previous interaction with her male groupmates. While Caleb and Issac went to Ms. Bridges to look for a speaker Cubelet, Emma built a Cubelets construction, which lit up. Caleb came back and watched the light on the construction, and this light became the motivation for their final artifact, a "robot alarm clock" which has a light and can move closer as needed. Although Emma's non-verbal communication in the problem generation process made her contribution difficult to notice, she still actively participated in defining a problem and building a robot with her groupmates.

In the mixed-gender group B, two children (Madison and Josh) were twins, and another student placed in this group was absent on that day. The twins worked as partners for the first time in the Cubelet class.

Vignette 3.3 Emma and Josh's Robot building in the Cubelet class

Madison and Josh stand on each side of a rectangular wooden table. Madison reads an engineer log, and Josh looks it over from the other side of the table. Josh looks around to see the other groups. Madison picks a pencil from a pencil case. I come to the table and ask, "Who will be the recorder (of the engineer log)?" Josh points to Madison. Josh picks a drive actor and pushes it with his hand. Madison writes her and her twin brother's names in the engineer log.

As shown in this vignette, Josh attempted to become a builder and assigned the role of a recorder to Madison. In the following vignette, Josh tried to generate ideas for his group problem by using a cylinder-shaped pencil case.

Vignette 3.4 Emma and Josh's Robot building in the Cubelet class

Josh picks up a drive Cubelet and pushes it on his hand. Coming to this group, I see Josh's trial and say, "Be careful. If you push the drive Cubelet [with your hand], it may not work well." Josh puts it on the table. I move to another group. Madison excitedly walks around the table and comes close to the Cubelets. She picks up a drive Cubelet in her right hand, while she picks up and looks at the other Cubelets. After looking at each Cubelet, Madison still holds a drive Cubelet and says, "Oh. This [drive Cubelet] is good." Josh looks at Madison and picks up a pencil case which has a cylinder-shape and has almost 10 pencils in it. He tilts the pencil case while he talks, "So. What…if…this pencil case tilted over and the pencils fell out?" Madison gazes at the pencil case. Josh looks at the Cubelets and says, "What would you do?" Madison still holds a drive Cubelet, and Josh comes close to her, "*Come on*." Madison hands the drive Cubelet to Josh and quickly comes back to her place. Madison grabs all of the pencils and pulls them out of the case. She suggests, "Okay. What if all these pencils are pulled out, and the Cubelets push them all away?"

Madison excitedly walked to the Cubelets and looked at each of them. Josh asked her to be engaged in generating ideas about their group problem (e.g., "What would you do?" "Come on"). Josh initially generated an idea about a tilted pencil case, but after moving back to the position, Madison elaborated on the idea and refined their problem (e.g.,

"What if all these pencils are pulled out, and the Cubelets push them all away?"). Here, Madison's role was crucial not only to recording the process of their activity, but also to confirming and refining ideas for the definition of a problem.

In these mixed-gender groups, initially the boys assigned the seemingly passive and insignificant role of a recorder to the girl, but both Emma and Madison turned their role as a recorder into an influential position through which they were able to engage in approving and defining their group problems and robot designs.

Roles in the Same-Gender Groups

In the same-gender groups, roles were chosen differently. In both the boys' and girls' groups, a dominant child became the main builder, while another member in each group voluntarily took the role of a recorder.

The recorder as an problem identifier. In group C, three girls (Sara, Nora, and Eliana) worked together. Eliana recorded in the engineer log, and she queried teammates to be engaged in generating ideas for their group problem.

Vignette 3.5 Sara, Nora, and Eliana's Robot building in the Cubelet class

Eliana writes the date and her group members' names on the engineer log. Eliana asks Sara and Nora, "What is our problem?" Nora looks at Eliana and takes Eliana's engineer log. Eliana asks again, "What is going to be our problem?" Nora brings back the engineer log to Eliana. Eliana says, "A mailman needs to push some boxes." She continues, "A mailman…needs…but he can't." Sara adds, "Because…the mail truck doesn't work anymore." Eliana starts to write, stops to think, and says, "He needs to carry something."

In this group, Eliana, Sara, and Nora did not verbally negotiate their roles, but, as shown above, Nora mainly manipulated the Cubelets and Eliana wrote their names in the group engineer log. As Eliana was documenting the group work process in the engineer log, she suggested an initial idea of a mailman faced by a challenge. This idea was expanded by Sara (e.g., "Because…the mail truck doesn't work anymore"), and Eliana further elaborated on the idea (e.g., "He needs to carry something"). These ideas were all used later for the group's problem definition (i.e., "Mailman broke his leg and his truck broke down") and for the functions of their robot (i.e., Robot that drives mailman around to deliver the mail). While Nora manipulated the Cubelets, Eliana discussed ideas with Sara to define the problem that was resolved by their robot.

In Group D, after discussing ideas about their robot, Craig announced that he would be the recorder, as presented in the following vignette.

> Vignette 3.6 Craig, Hector, and Josue's Robot building in the Cubelet class
>
> Craig, Hector, and Josue sit on the floor with their Cubelets (a drive actor, a light actor, a speaker actor, a distance sensor, a light sensor, and a battery) on a foam board. Hector asks Craig and Josue, "What is the problem you all wanted to solve?" After a pause, Craig responds, "People being mean at school." Hector considers how to make a robot that "senses bullies." Craig takes the engineer log from Hector, and Josue puts the drive Cubelet down on the foam board. Craig smiles and says, "He [Hector] chose me [to write in the engineer log]." Later, Shara comes to the group and says, "What problem are you drawing?" Craig smiles and says, "We are making a bullying detecting one." Shara nods. Hector

says to Shara that the bargraph detects the distance between the robot and the bully, drawing a line in the air with his finger.

In this group, Craig and Hector developed ideas together. The initial problem (i.e., "People being mean at school") was identified by Craig, and his idea was combined with Hector's sophisticated understanding of specific functions of the Cubelets (sensing, showing bars depending on input) for their robot design. Craig announced his intention to be the recorder after sharing his idea for the group's problem to solve. Regarding the problem Craig suggested, Ms. White gave us the contextual information related to these children's interest in building a robot to stop bullying:

> Ms. White: So there are bullies in both of [my and Josue's homeroom teacher's] classrooms, I hate to say it.
>
> Shara: And you've talked with the kids about bullies?
>
> Ms. White: Yes, we've talked. . . [Every] month our counselor has a counseling session with the kids, and the first thing she asks is, "Has anybody been bullied?" And sometimes it has already been resolved, but they still want to bring it up. . . [We] let them know that you can always tell somebody and not to be afraid to do that. . . The same thing's happening in [Josue's] classroom.

Ms. White explained that bullying was a shared concern among second-grade classrooms. Because of this ongoing issue, she "[wasn't] surprised" that Josue's group identified the problem of bullies. The second graders generated authentic ideas about problems they had experienced or were interested in. So, it is not surprising that Craig brought up the idea of bullying for their problem-solving robot because of the on-going classroom issue.

His attempt to link bullying to the problem solving activity may have implications in terms of designing curriculum.

In the same-gender groups, Eliana and Craig actively contributed to generating and elaborating on ideas. Their ideas were critical to their groups' robot designs and so the builders (Nora and Hector) were able to use these ideas by considering the specific functions for their robots.

Dominant builders. Nora and Hector mainly built their group robots. The builder in each group had assumed an active leadership role in his or her previous group work. For example, as shown in the following vignette, Nora dominated a Bee-Bot when she worked with two boys in the Bee-Bot route activity:

> Vignette 3.5 Nora, Josue, and Hector's Route activity in the Bee-Bot class
>
> In the third session of the Bee-Bot class, Nora, Josue, and Hector are in the same group. They sit on the floor, each holding an engineer log and a pencil. One route board is on the floor. Nora keeps a Bee-Bot close to her knee and puts the engineer log on her lap while holding the pencil in her right hand. Hector stretches his hand and touches the buttons on the Bee-Bot. Nora holds the Bee-Bot and moves her body backward, so Hector cannot touch the buttons. While Nora is documenting the command buttons in her engineer log, she keeps holding the Bee-Bot in her left hand. Nora puts her Bee-Bot at the starting point and pushes the command buttons, forward-forward. Hector looks at the Bee-Bot and quickly pushes the clear button. Nora shouts, "No!" She blocks Hector's

approach by using her hand. She holds the Bee-Bot and keeps it closer to her to program it.

As described above, Hector tried to touch the Bee-Bot's command buttons to see how the manipulative responded to those commands. Later, he pushed the clear button to delete Nora's program. Nora actively protected the Bee-Bot by blocking Hector's approach. In the Bee-Bot class and the Cubelets class, Nora dominated the manipulation of these tools in her groups. In the Cubelet robot building activity, Nora also dominated the Cubelets.

Vignette 3.6 Sara, Nora, and Eliana's Robot building in the Cubelet class

Sara, Nora and Eliana sit in a circle on the floor. Inside the circle, a light sensor, a distance sensor, a drive actor, a light actor, a speaker actor, and a battery are on the foam board. Nora pushes the wheels of the drive actor. While Eliana and Sara discuss the problem, Nora listens to their conversation, holds the drive Cubelet, and picks up the battery. She adds the speaker actor Cubelet to her creation. Nora puts down the speaker actor and picks up the distance sensor. Again, she detaches the distance sensor from her creation and picks up the light sensor to add it to her robot. Now the Cubelet combination is made up of a battery, a drive actor, and a light sensor.

Meanwhile, in the Cubelet class, Hector revealed his sophisticated understanding about sensors, actors and their relationships, as shown in the following vignette.

Vignette 3.7 Craig, Hector, and Josue's Robot building in the Cubelet class

Hector reaches out to the Cubelets that are resting on the board and starts indicating the drive actor Cubelet with his pencil. "We can put this with the sensor and it can move over there," he signals the other end of the board with his pencil and continues to share his ideas, "We can use the bargraph to show us how far away the bully is." Hector picks up the drive actor and swings it with his hand in the air. Josue moves his seat closer to the Cubelets. He grabs the drive Cubelet while Hector is checking the engineer log to see whether they have all the Cubelets presented in the log. Hector quickly looks at the Cubelets and sees Josue touching the drive actor.

Hector understood the sensor concept well and was able to apply it to design a robot which shows how far away the bully is. As seen in the above vignettes, Nora and Hector were actively engaged in their activities, and their strong willingness to manipulate the Cubelets made them work as builders in their own group activities.

Discussion

This chapter investigated how the 12 participating children negotiated with and performed different roles in their small groups during the problem identification and problem solving activity. In the mixed-gender groups, boys appeared to be the builders whereas the girls performed the role of the recorders. However, I discovered that these girls performed different roles: they were recorders as well as idea generators and idea supporters. In the same-gender groups, Eliana (from the girls' group) and Craig (from the boys' group) took on the role of the recorder; however, they also initiated ideas for their group problem identification and verbally articulated ways to design a robot and

solve the problems. Nora (from the girls' group) and Hector (from the boys' group), who were more competent in assembling the Cubelets became the builders. In these groups, these girls were actively involved in the robot building process and the engineering design process. In summary, the generated problems and elaborated ideas were heavily influenced by the recorders as well as the builders for each group's problem-solving and robot building activity. Whether they initially took their role as a builder or a recorder, each child's ideas and manipulation were interwoven through the robot building process, which included identifying problems, elaborating ideas, combining ideas into the design, and constructing a robot.

NGSS (2013) explained that engineer design could be used in problem solving, including defining problems or situations that people want to change, generating multiple solutions, testing solutions, and optimizing solutions through the construction process. In this study, defining problems and generating solutions were closely related to the process of robot construction. As problems and related stories were elaborated, robots were built with a sophisticated design and function. The findings of this study revealed that the recorders actively participated in identifying problems and generating ideas in order to construct a robot. The recorders' ideas and imagination greatly contributed to the robot construction. Eliana and Sara created the problem of how a mailman could not deliver mail due to his injured body and broken car, and these ideas influenced their robot building which became more sophisticated throughout the process. In another case, Emma, initially confirmed ideas as a part of the team and later voluntarily shared her ideas by demonstrating her own Cubelet construction. Engineering design in STEM emphasizes the fact that defining problems or generating solutions can guide the ways of

constructing and solving problems (NGSS, 2013), just as we saw with the recorders' idea generation in this study.

Dr. Chi Thai, a retired engineering professor at the University of Georgia, (personal communication, December 8, 2015) mentioned that students in engineering struggle to combine two areas of competence: software design and hardware construction. If a student performs well in the abstract thinking for computer programming, he or she often struggles with building hardware, or vice versa. In our activity, while some children generated ideas about how their robot could work, other children showed an interest in putting the manipulatives together to build their robot. Allowing children to perform various roles in the engineering design project might help overcome the struggle many engineers and engineering students experience with the two areas of competence.

The creativity of the girls (Emma, Madison, and Eliana) in this study sheds light on the fact that engineering design requires new ideas on design and imagining competences. Kelleher, Pausch, and Kiesler (2007) argued that incorporating creative elements into programming can motivate girls. In the study by Hanks, Fitzgerald, McCauley, Murphy, and Zender (2011), the researchers claimed that collaboration with peers and group programming increases girls' interest in technology. A variety of opportunities to collaborate in generating ideas may help close the gender gaps in STEM education.

The findings of this study have several implications for educational practice. First, the engineering education curriculum needs to be expanded to incorporate the engineering design process, including defining problems, generating solutions, testing

solutions, and optimizing solutions. Based on the results of this study, engineering designing process and idea generating activities can expand children's participation. Second, girls' subtle and verbal articulation should be appreciated and welcomed because they can contribute to the engineering design process. For children who do not have competence in hardware construction, other experiences (e.g., generating and elaborating on ideas for problem identification, documenting the design process, designing the final artifact) can be provided. Third, problem-based group activities allow children to explore different roles in engineering design, which may enable each child to discover his or her interest and strength. Performing various roles may also allow children to collaborate with their peers to solve problems and learn skills from one another. As Buxton (2006) suggested, children's authentic interests originating within their own lives make them more involved in scientific inquiry. In STEM learning, problem-based inquiry activities can motivate children to identify problems surrounding them and to find solutions for the problems.

CHAPTER 4

CHILDREN'S CONCEPTUALIZATION OF ROBOTS FROM THEIR DRAWINGS AND WRITINGS

In this chapter, I explore 24 second graders' drawings of and writings about robots to understand how children make sense of robots. In the previous robotics class in which our research team worked with young children (4 to 7 years old) at a community center[4], many participating children drew their robots with a human body shape having several mechanical functions (e.g., wheels on the feet, arms with swords). In this chapter, I try to understand how 7 to 8-year-old children understand robots' appearances and functions and look at whether their images of robots have changed because of the robotics class. Our research team designed the activities with pre- and post-instruction drawings and writings, and we also had a discussion session with the participating children after watching a video clip which showed the different shapes and designs of robots.

Context of the Robotics Class

In the first and the last session of our robotics class, 24 participating children were asked to respond to the questions and draw their images of robots in their engineer logs (see Figure 4.1). One child was absent in the post-instruction drawing and writing. The questions we posed to the children included: What is a robot? What can robots do?

[4] I explain the times and settings of the research project in detail in Chapter 1.

Figure 4.1 The engineer log used for pre- and post-instruction drawings and writing

Where can we find robots? Why do people build robots? How are robots similar to and different from other machines? In addition, they were asked to draw their image of robots and label each part. To understand the children's conceptions of robots, I

examined how they responded to each question and labeled each part of their robot drawings. We used the same engineer logs for both pre- and post-instruction drawings and writings.

Eight Sessions with Two Different Robotic Manipulatives

We offered a total of eight sessions of robotics class with two robotics manipulatives, Bee-Bots and Cubelets. For the activities, 24 participating children were divided into two groups: one group started with the Bee-Bot class, and the other group started with the Cubelets class. Each group spent four weeks with one type of the robotic manipulatives before switching to the other. The Bee-Bot activities were designed for children to control their Bee-Bots by pressing directional command buttons and to learn about basic programming skills (e.g., sequencing and debugging) by using grids, routes, and a maze (see Figure 4.2).



Figure 4.2 A route (left), a grid (middle), and a maze (right)

In the Cubelets class, the children explored the functions of three basic Cubelets, including a battery, a sensor, and an actuator, and their causal relationship (see the first photo in Figure 4.3). They also experimented with a distance sensor (see the second photo in Figure 4.3) and a light sensor to see how they work with different actuators, which light up, move around, make sound, and so on. In the third session (see the third photo in Figure 4.3), the children built robots to solve problems given to them by our

research team and in the fourth session (see the fourth photo in Figure 4.3), they solved problems created by themselves.

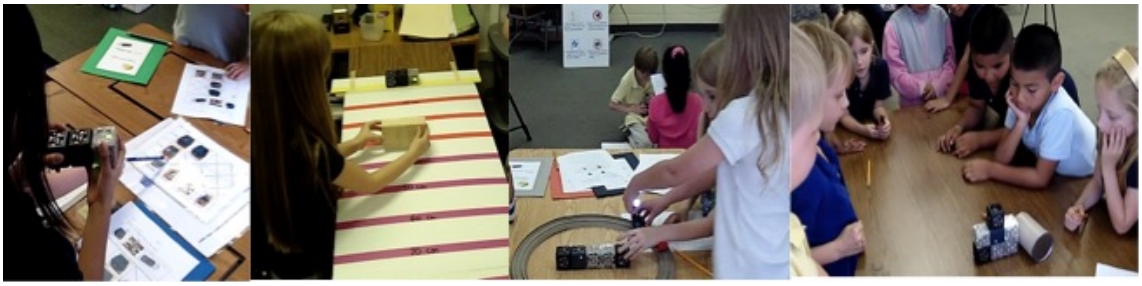


Figure 4.3 Experiencing three basic Cubelets (first) and a distance sensor (second), building a robot to solve a given problem (third) and solving a problem identified by the children (fourth)

Pre- and Post-Instruction Drawings and a Video about Robots

As mentioned above, before and after the 8-week robotics sessions, we asked the children to draw and respond to the questions about robots. For both the pre- and post-instruction drawing and writing, the children sat in a small group of three to four. During the time of pre-instruction drawing, the participating children seemed nervous because the setting for the robotics class was different from their regular classroom, as described below:

> Vignette 4.1
>
> Kelsey, Felipe, Jorge, and Cristian sit at a rectangular table. Each child has an individual activity log on the desk in front of her or him and holds a pencil. Four children do not talk. Jorge writes his name in his engineer log. When Jorge starts to write, Kelsey, without moving her head, takes a peek to see what Jorge writes. Felipe starts to write in his engineer log, and Cristian, who sits across from Felipe, peeks at Felipe's engineer log.

The activities and setting were designed by our research team members, and the children seemed cautious especially when they worked in the engineer log for the first time (see

Figure 4.4). Unlike this pre-instruction writing and drawing, however, during the time of the post-instruction drawing, the participating children seemed relaxed with the setting and the activity.



Figure 4.4 Pre-instruction writing and drawing

During the first session after switching to a different robotic manipulative, the children in each class had a discussion with the lead teacher about their images of a robot and where those images came from. After having the discussion, the children watched a 3-minute video clip of different kinds of robots, including a surgery robot, a packaging robot in a factory, a farming robot, an underwater detective (crab-shaped) robot, and a vacuum cleaner robot (see Figure 4.5).



Figure 4.5 A packaging robot (left), a farming robot (middle), and an underwater detective robot (right) from the video

The video clip showed the multiple functions of robots to the children so that they could see the roles of robots in human life. The appearance and functions of each robot were varied. For example, the packaging robot and the surgery robot used their arms a lot,

while the farming robot and the crab-shaped robot had wheels or legs to move around. In the ninth session, we engaged the two groups of children in a reflection on the 8-week robotics classes as a way to conduct a semi-structured group interview.

Data Sources and Data Analysis

This chapter used data categorized into two components: the participating children's drawings of and writings about robots collected in the pre-and post-instruction sessions; and recorded videos on the two group discussions about their images of robots. In particular, I used two sets of drawings and writings of the participating children, and 53 minutes of video footages of the children's discussions. In the pre-instruction session, all 24 children participated in drawing and writing about robots, but in the post-instruction session, one child was absent so 23 children participated. Data was analyzed by constant comparison inquiry (Butler-Kisber, 2010) and by microanalysis of video data (Graue & Walsh, 1998). Drawings about robots were constantly compared between pre- and post-instructions, and the writings were analyzed in order to understand whether the children expressed their written ideas differently compared to their drawings. The children's discussions about robots were transcribed and analyzed to understand where their images of human body shaped robots came from.

Where Do the Young Children's Robot Images Come from?

Robots are often regarded as alive or a being which has human-like sensors because of having similar human appearances, including facial features, eyes, ears, arms, and legs and because of functions, such as having conversations or moving around with wheels (Fong & Nourbakhsh, 2003; Woods, 2006). Also, there is a tendency that children recognize robots with physical and emotional characteristics similar to humans.

Beran et al. (2011) asked a total of 198 children ages 5-16 years (M= 8.18 years) what they thought about a robot's arm-like part which could stack blocks. The results showed that children considered the robot's thinking, behavioral, and emotional characteristics as having humanistic qualities.

Animism and Children's Perceptions on Robots

According to Piaget's (1951) cognitive development theory, children, particularly at the preoperational (2-7 year-old) stage, perceive objects with an animistic view. During these periods, children understand symbols and tend to coordinate symbols and abstract images. Piaget defined this process as a structuring thinking process. However, Piaget explained that children made an error in their thinking process, which was named "animism." Piaget defined the error as "the tendency to regard objects as living and endowed with will" (p. 170). According to him, in this period, children tend to perceive inanimate objects as living-beings.

Although Piaget's cognitive development theory has had an influence on education, previous studies revealed that there is no systematic evidence of the existence of animism in children between the ages of 2-11 years or above (Gelman, Spelke, & Meck, 1983, Golinkoff, Harding, Carlson, & Sexton, 1984). While some children do not show animism, when animism is demonstrated, research shows that it tends to decrease with age (Beran et al., 2011). Piaget's cognitive development theory might explain how some of the second graders naturally perceived or pretended the Bee-Bots were alive, and this chapter will show how the children's ideas about robots blurred the boundaries of inanimate and animate beings.

No Experience with Robots

Some researchers (e.g., Beran, Ramirez-Serrano, Kuzyk, Fior, & Nugent, 2011; Bumby & Dautenhahn, 1999) explained that children prefer human-like robots because of their lack of experience and knowledge with robots. Bumby and Dautenhahn (1999) found out that 37 participating children (7-11 years old) from an elementary school in England tended to perceive the robots positively, but this perception does not relate to robotics. Beran et al. (2011) argued that children might imagine robots without having any knowledge of robots. They might not know about "the mechanics of robots, thus, relying on their existing knowledge state pertaining to humans" (p. 547). Weiss, Wurhofer, and Tscheligi (2009) found that although children (3-15 years-old) provided imaginative and inventive concepts about what robots could do, they lacked the creativity and insight of how robots actually work and what robots can do.

Children might not have experienced various types of robots including human-like robots. In a study (Cabibihan, Javed, Ang, & Aljunied, 2013), the authors reviewed the use of socially interactive robots and categorized them into human-like (anthropomorphic) robots, animals or cartoon-like (non-anthropomorphic) robots, or not resembling any biological species (non-biomimetic) robots. Cabibihan et al. (2013) found that children (18 months-old to 16 years-old) who were on the autistic spectrum tended to show greater stimulation in response to robots with pet-like or cartoon-like features. They also responded positively to non-biomimetic robots, such as mobile, vehicular robots. However, human-shaped robots were only preferred when imitation and emotional skills have been taught through these robots in order to generalize them to other humans.

Images from Popular Culture

Real robots were inspired and often developed from an animation or a movie. Sone (2014) explained that robotics and popular culture in Japan are tied. The author showed an example of a robot, Asimo, developed by a roboticist who got his idea from the comic cartoon *Astro Boy,* which was popular in the early 1950s. Tindol (2012) mentioned that the Borg have human as well as robot characteristics, and they have appeared in various films and television versions of *Star Trek* since first created in the 1980s for the television series *Star Trek: The Next Generation*. The existing robots were built by the inspirations from the popular movies or cartoons.

Popular culture is embedded in children's play using technologies and digital media. However, according to Edwards (2016), existing studies have focused on teachers' beliefs and attitudes and/or confidence in using technologies. Edwards pointed out that digital media and popular culture in the field of education have not been studied. According to Cook (2004), digital media promotes children's engagement with popular culture through the consumption of toys, clothing and accessories related to movies and programs. Children's exposure to or use of technologies is interrelated with digital media and popular culture (Jenkins, 2006; Marshall, 2010).

In STEM education, popular culture has rarely been applied and studied. In STEM learning, Robertson and Lesser (2013) explained in their study that relevant contents (e.g., forces, motion, Newton's Laws of Motion, and simple machines) and practical methods (e.g., pedagogy, instruction) were combined by using music (songs) and Dr. Skateboard Action Science (curriculum), and these contents motivated middle school students to be engaged in learning. Christopher (2017) used hip-hop based

interventions as pedagogy in STEM education. Subramaniam, Ahn, Waugh, and Druin (2012) believed that using science fiction, sci-fi movies, and sci-fi games would increase children's motivation in learning science. Popular culture in STEM education needs to be explored further to show us how children use popular culture (e.g., *Big Hero Six, SpongeBob)* to reflect their conceptualization of robots.

Bakhtin's Notion of Hybridity

Tobin (2000) in his book, "*Good Guys Don't Wear Hats: Children's Talk about the Media,"* addressed the idea that the children in his study shared their opinions related to popular culture and media with a series of citations. Drawing on Mikahil Bakhtin's (1981) notion of heteroglot, Tobin understood how the children cited ideas from the media, but they also transformed them into their own thoughts and words. I used Bakhtin's idea of citation and hybridity to understand the participating children's ideas about robots in this study. Bakhtin (1981) argued that we use the words and ideas of others to generate our own words:

> As a living, socio-ideological concrete thing, as heteroglot opinion, language, for the individual consciousness, lies on the borderline between oneself and the other. The word in language is half someone else's. It becomes "one's own" only when the speaker populates it with his own intention, his own accent, when he appropriates the word, adapting it to his own semantic and expressive intention. (p. 293)

In the Bakhtinian approach, we often cite the words, phrases, and ideas of others in our speech. Yet, our utterances become new because the meaning of utterances and talk is contextual. Each individual has different intentions and meanings when using those cited

words in her or his speech. Tobin (2000) explained, “Speech is creative and original because although we necessarily must cite the words and ideas of others, we continuously cobble them together in new and unique ways” (p. 20). Bakhtin (1981) further explained that “hybridity” is embedded in our words. In our words, even in a sentence, two opposing ideas or intentions can be mingled. He continued,

> What we are calling a hybrid construction is an utterance that belongs, by its grammatical and compositional markers, to a single speaker, but that actually contains mixed within it two utterances, two speech manners, two styles, two ‘languages’, two semantic and axiological belief systems. (p. 304)

Bakhtin’s (1981) multiple voices or genres form hybrids through dialogic interactions so that the hybrids are understood as not simply combining two voices and languages, but as a process that "changes the character" of combined utterance (p. 165). Leander (2001) in his study explained that “school space-times themselves are continually constructed within discourse and are used to produce school in diverse physical locations, whether participants find themselves inside a school building, on a field trip, or on a game show” (p. 673). He interpreted space-time production and hybridization in his paper, and he drew on Bakhtin’s chronotopic analysis, which means “a type of time-space hybridization was produced in the interpretive process and involves the blending of representational (textual) and embodied (reader) chronotopes” (p.652).
Leander explained that Bakhtin’s notion of hybridity was a highly productive form of dialogue between persons in past, present, and future space-times.

Bakhtin’s (1981) concept of multiple consciousness has been used in education. Morson and Emerson (1990) have understood this concept to mean, “Selfhood is not a

particular voice within, but a particular way of combining many voices within" (p. 221). In education, Bakhtin's heteroglot was described as a "poly-consciousness approach" (Morson & Emerson, 1990, p. 221), which emphasizes that educators design curriculum to be dialogic between teachers and students, so that the curriculum allows for curiosity and discovery for students as well as for teachers (Matusov, 2009). Respecting children's various questions, interests, ideas and curiosities by arranging wide-ranging dialogic interactions promotes each individual child's engagement in learning (Berlyand, 2009; Miyazaki, 2006; Solomadin & Kurganov, 2009). According to Matusov (2011),

> The goal of education is not to make students have the same understanding as the teacher, but rather to engage them in historically valuable discourses, to become familiar with historically, culturally, and socially important voices, to learn how to address these voices, and to develop responsible replies to them without an expectation of an agreement or an emerging consensus. (p. 115)

In science educational research, Eijck and Roth (2011) drawing on Bakhtin's work, analyzed three examples that demonstrate how existing science education practices are inclined towards a unitary language and to cultural centralization–epicization. They articulated a concept of novelization for rethinking science education by interacting with and incorporating alternative forms of knowing that arise from cultural diversity. Bakhtin's (1981) notion of heteroglot has been used in education research in order to expand our understanding of children and instructional pedagogy. Thus, the existing research motivated me to look carefully at the children's expressions–drawings, writings, and verbal conversations in discussion–to understand their hybridized and heteroglot

ideas about robots. In this study, I pay attention to children's conceptualization about robots by focusing on Bakhtin's notions of hybridity.

Findings from Children's Drawings of and Writings about Robots

From data analysis, I identified several findings (see Table 4.1) from the children's drawings of and writings about robots. The drawings and writings were examined in order to understand how they conceptualized robots and whether their ideas expanded, changed, or remained the same. Finally, the drawings and writings were compared to look for common patterns in both.

Table 4. 1

Six Findings from the Children's Drawings of Robots

Findings	Pre-instruction drawings	Post-instruction drawings
1. Drawing a human body shaped robot	20 children (4 children, non-human shaped)	11 children (12 children, non-human shaped)
2. Responding that their images of robots came from popular culture		12 children
3. Drawing a personalized robot		3 children (3 girls)
4. Drawing a robot with sophisticated functions and design in post-instruction drawings		5 children (5 boys)
5. Drawing robots with cited ideas from the robotics class		5 children (2 girls, 3 boys)
6. No difference between pre- and post-instruction drawings		4 children (1 girl, 3 boys)

First, in the pre-instruction drawing, 20 participating children drew human-shaped robots, and four children drew different robots (e.g., a machine-like robot, a Cubelet-shaped robot). Second, in regard to drawing human body shaped robots, during the group discussion, 12 children responded that their images of robots came from popular culture, including animations, cartoons, or movies. Third, in the post-instruction drawings, three girls drew girl-like, personalized robots. Fourth, five children drew their robots with

sophisticated functions and designs in their post-instruction drawings, compared to the pre-instruction drawings. Fifth, in the post-instruction drawings, five children drew robots that were inspired from Bee-Bots, Cubelets, and a robot from the video. Sixth, four children drew a similar design of robots between the pre- and post-instruction drawings. I discuss each of these findings in what follows.

Human Body Shaped Robots

In this chapter, I attempted to define human-shaped robots. I regard human-shaped robots as having human-body shapes with a head, a body, arms and legs. I also see a face with eyes, a nose, and a mouth. I attempted to categorize human body shaped robots and non-human body shaped robots. I regarded a car-shaped and machine-like appearance, which does not have a face, body, arms, and legs, as non-human shaped robots.

Pre-instruction drawings. According to the aforementioned criteria, 20 out of 24 children drew human-shaped robots in their pre-instruction drawings (see Figure 4.6). The drawings show that the children tended to use geometric forms, such as a rectangle, a square, and a circle when they drew the face, the body, the arms, and the legs of their robots. Nine children drew a robot with antennae. Rectangles were mainly used in drawing heads and body parts, and the children frequently used straight lines rather than curvy lines when they drew the body.

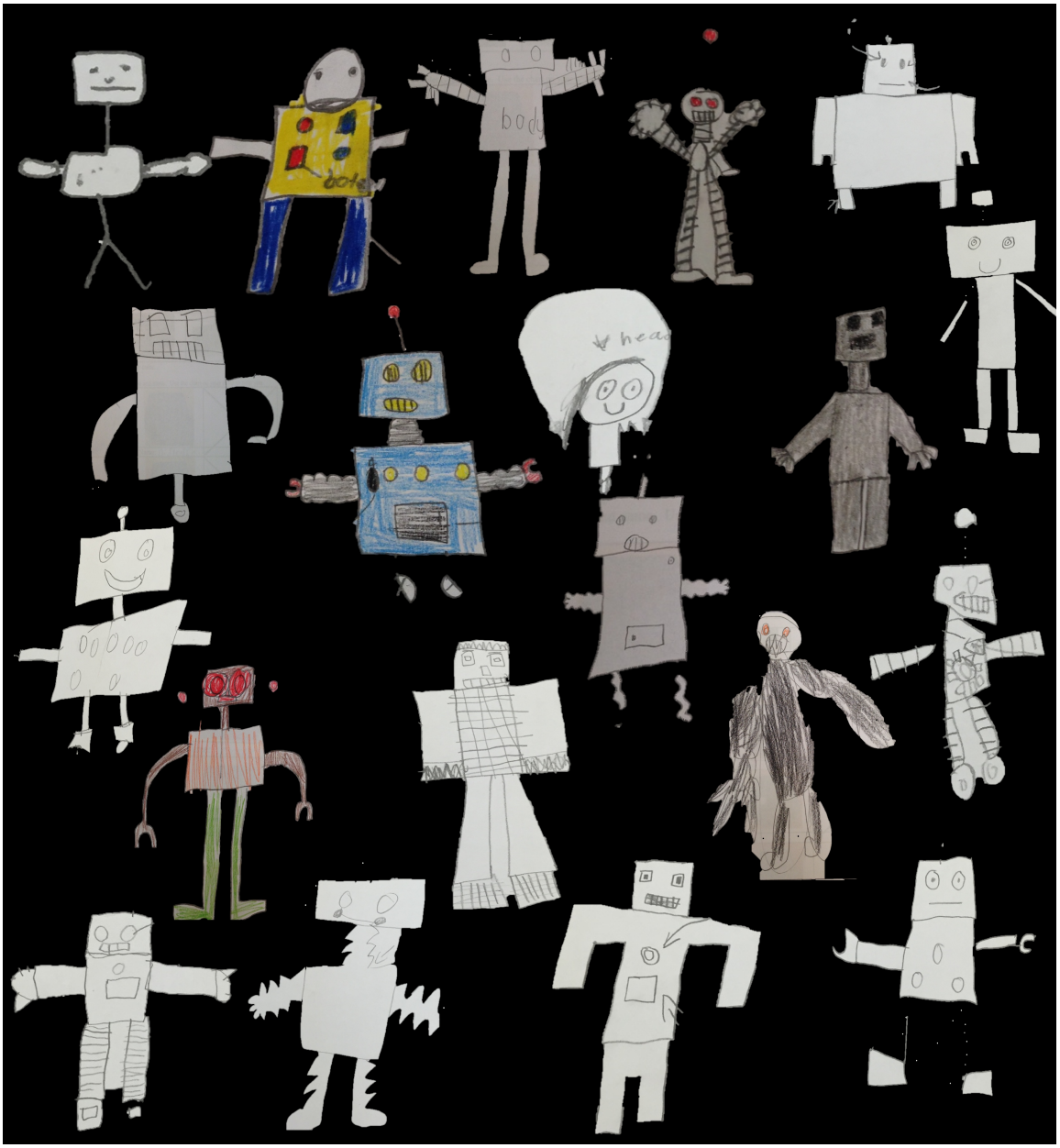


Figure 4.6 Pre-Instruction drawings of human body shaped robots

Bumby and Dautenhahn (1999) asked 38 children (7-11 years-old) to draw their image of a robot and found that children drew human-like faces even though they mainly used geometric forms in the other body parts (e.g., body, arms, legs, hands, feet). In these pre-instruction drawings, I was also able to see how the children drew their image of a robot as having human-like faces and body shapes.

In pre-instruction drawings, three children drew non-human shaped robots. Kaity (see the photo on the left in Figure 4.7) and Jorge (see the photo in the middle) drew a Cube-shaped robot. Issac (see the photo on the right) drew a machine-shaped robot. Another girl drew a rectangular shape, and she did not draw a robot.

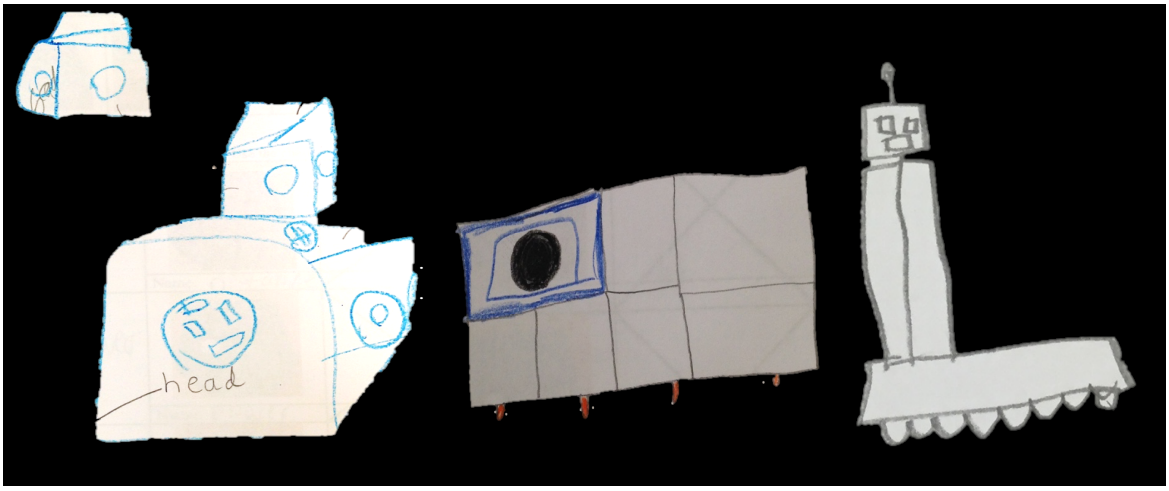


Figure 4.7 Pre-instruction drawings of non-human body shaped robots (first: Cubelet-shaped robot, second: Cubelet-shaped robot, third: a trailer shaped robot with multiple wheels)

Post-instruction drawings. In the post-instruction drawings, among 23 children, 11 children drew human-shaped robots (see Figure 4.8). Compared to the pre-instruction drawing, the numbers decreased from 20 to 11 children, and the remaining children drew new types of robots, inspired by the robotic manipulatives they used or watched from the video clip in our robotics class (see Figure 4.9). In the post-instruction drawings, the human body shaped-robots' design had become more sophisticated and many children attempted to use various colors, compared to their pre-instruction drawings.

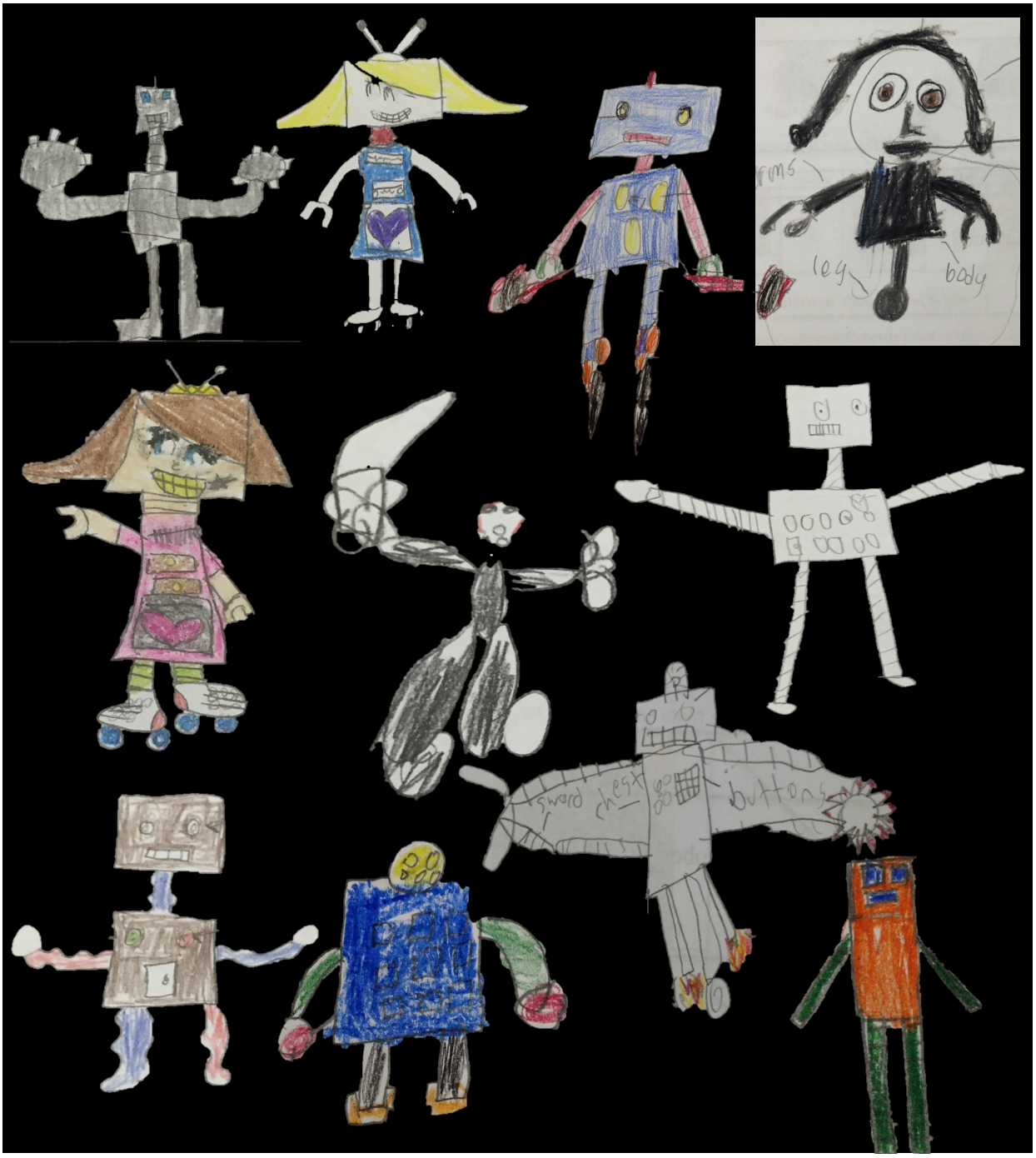


Figure 4.8 Post-instruction drawings of human body shaped robots

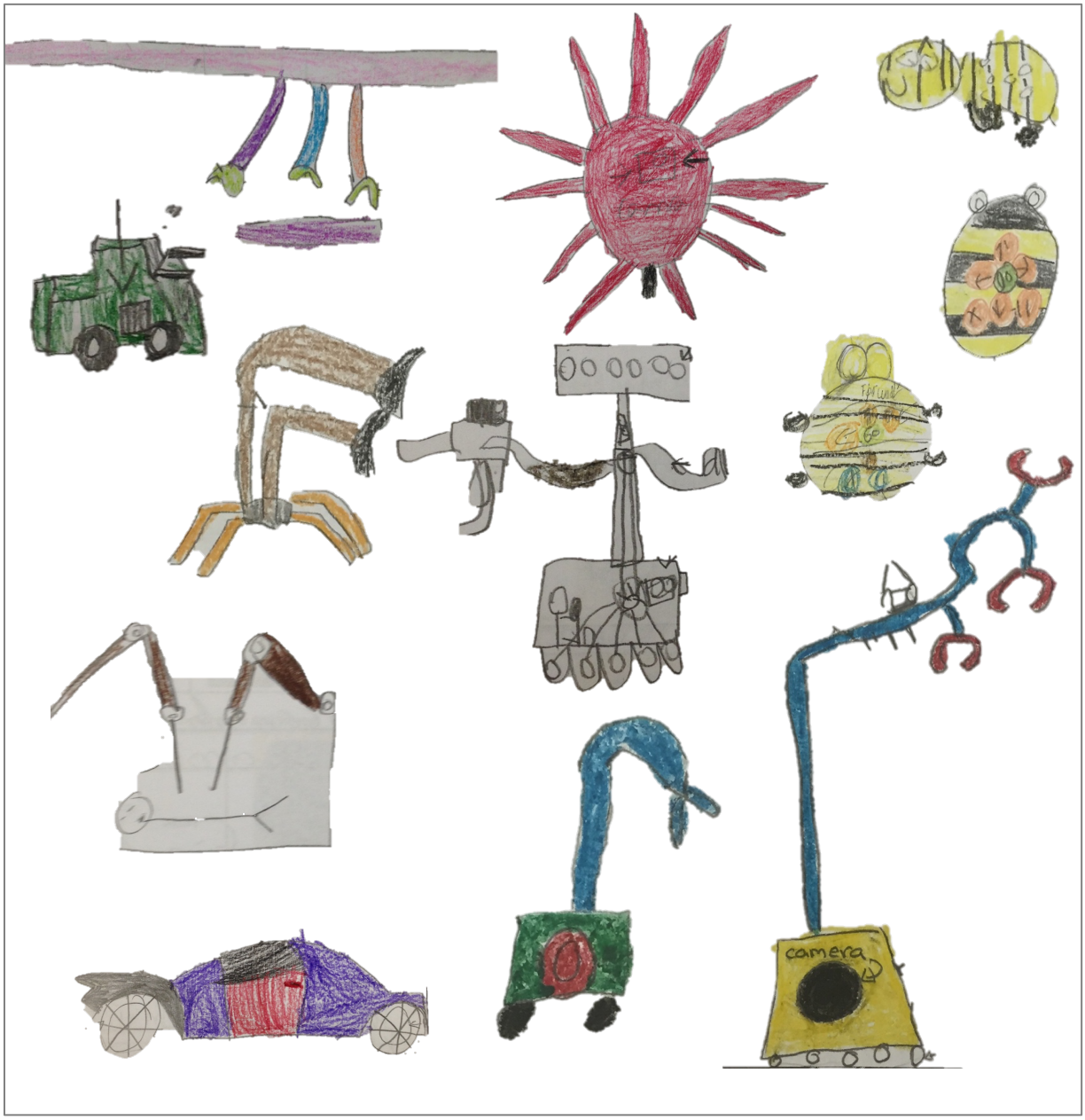


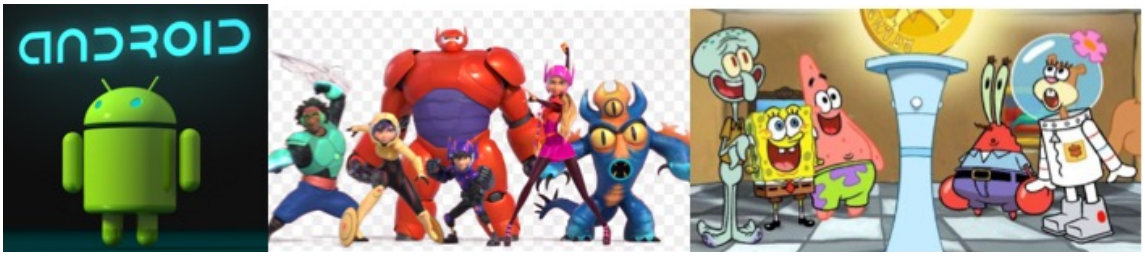
Figure 4.9 Post-instruction drawings of non-human shaped robots

As presented in Figure 4.9, in the post-instruction drawings, 12 children drew non-human shaped robots: Five children drew robots inspired by the video they watched, four children drew new types of robots (e.g., sniper robot, car-shaped robot, grabber robot, grabber robot with a camera), and three children drew Bee-Bots. Compared to the pre-

instruction drawings, non-human shaped robots in the post-instruction drawings were diversified in design and function.

Human-shaped Robot Images from Popular Culture

During the discussion before watching the video on different types of robots, the participating children were asked where their images of robots came from. In the discussion, a total of 12 children explained that TV shows (sitcom-no title), books (Diary of a Wimpy Kid), movies (*Alien, Big Hero Six*), cartoons (SpongeBob, Star Wars), video games (*Call of Duty*), and a mobile operating system (*Android*) (see Figure 4.10) were their motivation for the robot images. Two children added that they did not exactly know where their images came from, telling us that their robots were just drawings. Overall, many children's images of a robot were the visual representations of popular culture.



F*igure 4.10* A concept of a mobile operating system (left), images from animation movies, including Big Hero Six (middle) and SpongeBob(right)

Robots in children's popular movies or animations are often presented as living things. The robots' appearances from these cartoons or movies were described as having human characteristics, such as talking, walking, and having body parts (e.g., a head, a body, arms, and legs). While the children's image of robots was influenced by human-shaped robots in popular culture, they attempted to distinguish between humans and robots. For example, when Shara asked the 12 children in the Cubelet class if all robots look and act like humans, the children responded, "Noooo," but one boy, Caleb, responded, "Yes." Shara asked him why. Caleb responded that robots do not all look like

humans because “They do stuff that humans don’t do, like they walk and they move to the side, they talk different, and metal, we don’t have any metal.”

Personalized Robots

In the post-instruction drawings, three girls–Tamia, Kelsey, and Emily–drew their robots with more human like appearances than their pre-instruction drawings. Interestingly, they drew their robots with feminine appearances. These three girls’ robots looked like girls, and their robots were animated.

Tamia. In the pre-instruction drawing (see Figure 4.11), Tamia (an African-American girl) drew a robot which has an antenna, a square- shaped head, and a body, which included a space for inserting coins and storage. She labeled it with, “power on/off, face, neck, arms and hands, storage, wheels, and money for power.” Compared to this pre-instruction drawing, Tamia’s post-drawing became a robot resembling a girl like her.

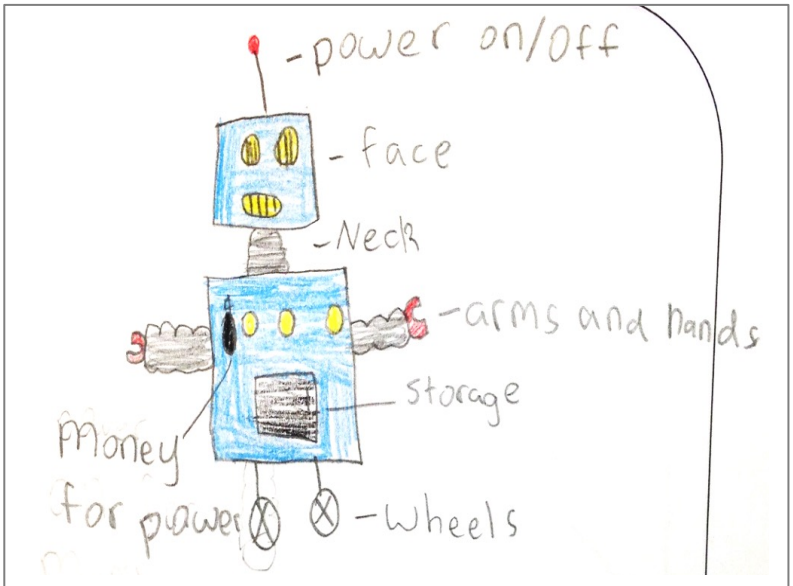


Figure 4.11 Tamia’s pre-instruction drawing: (clockwise) power on/off, face, neck, arms and hands, storage, wheels, money for power

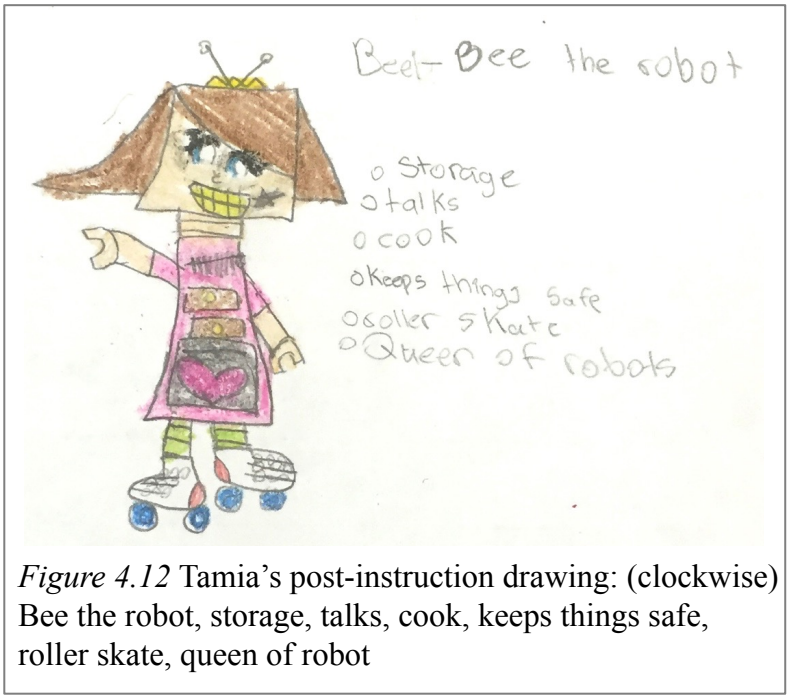


Figure 4.12 Tamia's post-instruction drawing: (clockwise) Bee the robot, storage, talks, cook, keeps things safe, roller skate, queen of robot

In the post-instruction drawing (see Figure 4.12), although Tamia wrote, the "Bee the robot" at the top, I also see she named it, "Queen of robots" in the label. She wrote that her robot could talk, cook, keep things safe, roller skate, and store things. Not only the roles of her robot, but also the robot's design exemplified a girl. Tamia's robot had brown hair and light brown skin.

Table 4.2

Tamia's Pre- and Post-Instruction Writings about Robots

Questions	Pre-instruction writing	Post-instruction writing
1. What is a robot?	Something that is very powerful	A moving machine that can do stuff
2. What can robots do?	Take care of places and fight	Help you around
3. Where can we find robots?	Junkyard, basement, toy factory	At some factories
4. Why do people build robots?	To make life	So they can help you to do things faster
5. How are robots similar to and different from other machines?	They can move around and do stuff.	They are different because in some factories robots do different things to help.

As presented in Table 4.2, in the post-instruction writing, her robot has specific functions (e.g., moving around, helping people, making things faster). In her pre-instruction writing, robots can take care of places and fight, but in her post-instruction writing her robot helps people and helps you to do things faster. While her drawings showed her modified image of robots as looking like herself, her writings also showed her sophisticated and specified imagination about robots.

Kelsey. In the pre-instruction drawing, Kelsey (a European-American girl) drew her robot with a rectangle face and body. Her robot has a rectangular-shaped head, a body, arms, and legs (see Figure 4.13).

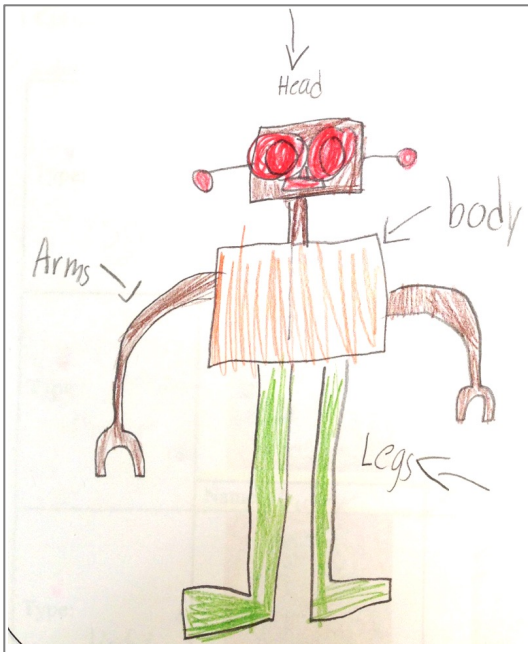


Figure 4.13 Kelsey's pre-instruction drawing: (clockwise) head, body, legs, arms

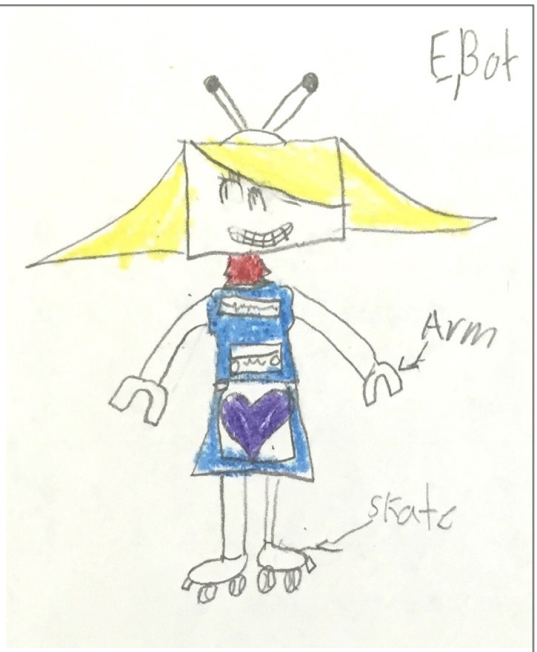


Figure 4.14 Kelsey's post-instruction drawing: E,bot, arm, skate

However, the robot's head had two antenna-like parts and its hands were less human-like. In the post-instruction drawing (see Figure 4.14), Kelsey drew a more human-like robot (e.g., a smiley face, yellow hair, wearing a dress and skates). Its name

is “E, Bot,” and the robot has similar arms and antennae with the pre-instruction drawing. The robot is gendered and has racial characteristics (e.g., with light skin and hair). The robot in her post-instruction drawing *looked* and *functioned more* like a Caucasian girl.

Table 4.3

Kelsey’s Pre- and Post-Instruction Writings about Robots

Questions	Pre-instruction writing	Post-instruction writing
1. What is a robot?	A robot is like a built [made] person.	A robot is a machine that helps.
2. What can robots do?	Robots can help people work in factories.	Help people work or carry things and help.
3. Where can we find robots?	We can find robots in factories or in space.	In factories
4. Why do people build robots?	To help them do things mostly in factories	To help other people
5. How are robots similar to and different from other machines?	They are similar to other machines because their built and different because they are built [made] like people.	They are similar because they are mechanical and different because one can do many things.

In Kelsey’s post-instruction writing (see Table 4.3), the function of robots was expanded, including “[helping] people work or carry things” “[doing] many things.” In her pre- and post-instruction writings, her robot has human-like (e.g., “built [made] like people”) and machine-like (e.g., “mechanical”) characteristics. In the pre-instruction writing, she defined a robot as “a built [made] person.” In addition, she also differentiated robots as “built [made] like people” in the pre-instruction writing, and “can do many things” in the post-instruction writings. As her pre-instruction drawing and writings represent her idea of having human-like and machine-like robots, her post-instruction drawing and writing showed a sophisticated and developed image of a robot which looked more girl-like and had varied functions.

Emily. In the pre-instruction drawing, Emily (a European-American girl) drew a robot with a head, body, arms, and a leg with a wheel (see Figure 4.15), and it looked like a girl, which has long hair and smiles on the face. She wrote, "I saw this robot on a video. It didn't say the name." She drew a robot based on ideas from the video she had previously watched. I also realized from her pre-instruction writing that her robot was made of material, metal. That might be the reason that Emily did not use colors in her drawing.



Figure 4.15 Emily's Pre-instruction Drawing: (clockwise) head, arms, body, leg. "I saw this robot on a video. It didn't say the name."

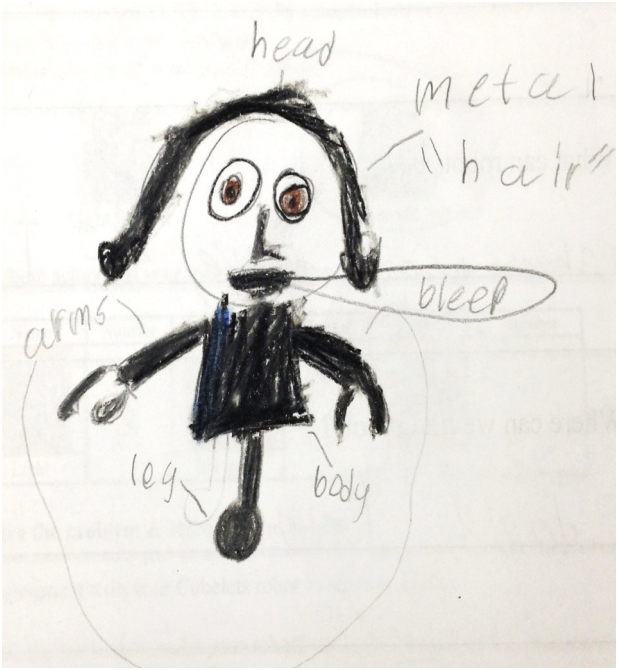


Figure 4.16 Emily's Post-instruction Drawing: head, metal "hair," bleep, body, leg, arms

In the post-instruction drawing, Emily's robot had unique mechanical characteristics, such as metal hair. Her robot could also make sounds (e.g., bleep) (see Figure 4.16). Her robots from both drawings were similar and looked like a girl, but the robot in the post-drawing had details in hair and in its function. She colored the robot's

eyes brown. Emily also colored her robot with black, and it might represent "metal." Emily's post-instruction drawing of a robot was a bit different from Tamia's and Kelsey's robots represented in their post-instruction drawings. While these two children's robots became personalized–a girl-like robot–through the robotics class, Emily's robot in the post-instruction drawing revealed sophisticated changes in appearances and functions. I see these added designs and functions as a personalization of her robot.

Table 4.4

Emily's Pre- and Post-Instruction Writings about Robots

Questions	Pre-instruction writing	Post-instruction writing
1. What is a robot?	A robot is a machine that can be human being.	A robot is a metal dude.
2. What can robots do?	They can do many things like sleeping.	Robots can move and talk.
3. Where can we find robots?	I do not know where.	I don't know.
4. Why do people build robots?	To have company	To be not lonely
5. How are robots similar to and different from other machines?	They talk, move, and are made out of metal.	They are the same because they are both metal.

Emily's conceptions of robots in both the pre- and post-instruction writings did not have much difference in function (see Table 4.4); however, as shown in her pre- and post-instruction writings, she thought that a robot has characteristics like a human or herself (e.g., sleeping, talking, moving) as well as a machine (e.g., made out of metal). In her pre-instruction writing, she wrote that a robot is a "machine that can be human being." She also wrote: "Robots can do many things like sleeping." She added that people build robots "to have company." In her post-instruction writing, she wrote that "A

robot is a metal dude," "Robots can move and talk," so people make a robot "not to be lonely."

Robots with Sophisticated Designs and Functions

Five boys' post-instruction drawings added sophisticated functions and designs, compared to their pre-instruction drawings.

Josue. In the pre-instruction drawing (see Figure 4.17), Josue (a Latino) drew a robot with an antenna, a square-shaped head with two eyes and a mouth, two arms and two legs. The robot has a square shaped-body with three circle-shaped buttons and rectangular-shaped arms and feet.

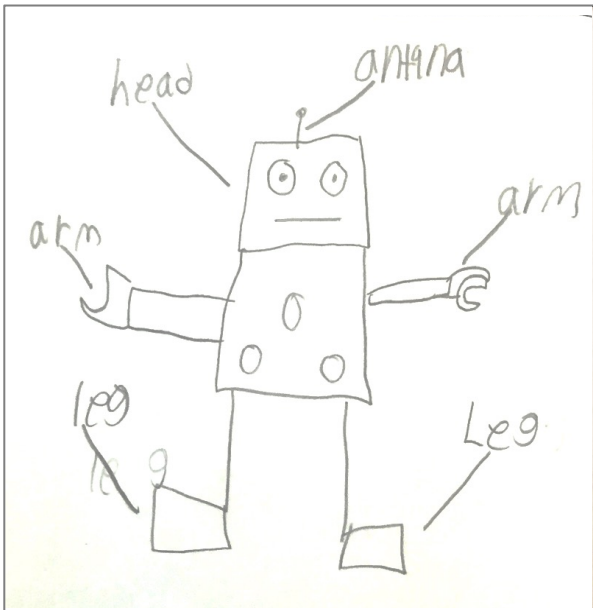


Figure 4.17 Josue's pre-instruction drawing : (clockwise) antina [antennae], arm, leg, leg, arm, head

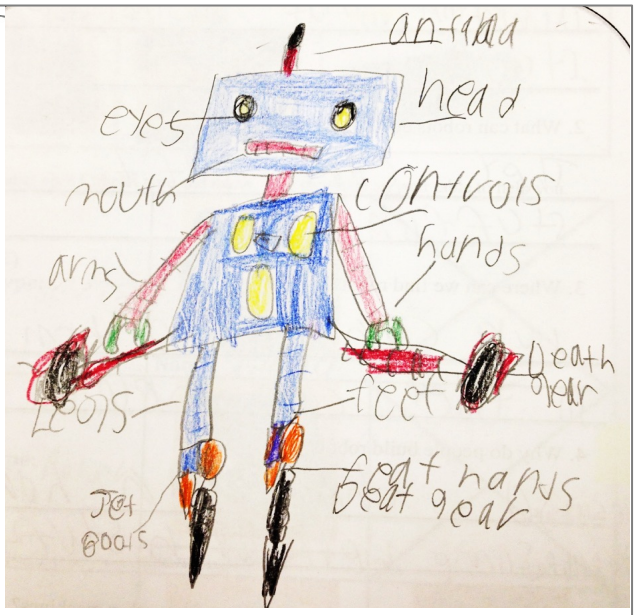


Figure 4.18 Josue's post-instruction drawing: (clockwise) antina [antennae], head, controls, hands, death gear, feet, feat hands, death gear, jet boots, legs, arms, mouth, eyes

In the post-instruction drawing (see Figure 4.18), his robot showed more complex functions and designs; his robot had developed. The robot in the post-drawing showed expanded functions, including antennae, head, controls, hands, death gear, feet, feat *hands*, death gear, jet boots, legs, arms, mouth, and eyes. The main body had three

yellow buttons, and he labeled one of those buttons as the "controls." In addition, he used a variety of colors in his post-drawing of his robot.

Table 4.5

Josue's Pre- and Post-Instruction Writings about Robots

Questions	Pre-instruction writing	Post-instruction writing
1. What is a robot?	A robot is metallic thing that can be hard to build.	A machine that helps to do stuffs
2. What can robots do?	Robot can help people if you are something hard.	They can lift stuff up.
3. Where can we find robots?	You can find robots in a factory.	We can build them so they can help us.
4. Why do people build robots?	People build robots to help other people.	People build robot so they can have.
5. How are robots similar to and different from other machines?	Robots are built with lot of things like machines.	They are both ….and robot can help with more stuff.

As his drawings show, Josue's ideas were developed through the robotics activities, so complex functions (e.g., controls, death gear, feat hands, jet boots) and designs (e.g., using various colors) were revealed in his post-instruction drawing. In the pre-instruction writing (see Table 4.5), he wrote that robots are a helper doing hard work for people, and this idea was developed in more detail with *lifting stuff up* in his post-instruction writing (e.g., "robots can help more stuff"). While his robot in the post-

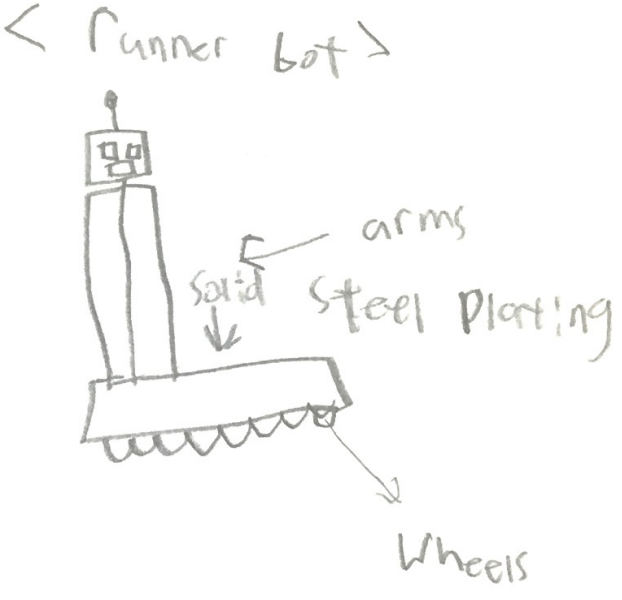


Figure 4.19 Issac's pre-instruction drawing: (clockwise) runner bot [robot's name], arms, solid steel plating, wheels

instruction drawing had aggressive functions (e.g., death gear, feat hands), his post-instruction writing revealed his idea that a robot is "a machine that helps to do stuffs."

Issac. In the pre-instruction drawing, Issac (a European-American boy) drew a runner bot which has arms, solid steel plating, and eight wheels (see Figure 4.19). He did not label it, but the robot has a face with an antennae. The steel plating part might work for carrying something.

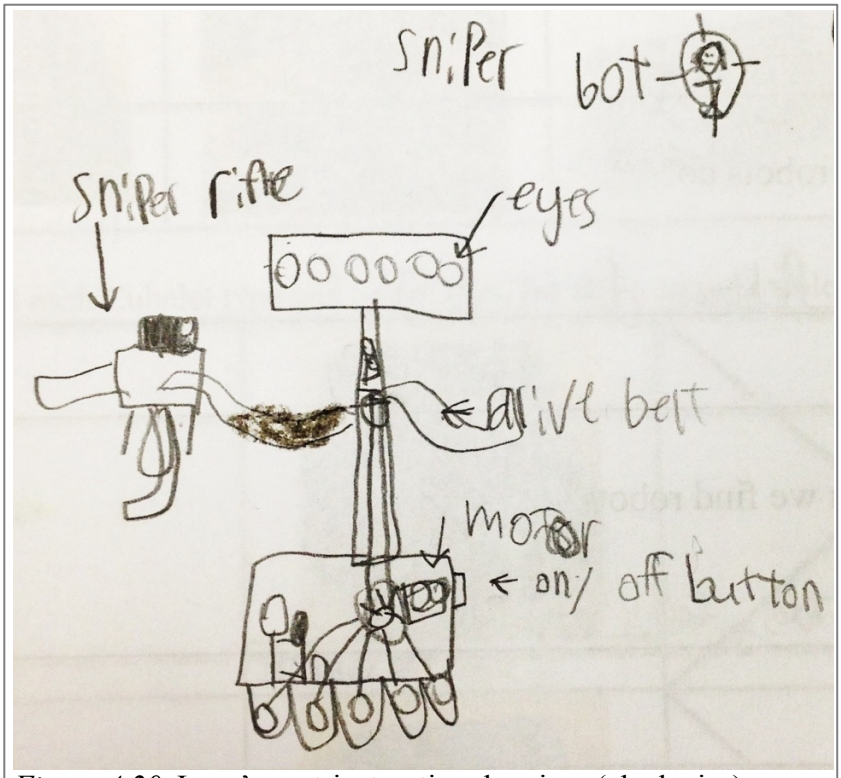


Figure 4.20 Issac's post-instruction drawing: (clockwise) sniper bot [robot's name] (clockwise) eyes, drive belt, motor, on/off button, sniper rifle

In the post-instruction drawing, Issac's robot evolved into a sniper bot that has eyes, a drive belt, a motor, an on/off button, and a sniper rifle (see Figure 4.20). He used and developed some parts (e.g., steel plating, multiple wheels) from the pre-instruction drawing into the post-instruction drawing. In the post-instruction drawing, a person sits on the bottom and controls the sniper rifle. The robot had changed into having

complicated functions (e.g., a sniper rifle, an on/off button, a motor) and design (e.g., multiple eyes, complicated connections with wheels, and a drive belt).

Table 4.6

Issac's Pre- and Post-Instruction Writings about Robots

Questions	Pre-instruction writing	Post-instruction writing
1. What is a robot?	A robot is a device.	A machine that can move
2. What can robots do?	All robots have microchips that help robots run.	Solve problems of all sorts
3. Where can we find robots?	In factory, etc.	In stores, farms etc.
4. Why do people build robots?	To do things we cannot do	To help do hard things
5. How are robots similar to and different from other machines?	How robots are different they can walk.	Most robots are mobile normal machines are stationary. Some robots run on drive belts some stationary machines too.

As presented in Table 4.6, Issac had ideas of the robots' working system (e.g., microchips for movement) in pre-writing, and this working system was sophisticated (e.g., "Some robots run on drive belts"). In the pre-instruction writing, he wrote: "All robots have microchips that help robots run," and robots are different because "they can walk." He elaborated ideas on movement, "Most robots are mobile, normal machines are stationary. Some robots run on drive belts, some stationary machines too." Like Josue, although Issac's post-instruction drawing, a sniper bot, represented the fearful function of killing, his writings showed that robots are built "to help [people] do hard things."

Craig. In the pre-instruction drawing (see Figure 4.21), Craig (a European-American boy) drew a robot with antennae, eyes, mouth, gere [gear], legs, wells [wheels], arms, lable [label], and a head. His robot had human like body parts (e.g., eyes,

mouth, legs, arms, head) and mechanical parts (e.g., cationtilite [caution light], gere [gear], wells [wheels]).

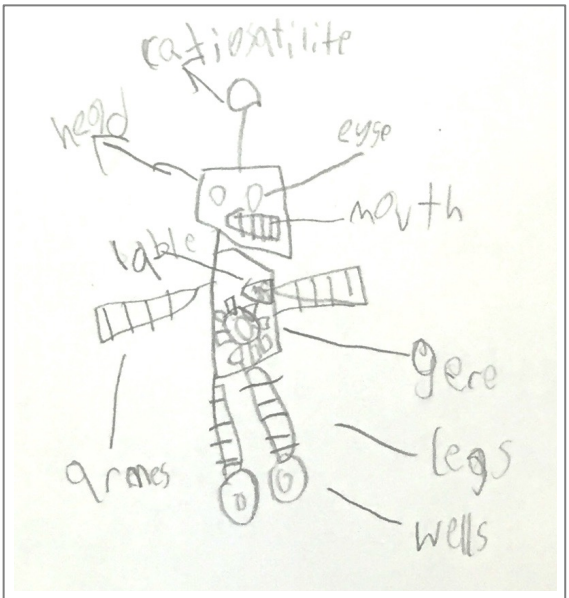


Figure 4.21 Craig's Pre-instruction Drawing: (clockwise) cationtilitie [caution light], eyes, mouth, gere [gear], legs, wells [wheels], arms, lable [label], head

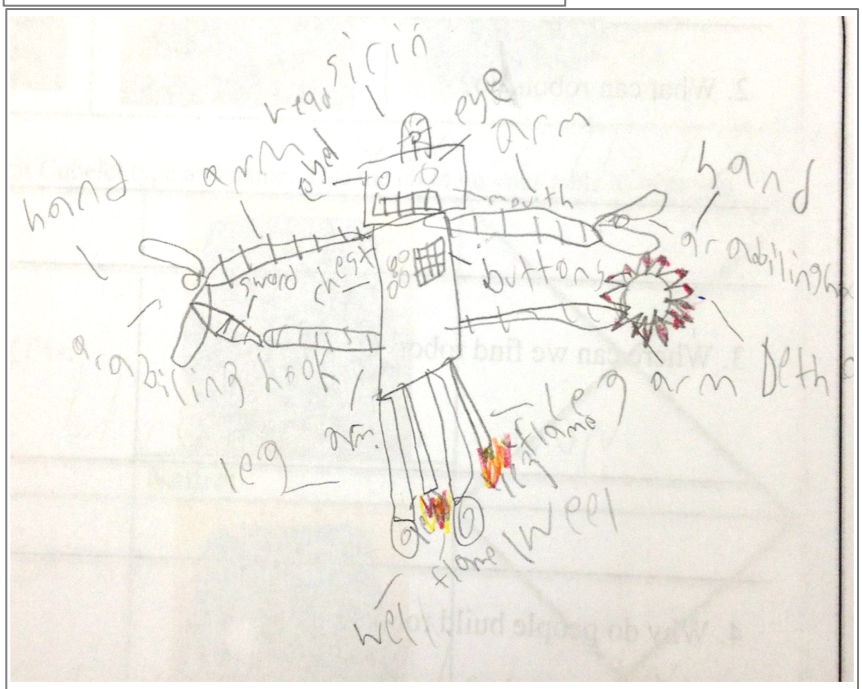


Figure 4.22 Craig's Post-instruction Drawing: (clockwise) sirin [siren], eye, arm, mouth, hand, grabiling [grabbling] hook, buttons, arm, deth [death] gear, flame leg, leg, weel [wheel], flame, well [wheel], leg, arm, grabiling [grabbing] hook, sword, chest, hand, arm, eye, head

In the post-instruction drawing (see Figure 4.22), Craig drew a robot with sirin [siren], eye, arm, mouth, hand, grabiling [grabbing] hook, buttons, arms, deth [death] gear, flame leg, weel [wheel], flame, leg, sward [sword], chest, hand, eye, and head. He brought ideas about several parts (e.g., head with eyes and mouth, body, arms, legs, wheel) from his pre-instruction drawing and he added extra functions (e.g., siren, grabbing hook, death gear, flame leg, sword). In the post-instruction drawing, the robot had extra arms with grabbing hooks, a sword, a death gear and extra legs with flames. Also, he attempted to use colors on the death gear and the flames.

Table 4.7

Craig's Pre- and Post-Instruction Writings about Robots

Questions	Pre-instruction writing	Post-instruction writing
1. What is a robot?	A robot is a machine that helps people with stuff.	Something that do use stuff for you.
2. What can robots do?	Robots have microchips and they can do stuff like pick stuffs and destroy stuffs.	They can help you.
3. Where can we find robots?	In science and in government facalities [facilities]	You can build them.
4. Why do people build robots?	To help them with three projects.	People build robots to help them do things.
5. How are robots similar to and different from other machines?	Robots have heads and can move around by itself unlike computers.	They have their own personalities.

Craig's ideas in writings also developed after the robotics class. In the pre-instruction writing (see Table 4.7), he wrote that a robot is a machine that "helps people with stuff" and that robots "have microchips and they can do stuff like pick stuffs and destroy stuffs." In the post-instruction writings he expanded his ideas about robots as having "their own personalities." However, his image of robots was different between the drawings and writings, like the aforementioned two boys. Again, in his drawings, his

robot had powerful and aggressive functions (e.g., death gear, flame leg, sword), but in his writings he wrote: “robots can help you” and are built “to help them with three projects.”

Robots Inspired by the Robotics Class

The children tended to draw what they experienced from the robotics class. In the pre-instruction drawings, two children drew Cubelet-like robots. In the post-instruction drawings, five children drew a robot similar to what they had watched from the video shown in the robotics class, and the other three children drew a Bee-Bot.

Drawing Cubelet-shaped robots. Two children drew Cubelet-like robots in their pre-instruction drawing. In the pre-instruction drawing and writing, the children drew their image of a robot based on their previous experiences. We intentionally did not show them the Bee-Bots and Cubelets when they drew and wrote about robots before our robotics class. However, accidently, there was a small picture of the Cubelets (see Figure 4.23) which was on the top of the schedule board in the class.

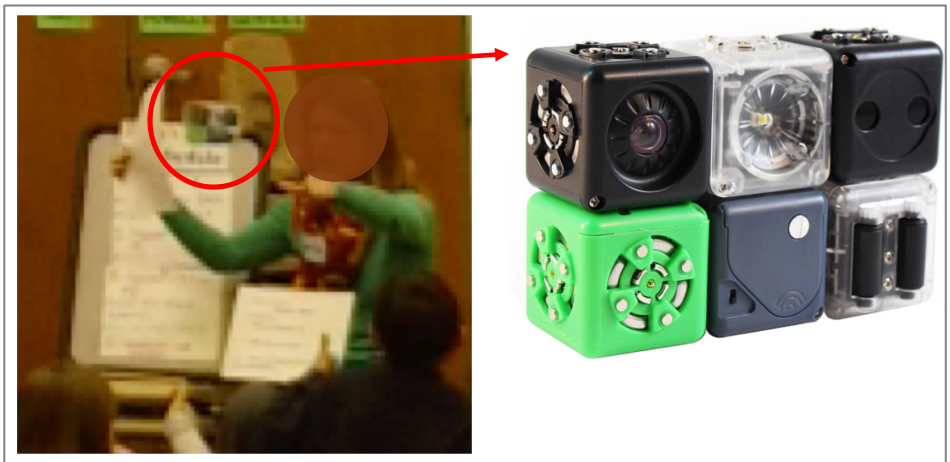


Figure 4.23 Shara’s explaining pre-instruction drawing and writing (Cubelets photo on the schedule board)

Jorge and Kaity saw this photo of the Cubelets, and their pre-instruction drawing incorporated this image. Figures 4.24 and 4.25 show how the two children imitated the

Cubelet and combined it into their own interpretations of robots. Kaity (see Figure 4.24) labeled each part of the Cubelet (e.g., heads, legs) and several body parts. Interestingly, she also drew a Bee-Bot in her post-instruction drawing (explained in the next section, see Figure 4.29). Jorge (see Figure 4.25) drew his robot with almost the same physical design as the Cubelet photo and added a camera, eyes, and wheels on it.

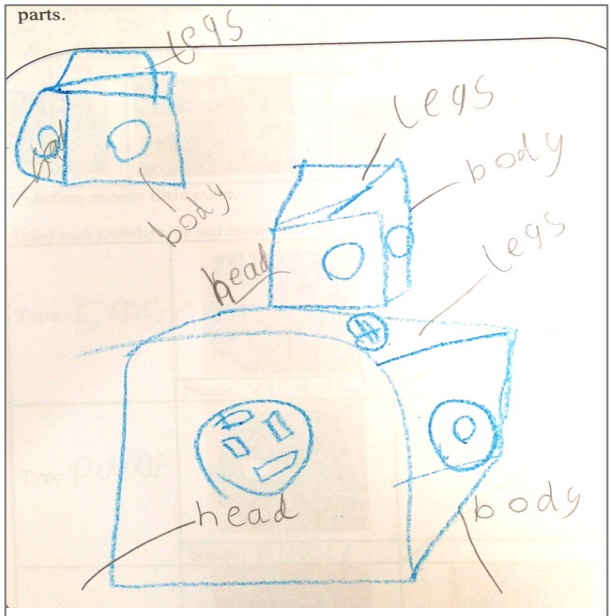


Figure 4.24 Kaity's pre-instruction drawing: (clockwise) legs, body, legs, body, head, head, body, legs

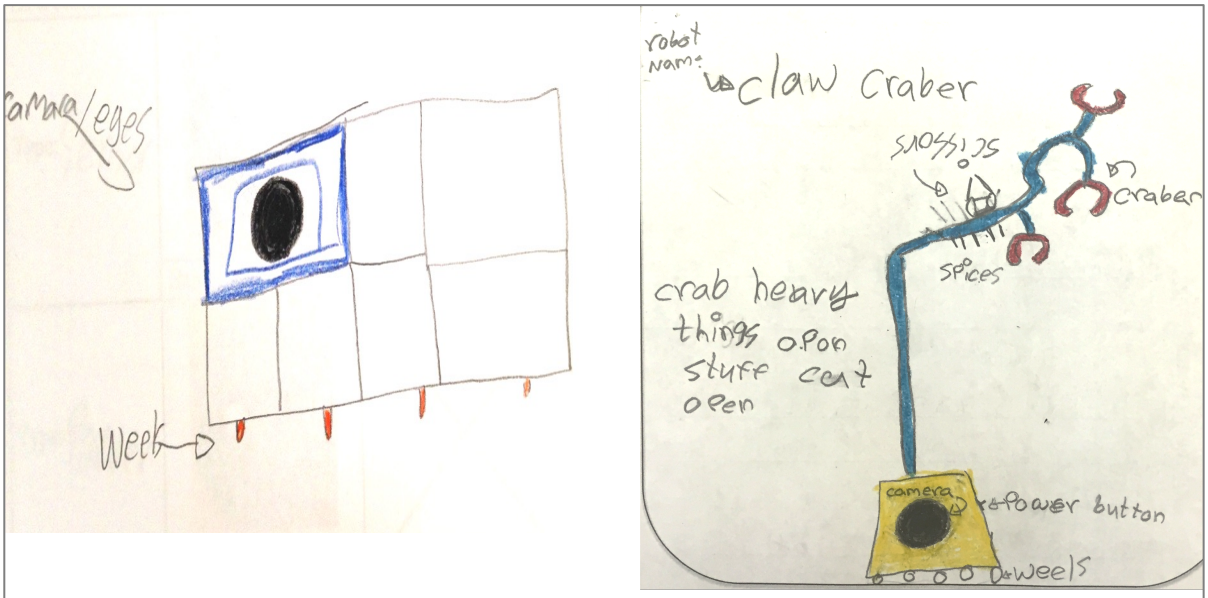


Figure 4.25 Jorge's pre-instruction drawing (left)- camera, eyes, weels [wheels] Jorge's post-instruction drawing (right)- (clockwise) craber [grabber], spices [spikes], power button, weels [wheels], crab [grab] heavy things opon [open] stuff cut open, robot name-claw craber [grabber], scissors

In the post-instruction drawing, Jorge drew a machine-like grabber robot. Jorge's and Kaity's pre-instruction drawings showed that they incorporated ideas borrowed from the robotics class into their imagination of robots.

Drawing robots from the video. In the post-instruction drawings, five children drew a robot similar to what they watched from the video shown in the robotics class, and two of them drew multiple robots from the video and Cubelets in their drawings. The other three children drew a Bee-Bot.

Sara. In the pre-instruction drawing, Sara drew a human shaped robot without labels (see the photo on the left in Figure 4.26). In the post-instruction drawing, Sara (a Latina) drew a packaging robot and a crab shaped robot adopted from the video (see the photo on the right in Figure 4.26).

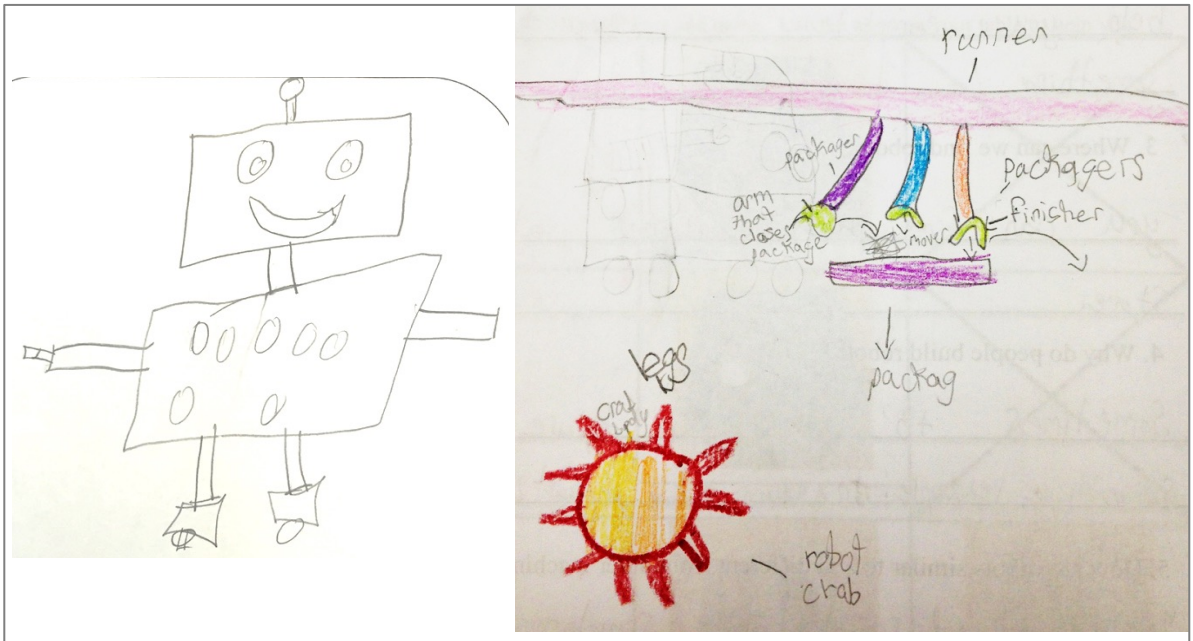


Figure 4.26 Sara's pre-instruction drawing (left) Sara's post-instruction drawing (right) : (clockwise) runner, packagers, finisher, mover, packag [package], robot crab, crab body, legs, arm that chases package, packager

The packaging robot in the video wrapped products and sent them to the next step on conveyor belts. In her drawing, the packaging robot was made out of sophisticated parts (e.g., an arm that chases packages, packagers, movers, finisher). The crab shaped robot was an underwater detective in the video. In her post-instruction drawing, her crab shaped robot had 10 legs with a body.

Table 4.8

Sara's Pre- and Post-Instruction Writings about Robots

Questions	Pre-instruction writing	Post-instruction writing
1. What is a robot?	A robot is a mechanical person that is programed by using a pad.	A robot is a type of machine.
2. What can robots do?	They do what you want them to do.	Help you complete or accomplish something
3. Where can we find robots?	We can't find robots we have to build them.	You can find them sometimes at a store.
4. Why do people build robots?	Because it is fun to build them and maybe they do not want to get something themselves.	Sometimes to help you figure out something. (e.g. doing an art project)
5. How are robots similar to and different from other machines?	Because all have microchips. They are different because they do what you want.	Machine and robots are similar because both of them have a microchip.

Sara's drawings and writings showed that her image of a human shaped robot has expanded. In the post-instruction writing (see Table 4.8), she wrote: A robot "helps you complete or accomplish something." She added that people build robots because "sometimes [robots] help you figure out something such as doing an art project." Specifically, her idea of robots has changed from human body shaped to machine shaped robots. In the pre-instruction writing, Sara wrote: "A robot is a mechanical person that is programmed by using a pad," and her robots in the pre-drawing had human characteristics (e.g., human body shaped robot). In the post-drawing, she drew a non-human shaped and variously designed robots (e.g., packaging robot and a crab-shaped robot) that she watched in a video clip from the robotics class.

Nora. In the pre-instruction drawing, Nora (an African-American girl) drew a robot with a rectangular-shaped head and body (see Figure 4.27). Her robot had three lights on its head, and its neck, arms, and legs were drawn with wavy lines. In the pre-

instruction drawing, the robots did not have specific functions labeled.

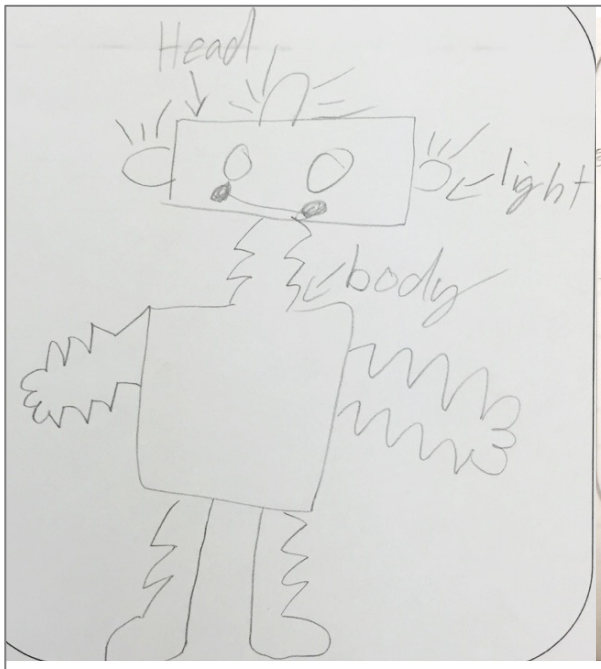


Figure 4.27 Nora's Pre-instruction Drawing: head, light, body

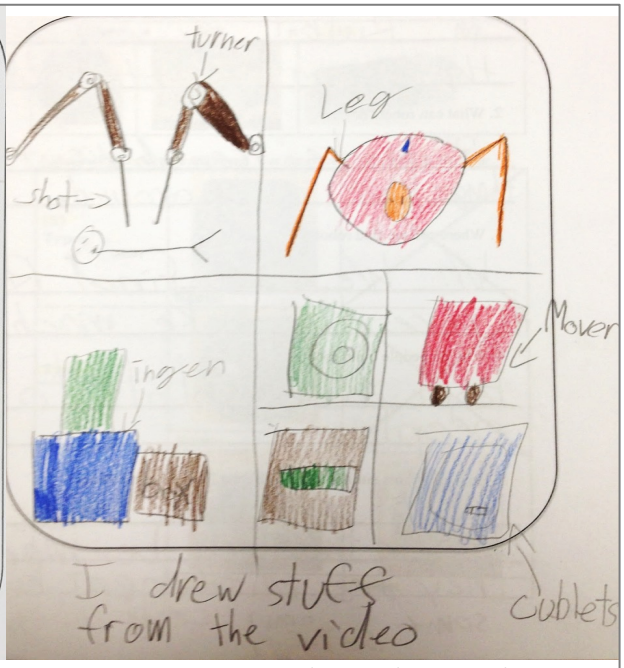


Figure 4.28 Nora's Post-instruction Drawing: (from top-left, clockwise) [surgery robot]-turner, shot [crab robot]- leg [Cubelet robot]- mover, cubelets, ingen [engine] "I drew stuff from the video."

In the post-instruction drawing, Nora drew three different robots adopted from the video and Cubelets (see Figure 4.28). From the video, Nora drew a surgery robot (e.g., turner, shot) with a horizontal patient, a crab shaped robot (e.g., leg), and a robot [engine] (not recognized). She also drew four different Cubelets (e.g., mover [driver], cubelet [battery], [bargraph], [light sensor]) that she had used in the activities. She wrote, "I drew stuff from the video."

Nora writings showed that her image of robots became a machine that had additional functions (see Table 4.9). In the pre-instruction writing, she wrote: "A robot is a thing that is metal and it is smart. It has cords in it to [too]" and "robots can measure." In the post-instruction writing, she stated: "A robot is a machine that can control themselves." She knew that robots are "smart," but after robotics class, she could

articulate how robots can "control themselves," and "Robots can do different things like move around." Her post-instruction writing added the function of robots, including the autonomous aspect (e.g., "can control themselves") and the locomotive aspect (e.g., "move around").

Table 4.9

Nora's Pre- and Post-Instruction Writings about Robots

Questions	Pre-instruction writing	Post-instruction writing
1. What is a robot?	A robot is a thing that is metal and it is smart. It has cords in it to [too].	A robot is a machine that can control them selfs [themselves].
2. What can robots do?	Robots can measure it can make it can do a lot.	Robots can do different things like move around.
3. Where can we find robots?	You don't find them. You make them.	We can find robots in places that make machines.
4. Why do people build robots?	So it can help them and so it can do stuff they can't do.	People build robots to help people.
5. How are robots similar to and different from other machines?	They are similar because it has cords in it. It is different because it has wheels or feet.	Robots are the same because they can be made. They are different because some can control themselves.

Drawing Bee-Bots. Three girls–Anne, Shelby, and Kaity–drew a Bee-Bot in their post-instruction drawings. In the pre-instruction drawing (see the photo on the left in Figure 4.29), Anne drew a robot with a "head, arms, a body, and a leg." In the post-instruction drawing (see the photo on the right in Figure 4.29), she drew a Bee-Bot and a Cubelet. She labeled the Bee-Bot with "hook (connects them), wheels, and eyes" and drew a cubelet with a label, "cubelets."



Figure 4.29 Anne's pre- (left) and post-instruction (right) drawings: (left)- a robot with a head, arm, body, and leg, (right)- bee-bot with hook (connects them), wheels, eyes, and a cubelet

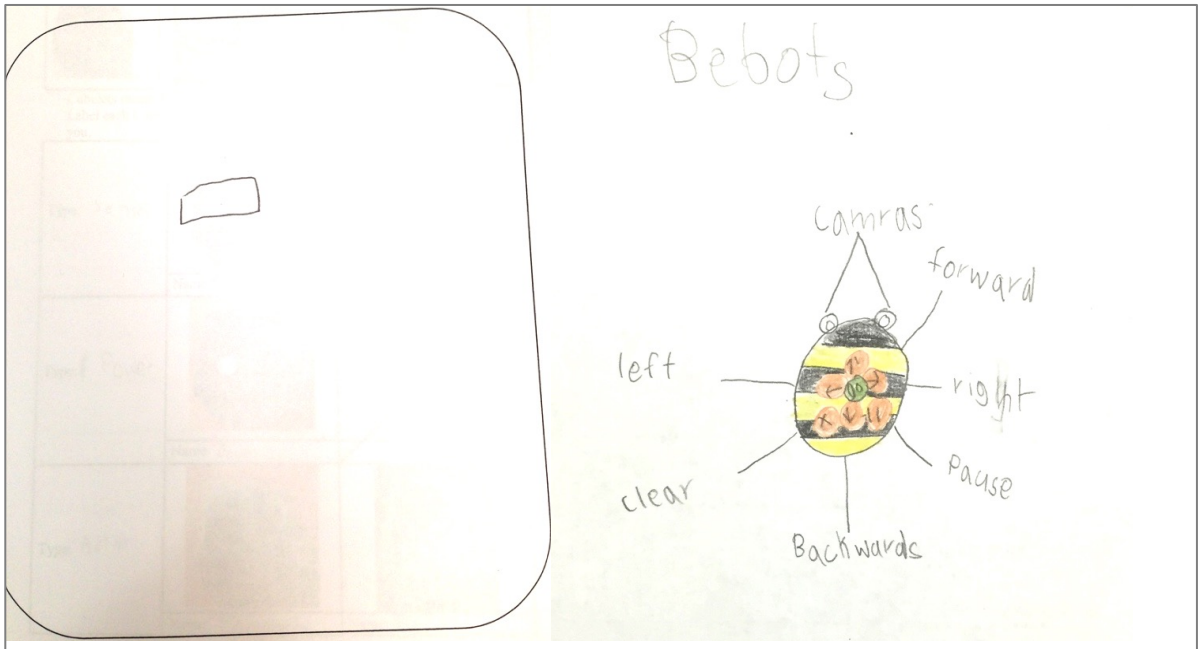


Figure 4.30 Shelby's pre- (left) and post-instruction (right) drawings: (left)- no drawing (right)- Bebots [bee-bot] with camras [cameras], forward, right, pause, backwards, clear, left

Another child, Shelby, drew a small square in the pre-instruction drawing (see the photo on the left in Figure 4.30). However, in the post-instruction drawing (see the photo

on the right in Figure 4.30), she drew a "Bebots" [Bee-Bot] and labeled each part: "camras" [cameras] and command buttons, including "forward, right, pause, backward, clear, [and] left."

As described earlier, in the pre-instruction drawing, Kaity drew a Cubelet shaped robot. In the post-instruction drawing (see Figure 4.31), she drew a Bee-Bot and wrote: "A beebot's talent is to move. You give it commands and it rollous [rolls out] them. My favorite robot class was Beebots class. The [They] even look like bees." She labeled the Bee-Bot with a "head, symbols/commands, forward, right, go, pause, backward, wheels, clear, and left."

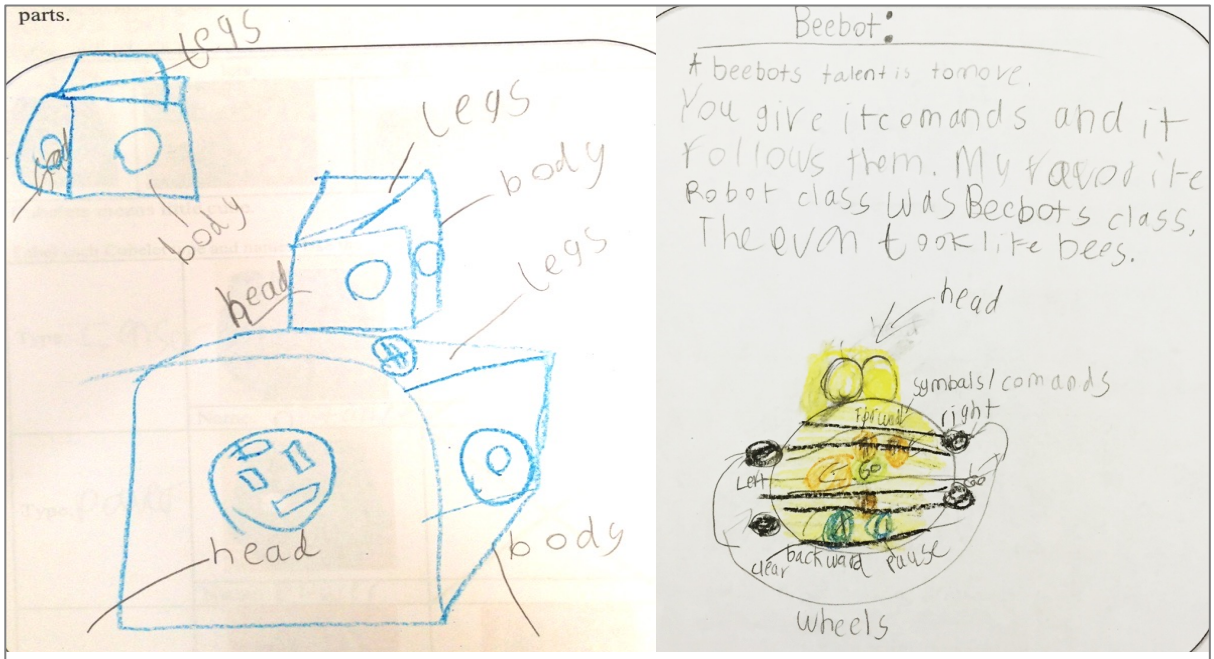


Figure 4.31 Kaity's pre drawing and post-instruction drawing: (pre) legs, body, legs, body, head, head, body, legs (post) "Beebot: Beebots talent is to move. You give it commands and it rollous [rolls out] them. My favorite robot class was Beebots class. They even look like bees." (clockwise) head, forward, symbols/commands, right, go, pause, backward, wheels, clear, left

These three girls drew a Bee-Bot in their post-instruction drawing, and those drawings and labels looked similar to the Bee-Bots' appearance and function. The Bee-Bots in these three girls' post-instruction drawings were colored with yellow and black,

and the three girls attempted to label each command button.

Similar Robots between Pre- and Post-Instruction Drawings

Four children drew their robots with almost no difference between their pre- and post-instruction drawings, and two of them were 7 years-old (one year younger than their classmates) at the time of implementation.

Cristian. Cristian (an 8 year-old Latino boy) participated in all the activities. In his pre-instruction drawing, he drew a human shaped robot having a head, arms, body, legs, and feet (see Figure 4.32). His post-instruction drawing did not change much from the pre-instruction drawing except for the function of stretching (see Figure 4.33).

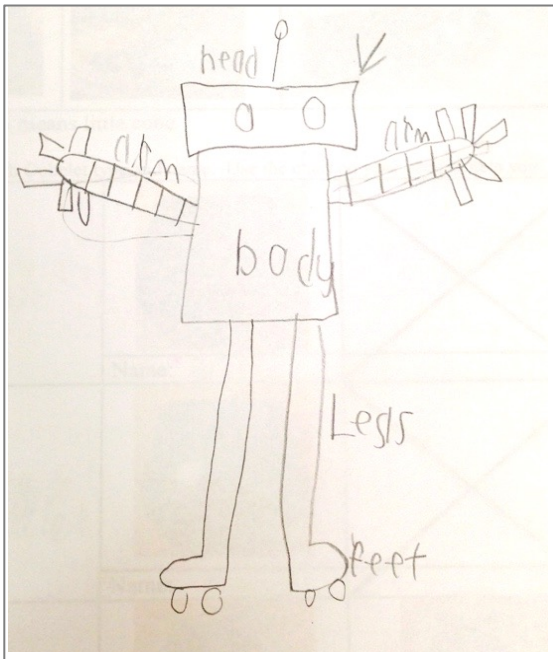


Figure 4.32 Cristian's pre-instruction drawing: (clockwise) head, arm, body legs, feet, arm

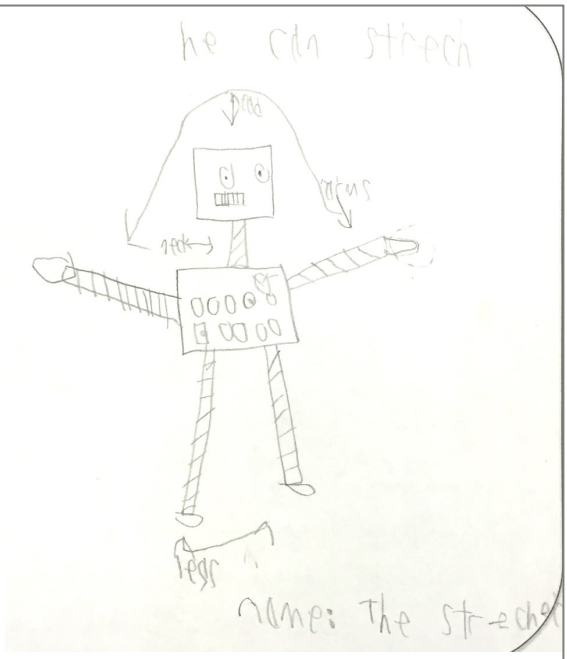


Figure 4.33 Cristian's post-instruction drawing: "he can stretch" (clockwise) head, arms, neck, legs, "name: the strecher [stretcher]"

In the post-instruction drawing, he wrote, "He can stretch," and he drew and labeled head, arms, neck, and legs. He named it "the stretcher [stretcher]."

Cristian's writings showed that his understanding about robots had not changed from pre- and post-writings, either (see Table 4.10). In the pre-instruction writing, he wrote that robots "move by themselves [themselves]," and in the post-instruction writing, he wrote that "a robot is a machine that works by itself." He responded in his pre- and post-writings that robots have locomotive characteristics, and his pre-instruction drawing showed his robot wore roller skates. His written response both from pre- and post-writings showed that a robot is a machine that works for people (e.g., "carry heavy stuff" "can do the work") in pre-instruction writings and "move and grab stuff" "can do the work faster" in the post-instruction writings. Although he added the idea of "work faster" in the post-instruction drawing, other ideas about robots (e.g., locomotive, carry stuff, grab stuff) overlapped.

Table 4.10

Cristian's Pre- and Post-Instruction Writings about Robots

Questions	Pre-instruction writing	Post-instruction writing
1. What is a robot?	A robot is a machine that works for you.	A robot is a machine that works by itself.
2. What can robots do?	Robots can carry heavy stuff.	They can move and grab stuff.
3. Where can we find robots?	At factories the dumpster	We can find them at factories.
4. Why do people build robots?	They build robots so the robots can do the work.	So the robots can do the work faster.
5. How are robots similar to and different from other machines?	The robots move by themselves and you have to move machines but they are both metal.	A robot can make and a machine stays.

Emma. Another girl, Emma (a 7 year-old European-American girl) also drew similar robots in her pre- and post-drawings. She attended all the activities. Her pre- (Figure 4.34) and post- (Figure 4.35) drawings of a robot were human-shaped robots,

which had a head, a body, arms, legs, eyes, and a mouth. She used colors to draw a robot in her post-drawing, but the functions or design had not changed.

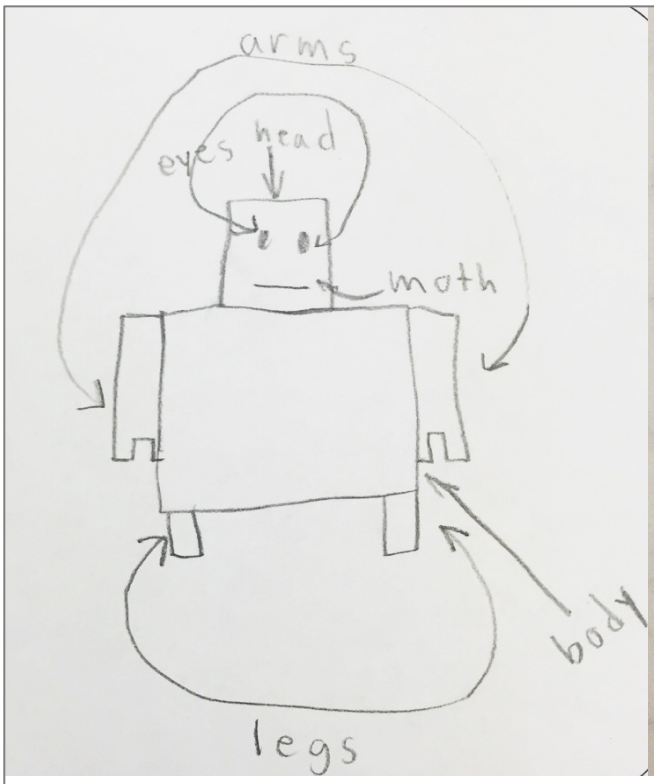


Figure 4.34 Emma's pre-instruction drawing: (clockwise) arms, eyes, head, moth [mouth], body, legs

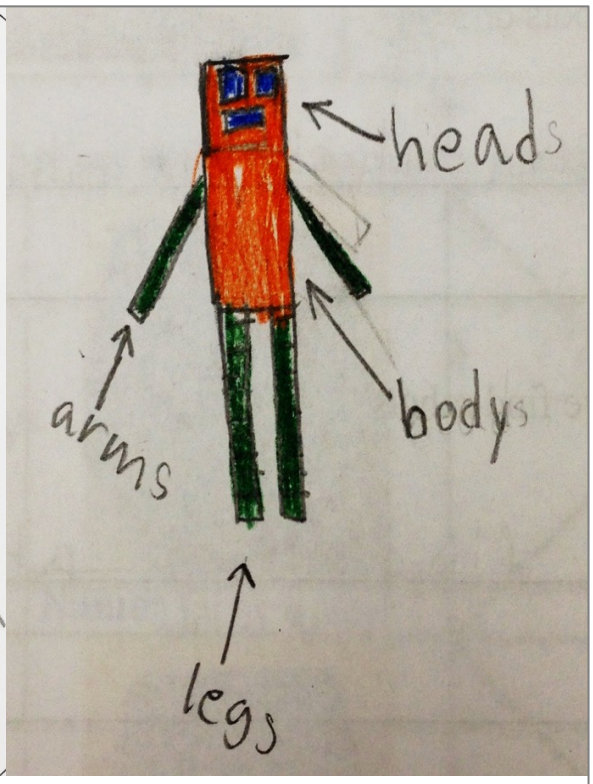


Figure 4.35 Emma's post-instruction drawing: (clockwise) head, body, legs, arms

Table 4.11

Emma's Pre- and Post-Instruction Writings about Robots

Questions	Pre-instruction writing	Post-instruction writing
1. What is a robot?	It is a machenical [mechanical] machine.	Robots are machines.
2. What can robots do?	They can grab and move stof [stuff].	Robots can help people.
3. Where can we find robots?	I do not know.	You can find some at stores.
4. Why do people build robots?	I do not know.	They build them to help them.
5. How are robots similar to and different from other machines?	I do not know.	Because I do not like it

Emma responded in her pre-instruction writing that robot is a "mechanical [machenical] machine," and "they can grab and move stof [stuff]." In her post-writing, similarly, she answered that "Robots are machines," and "Robots can help people." In her post-writing, robots can be found at "stores," and people build robots "to help them [people]" (see Table 4.11).

Mark. Mark (a 7 year-old Latino boy) participated in all activities in the robotics class. In the pre-instruction drawing, Mark drew a robot with zombie teeth, a flame thrower, and a claw (see Figure 4.36). In the post-instruction drawing, his robot held a sword and wore a hockey mask, which was named *Jason Voohe* (see Figure 4.37).

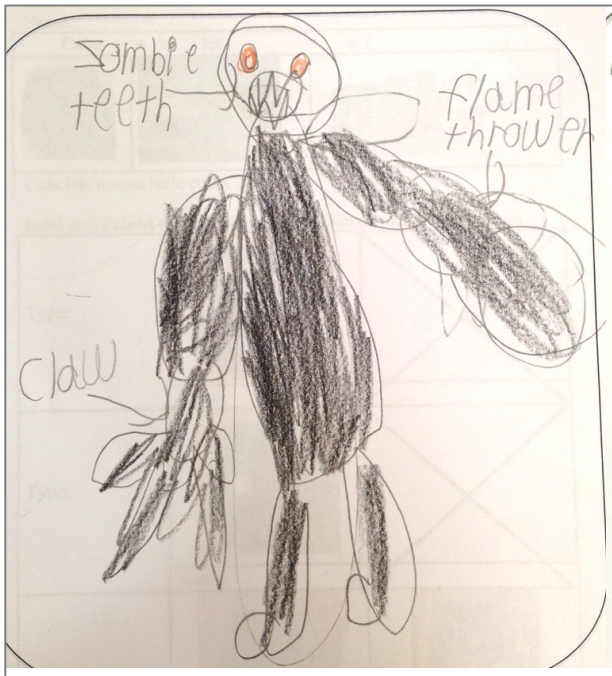


Figure 4.36 Mark's pre-instruction drawing: (clockwise) flame thrower, claw, zombie teeth



Figure 4.37 Mark's post-instruction drawing: (clockwise) Mashataiy [Machete], Jason voohes (name), ceereeol [serial] killer, hockey mask, killing

Some parts were changed, but both have human body parts, including a head, a body, two arms, and legs. The post-instruction drawing of a robot had an extra function of "killing," and I understood his pre- and post-instruction drawings as powerful beings

in his imagination. In the pre- and post-instruction writings (see Table 4.12), Mark's idea had not changed. In both writings, Mark wrote that robots can be found "in factories," and robots are made [for people] "to be lazy." He differentiated in comparing machines, so in his pre-writing he wrote that "robots and machines run on gas," and in his post-writing he wrote that robots have hands.

Table 4.12

Mark's Pre- and Post-Instruction Writings about Robots

Questions	Pre-instruction writing	Post-instruction writing
1. What is a robot?	Robots are in a factory androids fight.	A robot is a machine that helps people.
2. What can robots do?	They can work.	Help people
3. Where can we find robots?	In factories	In factories
4. Why do people build robots?	To be lazy	To be lazy
5. How are robots similar to and different from other machines?	They both run on engines. Some machines run on gas.	Robots have hands.

Mark's conception of robots from his drawings and writings was different, much like the other boys discussed earlier. His pre- and post-instruction drawings were aggressive robots with weapons (e.g., claw, flame thrower, mashataiy [machete]); however, in the pre- and post-instruction writings, robots are functional (e.g., "work" "in factories" "have hands") and positive (e.g., "help people" "to be lazy"). Mark's ideas about robots were contradictory between his drawings and writings, and this pattern was discovered with Josue and Issac. Josue and Issac drew their robots with sophisticated functions and designs in the post-instruction drawings, and these functions and designs were furious and powerful, including sniper rifle, jet boots, feat hands, and death gear.

I noticed that Cristian and Emma, in their pre- and post-drawings, tended to draw robots with similar designs and functions. In the pre- and post-instruction writings, their ideas about robots were not sophisticated, and their written responses were similar. Emma responded "I do not know" for three questions out of five. Mark drew his robots as aggressive beings in the pre- and post-instruction drawings, and the robots did not expand their functions in his writings. These children had attended all activities, and they were seven years-old at the time of implementation.

Discussion

Drawing on Bakhtin's (1981) notion of hybridity, analysis on the children's drawings of and writings about robots showed that the children's ideas about robots were hybridized through their imagination and experiences (e.g., animations, movies, cartoons, robotic manipulatives–Bee-Bots and Cubelets, robots from the class movie). In their post-instruction drawings, three girls drew a robot which looked like a girl or herself. Five boys in their post-instruction drawing drew robots having sophisticated functions and designs, compared to their pre-instruction drawings. Another five children in their post-instruction drawing drew robots that they had seen in the video and drew Bee-Bots and Cubelets. Lastly, four children drew a robot that had similar functions and designs between the pre- and post-instruction drawings. Their pre- and post-instruction writings also did not show idea changes.

The children's pre- and post-instruction writings represented a similar pattern in their idea expansion or changes in drawings. In the writings of three children who drew girl-like robots and the children who drew human body shaped robots, they described their conception of robots situated in-between humans and machines (e.g., a robot is a

built person, a robot is a machine that can be human being). In the drawings of the children who drew sophisticated robots in their post-drawings, their writings showed that their robots had developed compared to the pre-instruction writings and their functions varied. Three boys drew their robots with aggressive functions (e.g., serial killer, zombie teeth, death gear, sniper rifle) in the post-instruction drawing, and interestingly their pre- and post-instruction writings showed that their robots can help people.

The children's imaginations about robots freely crossed between human and non-human. The children's robots have human-like characteristics (e.g., speaking, making sounds, moving around, carrying stuff & human shaped body parts) with mechanical aspects (e.g., jet boots, antennae, grabber, on/off switch). The children's hybridized perceptions on robots blurred the boundaries between human and non-human and/or humans and machines. However, the Next Generation Science Standards (2013) emphasize distinguishing between living and non-living things and between human and nonhuman. One of the standards for K- 2nd graders is titled, "From Molecules to Organisms: Structures and Processes (1-LS1)." In this standard, animals, materials, and the natural world are divided in order to learn the patterns, structures, and functions of nature and objects.

Pitsch and Koch (2010) argued that 3-8 year-old children's animistic views cannot be defined with a single definition. These authors explained that the children's perceptions and categorizations of a robot (i.e., the robotic baby dinosaur Pleo) emerge and change at each incident throughout their interactions. In their study, there was no clear limit to determine living and non-living characteristics in robots. Specifically, the robot–Pleo–in the study has been variously considered as an inanimate object, an animate

object that initially looked aggressive, an animate object that is able to engage with a focal child in interactions, and finally a multifunctional object with which the child can interact in different (real and symbolic) worlds. In the past few years, researchers suggested that artefacts with living characteristics (e.g., personal/intentional behaviors, cognitive/emotional aspects) should be described in an "animate-inanimate continuum" (Keil 1991; van Duuren & Scaife, 1995).

In this study, I suggest several thoughts for research and educational practices. First, a science standard for distinguishing between human and nonhuman does not match with children's hybridized conceptualizations to understand the world. When adults see the children's blurred boundaries between animate and inanimate, they may realize they have their own fixed preconceptions about the boundaries. Drawing on Bakhtin's notion of hybridity, we can learn from the children's openness and build a classroom where their perceptions are nurtured.

Second, in this study, children hybridized ideas from popular culture helped us to understand the children's perspectives in terms of their thoughts and images about robots. Children's popular culture such as movies, animations, and cartoons need to be studied because children use popular culture to refer to their own ideas and views about real life. Third, children are active participants both in imagining and manipulating robots. In learning robotics, they were able to elaborate on their original ideas (e.g., a human shaped robot became a girl-like robot) with enthusiasm. Fourth, in the pre- and post-instruction drawings, several robots have aggressive and fearful functions and designs due to the children's imaginations of powerful beings; however, in the pre- and post-instruction writings, those children who drew masculine robots wrote that their robots also have

positive roles. For instance, Mark wrote, "A robot is a machine that helps people," and we can find robots "in factories." Issac wrote robots "solve problems of all sorts," and robots can be found in "stores or farms." These examples show how these boys in their fantasy freely imagined robots and their competences, and the boys might *pretend to be just what they know they will never be* (Jones, 2008).

CHAPTER 5

CONCLUSION

The purpose of this study was to identify and trace various actors and their heterogeneous associations in a robotics class to move beyond the limitations of the theoretical frameworks of constructivism and constructionism. The previous research using constructivism and constructionism on robotics education tended to emphasize the one-way influence of robotic manipulatives on children's learning. In this study, I attempted to explore the multi-dimensional relationships among the multiple actors. The central research question for this study was: What actors are associated with robotics learning of 2nd graders? Drawing on ANT (Latour, 2005), three chapters investigated different actors: In Chapter 2, I was able to trace and identify the human, material, and quasi-human/quasi-material actors in programming Bee-Bots. In Chapter 3, I considered the roles performed by the participating children in the problem identification and robot building activity. I learned that various abilities, including generating problems/ideas, confirming ideas, and elaborating on ideas, were associated with problem identification in robot building. In addition, other actors, including robotic manipulatives, peer comments, teacher questions, and engineer logs, were also involved in the children's problem generation and robot building activity. In Chapter 4, I identified a variety of actors which were involved in children's conceptualization of robots as reflected in their pre- and post-instruction drawings and writings. Compiling all the information, I created

a network of actors (see Figure 5.1). In Figure 5.1, three chapters reflect how the process of learning about robotics is intermingled with materials, humans, and quasi-material/quasi-humans actors.

Implications for Early Childhood Robotics Education

This dissertation study has several implications for the field of early childhood robotics education. First, shown in Figure 5.1, drawing on Latour's (2005) ANT, varied actors were associated with learning about robotics, and these actors allowed us to move beyond examining the one-way influence of robotic manipulatives on children's learning in previous studies that used constructivism and constructionism. Use of ANT allowed us to see the roles of the strongly connected networks of robotic manipulatives–Bee-Bots and Cubelets, engineer logs, comments from adults, peer demonstrations, and so on. I see that each one of these actors was involved in making differences. In this dissertation study, use of ANT allowed me to discover actors which have not been revealed in previous studies. For instance, in Chapter 2, the children who used engineer logs as a means of recording showed a higher percentage of success in programming than the children who did not. The children's use of engineer logs might be associated with their interests and preferences related to programming experiences. We need to pay attention to how activity logs can be designed and provided to children in programming activities in particular and in educational activities in general.

Using ANT allowed us to see the actors' associations (e.g., confusion with the turn button, Bee-Bots' design and system, failure to push the reset button), and this fact has not been emphasized in previous research. I see that actors do not work by themselves, but work together when they are linked with other nodes.

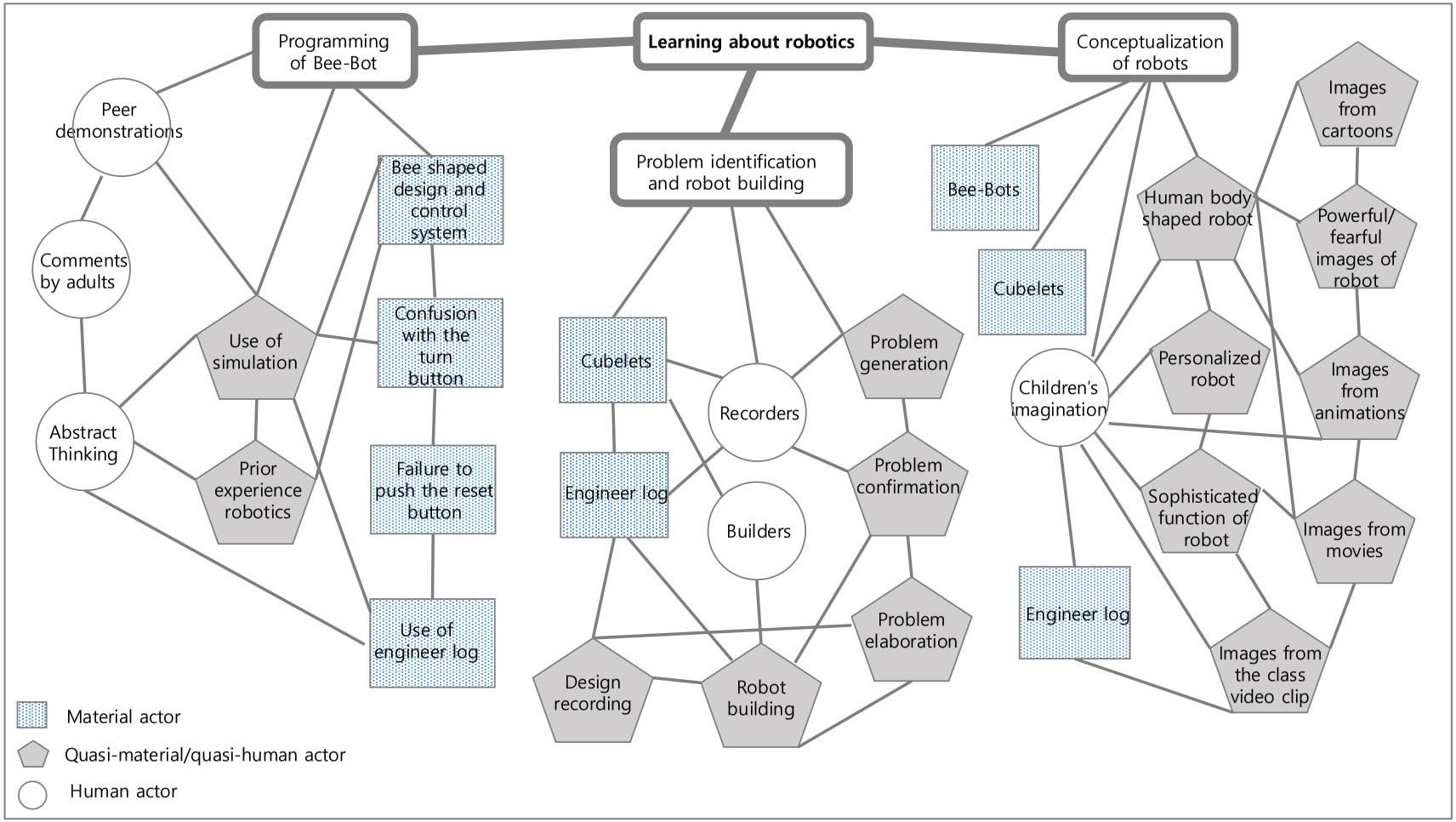


Figure 5.1 Actors associated with 2nd graders robotics class

In ANT, networks are held with those nodes:

> ANT's unique contribution is to focus on the individual nodes holding these networks together, examining how the connections came about and what sustains them. These include negotiations, forces, resistances, and exclusions, which are at play in these micro-interactions that eventually forge links. (Fenwick & Edwards, 2010, p. 9)

Second, this dissertation study used two different robotic manipulatives–Bee-Bots and Cubelets. Two different groups of the participating children in the Bee-Bot class had different experiences in learning robotics. One group started with Bee-Bots class as their first robotics class, and the other group experienced learning robotics with the Cubelets class and moved to the Bee-Bots class. In Chapter 2, I was able to identify that the group who had previously experienced Cubelets tended to do more abstract thinking and use more simulations than the other group who had experienced only the Bee-Bot class (see Figure 2.13). Abstract thinking and the use of simulation were actors strongly associated with programming Bee-Bots. Thus, experience in learning about robotics was also an actor.

Regarding the tools–Bee-Bots and Cubelets, Dr. Chi Thai (personal communication, November 8, 2017) told me that these two robotic manipulatives have different systems. Using his material (see Figure 5.2), Dr. Thai explained that robots have a "sense-think-act paradigm" in that sensors detect inputs and actuators create outputs through a computer. In Bee-Bots, command buttons create inputs (sensors), and movements with beeping sounds are actuators (outputs). Cubelets are pre-programmed

so that when a sensor detects inputs (e.g., light, object), it automatically shows actions (e.g., moves around, makes sounds, turns lights on) without passing through computers.

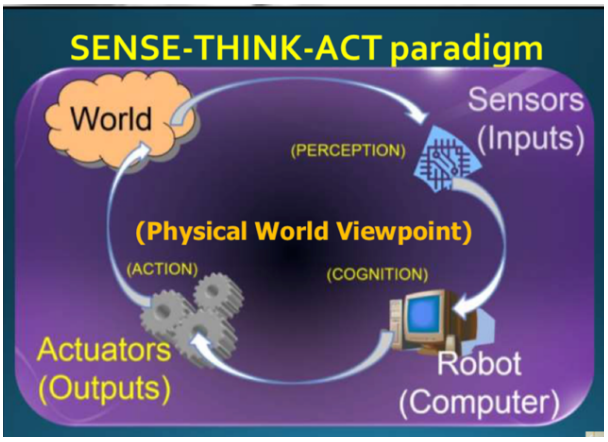


Figure 5.2 Dr. Thai's sense-think-act paradigm of robots

Based on these two different tools, the participating children showed various preferences for them (see Chapter 2). This finding suggests the importance of further investigation into the different types of robotic manipulatives in children's robotics learning. Future research on using two or more robotic manipulatives needs to focus on which type of tools match children's interests and preferences; which sequence is the most effective in learning; or if the sequence of activities influences knowledge transfer from one setting to the other.

Third, we need to expand the research on learning robotics into problem identification and the robot building process. NGSS (2013) emphasized "defining problems" and "designing solutions" for engineering. The National Research Council (2012) explained that "for engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution" (p. 56). NRC further explained the process of designing solutions in engineering:

> The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however,

> have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation. (pp. 68–69)

Chapter 3 showed the 2nd graders' problem identification and robot building process. With careful observation on the process of what kinds of problems the participating children defined and elaborated, I found that the children who were not the main builders actively engaged in idea generation, confirmation, and elaboration. Similarly, in arts education, a child's drawing and art making process does not refer to the drawing performance itself; rather, Schulte (2011) explained that verbal articulation, drawing, and thinking emerge as part of the art making process. Thus, I argue that children who generate and elaborate on ideas are also robot builders. In engineering education research, we need to expand our understanding about how children identify their own problems, define them, and build their robots. Regarding the children's various roles in robot building activities, further research is necessary to examine at what point the children divide their roles (e.g., idea generator, a builder, a recorder) and how their role negotiation and performance are related to their prior experience with robotic manipulatives (e.g., Legos), their gender, and their performance in reading, writing, and other academic areas.

As I explained in Chapter 4, the children drew human body shaped robots in their pre- and post-instruction drawings, and their image of these robots tended to come from

popular culture (e.g., animations, movies, cartoons). Experiencing various robotic manipulatives, observing a variety of robots from videos, and visiting places where people use robots can expand and enrich children's understanding about robots. In the children's drawings, they had blurred the boundaries between human and machine as well as between animate and inanimate. In our society hybridity between artificial and natural existences has been advocated and increasingly available, and young children's hybridized conceptualization fits in with this trend. Thus, their perceptions should be nurtured instead of being pushed to adopt the binary categorization. In addition, the children's drawings revealed their fantasy and (i.e., robots can do things that humans cannot do) and their desire to be powerful. We need to be careful not to interpret their images literally (Tobin, 2000).

REFERENCES

Achieve. (2013). *Next Generation Science Standards*. Retrieved from http://www.nextgenscience.org/next-generation-science-standards

Alfonso, S. (2016). Implementing the project approach in an inclusive classroom: A teacher's first attempt with project-based learning. *Voice of Practitioners, 11(*1), 52-59.

Badcock, P. B., Pattison, P. E., & Harris, K. L. (2010). Developing generic skills through university study: a study of arts, science and engineering in Australia. *Higher Education*, *60*(4), 441-458.

Bakhtin, M. M. (1981). *The Dialogic Imagination: Four Essays*, translated by Caryl Emerson and Michael Holquist, Austin.

Barris, C., Torres, L., & Simon, E. (2016). Learning based on the project entitled "Design and Construction of a wooden bridge" *Journal of Technology and Science Education*. doi: http://dx.doi.org/10.3926/jotse.219 Retrieved 31 Jan 2018.

Bath, D., Smith, C., Stein, S., & Swann, R. (2004). Beyond mapping and embedding graduate attributes: Bringing together quality assurance and action learning to create a validated and living curriculum. *Higher Education Research and Development, 23*, 313–328.

Beals, L., & Bers, M. (2006). Robotic technologies: When parents put their learning ahead of their child's. *Journal of Interactive Learning Research, 17*(4), 341–366.

Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education*, *58*(3), 978-988.

Beran, T. N., Ramirez-Serrano, A., Kuzyk, R., Fior, M., & Nugent, S. (2011). Understanding how children understand robots: Perceived animism in child–robot interaction. *International Journal of Human-Computer Studies, 69*(7-8), 539-550.

Berlyand, I. E. (2009). Puzzles of the number: Dialogue in the early grades of the School of the Dialogue of Cultures. *Journal of Russian & East European Psychology, 47*(1), 3–19.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, *72*, 145-157.

Bers, M. U., & Portsmore, M. (2005). Teaching partnerships: Early childhood and engineering students teaching math and science through robotics. *Journal of Science Education and Technology*, *14*(1), 59-73.

Bers, M. (2010). The tangibleK robotics program: Applied computational thinking for young children. *Early Childhood Research & Practice. 12*(2), n2.

Betz, D. E., & Sekaquaptewa, D. (2012). My fair physicist? Feminine math and science role models demotivate young girls. *Social Psychological and Personality Science, 3*(6), 738-746

Blank, J., Damjanovic, V., Silva, A., & Weber, S. (2014). Authenticity and "standing out:" situating the project approach in contemporary early schooling. *Early Childhood Education Journal, 42*, 19-27.

Bumby, K., & Dautenhahn, K. (1999, August). Investigating children's attitudes towards robots: A case study. *Proceedings of The Third International Cognitive Technology Conference CT99,* 391-410.

Butler-Kisber, L. (2010). *Qualitative inquiry: Thematic, narrative and arts-informed perspectives*. Sage Publications.

Buxton, C. A. (2006). Creating contextually authentic science in a "low-performing" urban elementary school. *Journal of Research in Science Teaching*, *43*(7), 695-721.

Cabibihan, J. J., Javed, H., Ang, M., & Aljunied, S. M. (2013). Why robots? A survey on the roles and benefits of social robots in the therapy of children with autism. *International journal of social robotics, 5*(4), 593-618.

Castledine, A. & Chalmers, C. (2011). LEGO Robotics: An authentic problem-solving tool? *Design and Technology Education, 16*(3), 19-27.

Cho, E., Lee, K., Cherniak, S., & Jung, S. E. (2017). Heterogeneous Associations of Second-Graders' Learning in Robotics Class. *Technology, Knowledge and Learning*, *22*(3), 465-483.

Christopher, R. (2017). Hip Hop DJs and the Evolution of Technology: Cultural Exchange, Innovation, and Democratization. *The Journal of Hip Hop Studies, 4*(1), 148-149.

Chun-Wang, W., I-Chun, H., Ling, L., & Nian-Shing, C. (2011). A joyful classroom learning system with robot learning companion for children to learn mathematics multiplication. *The Turkish Online Journal of Educational Technology, 10*(2), 11–23.

Cook, S. E. (2004). New technologies and language change: Toward an anthropology of linguistic frontiers. *Annual Review of Anthropology, 33*, 103-115.

Correa-Chávez, M., Rogoff, B., & Mejía Arauz, R. (2005). Cultural patterns in attending to two events at once. *Child Development*, *76*(3), 664-678.

Daugherty, J. L., & Custer, R. L. (2012). Secondary level engineering professional development: Content, pedagogy, and challenges. *International Journal of Technology and Design Education*, *22*(1), 51–64.

Denson, C. D., Kelley, T. R., & Wicklein, R. C. (2009). Integrating engineering design into technology education: Georgia's Perspective. *Journal of Industrial Teacher Education, 46*(1). Retrieved from http://scholar.lib.vt.edu/ejournals/JITE/v46n1/denson.html

De Jong, T., Van Joolingen, W. R., Giemza, A., Girault, I., Hoppe, U., Kindermann, J., ... & Weinbrenner, S. (2010). Learning by creating and exchanging objects: The SCY experience. *British Journal of Educational Technology*, *41*(6), 909-921.

Disessa, A. A. (2000). *Changing minds*. Cambridge, MA: MIT press.

Donnelly, D. F., McGarr, O., & O'Reilly, J. (2014). 'Just Be Quiet and Listen to Exactly What He's Saying': Conceptualising power relations in inquiry-oriented classrooms. *International Journal of Science Education*, *36*(12), 2029-2054.

Edwards, S. (2016). New concepts of play and the problem of technology, digital media and popular-culture integration with play-based learning in early childhood education. *Technology, Pedagogy and Education, 25*(4), 513-532.

Edwards, R., Biesta, G., & Thorpe, M. (Eds.). (2009). *Rethinking contexts for learning and teaching: Communities, activities and networks*. Routledge.

Eisenhart, M. (2001). *The meaning of culture in the practice of educational research in the US and England.* In meeting of VIIIe Congrès International de l'Association pour la Recherche Interculturelle, Geneva, Switzerland. Retrieved from http://www.unifr.ch/ipg/aric/assets/files/ARICManifestations/2001Actes8eCongres/EisenhartM.pdf

Eguchi, A. (2014, July). *Robotics as a learning tool for educational transformation*. Paper presented at the meeting of 5th International Conference Robotics in Education, Italy.

Fenwick, T., & Edwards, R. (2010). *Actor-network theory in education*. Routledge.

Gattie, D., & Wicklein, R. (2007). Curricular value and instructional needs for infusing engineering design into K-12 technology education. *Journal of Technology Education, 19*(1), 6-18.

Gelman, R., Spelke, E. S., and Meck, E. (1983). What preschoolers know about animate and inanimate objects. In Rogers, D., and Sloboda, J. (Eds.), *The development of symbolic thought* (pp. 297-328). London: Plenum.

Golinkoff, M., Harding, G., Carlson, V., & Sexton, E. (1984). The infant;s perception of causal events: the distinction between animate and inanimate objects. In L.P. Lipsitt & C. Rovee-Collier (Eds.) *Advances in Infancy Research*. Norwood NJ: Ablex.

Gopnik, A., Glymour, C., Sobel, D., Schultz, L., & Kushnir, T. (2001). Theory formation and causal learning in children: Causal maps and bayes nets. *Psychological Review*.

Graue, M. E., & Walsh, D. J. (1998). *Studying children in context: Theories, methods, and ethics*. Sage.

Hanks, B., Fitzgerald, S., McCauley, R., Murphy, L., & Zander, C. (2011). Pair programming in education: A literature review. *Computer Science Education*, *21*(2), 135-173.

Hamlen, K. R. (2010). Re-examining gender differences in video game play: Time spent and feelings of success. *Journal of Educational Computing Research*, *43*(3), 293-308.

Harman, G. (2010). *Prince of networks: Bruno Latour and metaphysics*. Re.press.

Heybach, J. & Pickup, A. (2017). Whose STEM? Disrupting the gender crisis within STEM. *Educational Studies, 53*(6), 614-627.

Highfield, K., Mulligan, J., & Hedberg, J. (2008). Early mathematics learning through exploration with programmable toys. *Proceedings of the International Group for the Psychology and Mathematics Education, Mexico, 32,* Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.688.897&rep=rep1&type=pdf#page=198

Highfield, K. (2010). Robotic Toys as a Catalyst for Mathematical Problem Solving. *Australian Primary Mathematics Classroom*, *15*(2), 22-27.

Horn, M. S., Crouser, R. J., & Bers, M. U. (2012). Tangible interaction and learning: the case for a hybrid approach. *Personal and Ubiquitous Computing*, *16*(4), 379-389.

Howard, V. A., & Barton, J. H. (1986). *Thinking on paper*. New York: Morrow.

Hoyles, C., & Noss, R. (2003). What can digital technologies take from and bring to research in mathematics education? In *Second international handbook of mathematics education* (pp. 323-349). Springer, Dordrecht.

Janka, P. (2008). Using a programmable toy at preschool age: why and how. In *Teaching with robotics: didactic approaches and experiences. Workshop of International Conference on Simulation, Modeling and Programming Autonomous Robots (SIMPAR 2008)*.

Jenkins, H. (2006). *Convergence culture: Where old and new media collide*. NYU press.

Jones, G. (2008). *Killing Monsters: Our Children's Need For Fantasy, Heroism, and Make-Believe Violence*. Basic Books.

Jones, S., & Myhill, D. (2004). 'Troublesome boys' and 'compliant girls': Gender identity and perceptions of achievement and underachievement. *British Journal of Sociology of Education*, *25*(5), 547-561.

Katehi, L., Pearson, G., Feder M. (2009). The status and nature of K-12 engineering education in the United States. *The Bridge, 39*(3), 5-10.

Kazakoff, E. R. & Bers, M. U. (2012). Programming in a robotics context in the kindergarten classroom: The impact on sequencing skills. *Journal of Educational Multimedia and Hypermedia, 21*(4), 371-391.

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal, 41*, 245-255.

Keil, F. C. (1991). Intuitive belief systems and informal reasoning in cognitive development. In J. Voss, D. Perkins & J. Segal (Eds.), *Information Reasoning and Education* (pp. 247-264). New York, NY: Routledge.

Kelleher, C., Pausch, R., & Kiesler, S. (2007, April). Storytelling alice motivates middle school girls to learn computer programming. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 1455-1464). ACM.

Kelley, T. R., & Wicklein, R. C. (2009). Teacher challenges to implement engineering design in secondary technology education (Third article in 3-part series). *Journal of Industrial Teacher Education*, *46*(3), 34–50. Retrieved from http://scholar.lib.vt.edu/ejournals/JITE/v46n3/pdf/kelley.pdf

Kessels, U. (2015). Bridging the gap by enhancing the fit: how stereotypes about STEM clash with stereotypes about girls. *International Journal of Gender, Science and Technology*, *7*(2), 280-296.

Kessels, U., Rau, M., & Hannover, B. (2006). What goes well with physics? Measuring and altering the image of science. *British Journal of Educational Psychology*, *76*(4), 761-780.

Kozulin, A. (1990). *Vygotsky's psychology: A biography of ideas*. Cambridge, MA: Harvard University Press.

Krajcik, J. S., & Blumenfeld, P. C. (2006). Project-based learning. In R. Keith Sawyer (Ed.) *The Cambridge Handbook of the Learning Sciences* (pp. 317-334) Cambridge University Press.

Kushnir, T., & Gopnik, A. (2007). Conditional probability versus spatial contiguity in causal learning: Preschoolers use new contingency evidence to overcome prior spatial assumptions. *Developmental psychology*, *43*(1), 186.

Latour, B. (2005). *Reassembling the Social: An Introduction to Actor- Network- Theory*. New York, NY: Oxford University Press.

Leander, K. M. (2001). "This is our freedom bus going home right now": Producing and hybridizing space-time contexts in pedagogical discourse. *Journal of Literacy Research, 33*(4), 637-679.

Levy, S. T., & Mioduser, D. (2008). Does it ''want'' or ''was it programmed to...''? Kindergarten children's explanations of an autonomous robot's adaptive functioning. *International Journal of Technology and Design Education, 18*, 337–359.

Law, J. (2002). Objects and Spaces. *Theory Culture Society*, *19*(5-6), 91-105.

Lethbridge, T. C., Singer, J., & Forward, A. (2003). How software engineers use documentation: The state of the practice. *IEEE software*, *20*(6), 35-39.

Levy, S. T. & Mioduser, D. (2008). Does it "want" or "was it programmed to…"? Kindergarten children's explanations of an autonomous robot's adaptive functioning. *International Journal of technology and Design Education, 18*, 337-359.

Lleras, C., & Rangel, C. (2008). Ability grouping practices in elementary school and African American/Hispanic achievement. *American Journal of Education*, *115*(2), 279-304.

Liu, E. Z., Lin, C. H., Liou, P. Y., Feng, H. C., & Hou, H. T. (2013). An analysis of teacher-student interaction patterns in a robotic course for kindergarten children: A pilot study. *The Turkish Online Journal of Educational Technology, 12*(1), 9-18.

Master, A., Cheryan, S., Moscatelli, A., & Meltzoff, A. N. (2017). Programming experience promotes higher STEM motivation among first-grade girls. *Journal of experimental child psychology*, *160*, 92-106.

Marshall, D. (2010). Popular culture, the 'victim'trope and queer youth analytics. *International Journal of Qualitative Studies in Education, 23*(1), 65-85.

Mataric, M. J. (2004, March). Robotics education for all ages. In *Proceedings of the AAAI Spring Symposium on Accessible, Hands-on AI and Robotics Education*.

Mataric, M. J. (2007). *The robotics primer*. Mit Press.

Matusov, E. (2009). Guest Editor's Introduction to Parts I and II: The School of the Dialogue of Cultures Pedagogical Movement in Ukraine and Russia. *Journal of Russian & East European Psychology, 47*(1), 3-19.

Matusov, E. (2011). Irreconcilable differences in Vygotsky's and Bakhtin's approaches to the social and the individual: An educational perspective. *Culture & Psychology, 17*(1), 99-119.

McDonald, S., & Howell, J. (2012). Watching, creating and achieving: Creative technologies as a conduit for learning in the early years. *British Journal of Educational Technology. 43*(4), 641-651.

McKenney, S., & Voogt, J. (2010). Technology and young children: How 4–7 year olds perceive their own use of computers. *Computers in Human Behavior*, *26*(4), 656-664.

Mejía-Arauz, R., Rogoff, B., Dexter, A., & Najafi, B. (2007). Cultural variation in children's social organization. *Child development*, *78*(3), 1001-1014.

Merriam, S. B. (1988). *Case study research in education: A qualitative approach*. Jossey-Bass.

Mitnik, R., Nussbaum, M., & Soto, A. (2008). An autonomous educational mobile robot mediator. *Autonomous Robots*, *25*(4), 367-382.

Mikulec, E., & Miller, P. C. (2011). Using project-based instruction to meet foreign language standards. *The Clearing House*, *84*(3), 81-86.

Mioduser, D., & Betzer, N. (2008). The contribution of Project-based-learning to high-achievers' acquisition of technological knowledge and skills. *International Journal of technology and design education*, *18*(1), 59-77.

Mitchell, S., Foulger, T., Wetzel, L., & Rathkey, C. (2009). The negotiated project approach: Project-based learning without leaving the standards behind. *Early Childhood Education Journal, 36*(4), 339-346.

Miyazaki, K. (2006). Another imaginative approach to teaching: A Japanese view. *Academiea, 4*(5), 22–31.

Morson, G. S., & Emerson, C. (1990). *Mikhail Bakhtin: Creation of a prosaics.* Stanford University Press.

Moore, T. J., Glancy, A. W., Tank, K. M., Kersten, J. A., Smith, K. A., & Stohlmann, M. S. (2014). A framework for quality K-12 engineering education: Research and development. *Journal of pre-college engineering education research, 4*(1), 2.

Nugent, G., & Barker, B. (2010). Impact of robotics and geospatial technology interventions on youth STEM learning and attitudes. *Journal of Research on Technology in Education, 42*(4), 391-408.

National Research Council. (2013). Next generation science standards: For states, by states.

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press.

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International journal of science education*, *25*(9), 1049-1079.

Oulanne, L. (2016). Affective Bodies: Nonhuman and Human Agencies in Djuna Barnes's Fiction. *On_Culture: The Open Journal for the Study of Culture*. Retrieved from http://geb.uni-giessen.de/geb/volltexte/2016/12351/

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books, Inc.

Papert, S. & Harel, I (1991). *Constructionism*. Retrieved from http://www.papert.org/articles/SituatingConstructionism.html

Papert, S. (1980). *Powerful ideas in mind-size bites. Mindstroms: children, computers, and powerful ideas*. New York. NY: Basic Books.

Papert, S. (1991). Situating constructionism. In I. E. Harel & S. Papert (Eds.), *Constructionism* (pp. 1–11). Norwood, NJ: Ablex Publishing.

Papert, S. (1993). The children's machine. *Technology Review- Manchester NH, 96*, 28-28.

Papert, S. (1993). *The children's machine: Rethinking school in the age of the computer*. New York, NY: Basic Books.

Parks, A. N., & Schmeichel, M. (2014). Children, mathematics, and videotape: Using multimodal analysis to bring bodies into early childhood assessment interviews. *American Educational Research Journal*, *51*(3), 505-537.

Patrick, H., Mantzicopoulos, P., Samarapungavan, A., & French, B. F. (2008). Patterns of young children's motivation for science and teacher-child relationships. *The Journal of Experimental Education*, *76*(2), 121-144.

Petersen, C., & Nassaji, H. (2016). Project-based learning through the eyes of teachers and students in adult ESL classrooms. *Canadian Modern Language Review, 72*(1), 13-39.

Petre, M. & Price, B. (2004). Using robotics to motivate 'black door' learning. *Education and Information Technologies. 9*(2). 147-158.

Piaget, J. (1951). Principal Factors Determining Intellectual Evolution from Childhood to Adult Life. In D. Rapaport (Ed.), *Organization and Pathology of Thought* (pp. 154-175). New York, NY: Columbia University Press.

Piaget, J. (1973). *The Psychology of Intelligence.* New Jersey: Lifflefield, Adams and Cooperation.

Pitsch, K., & Koch, B. (2010). How infants perceive the toy robot pleo. an exploratory case study on infant-robot-interaction. *Proceedings AISB 2010 Symposium New Frontiers in Human-Robot-Interaction, Leicester, UK, 80-87*

Robertson, W., & Lesser, L. M. (2013). Scientific Skateboarding and Mathematical Music: Edutainment That Actively Engages Middle School Students. *European journal of science and mathematics education, 1*(2), 60-68.

Rockland, R. Bloom, D., Carpinelli, J., Burr-Alexander, L., Hirsch, L., & Kimmel, H (2010). Advancing the "E" in K-12 STEM education. *Journal of Technology Studies, 36*(1), 53-64.

Rogers, C., & Portsmore, M. (2004). Bringing engineering to elementary school. *Journal of STEM Education: innovations and research*, *5*(3/4), 17.

Roth, W. M. (1996). Art and artifact of children's designing: A situated cognition perspective. *The Journal of the Learning Sciences, 5*(2), 129–166.

Rusk, N., Resnick, M., Berg, R., & Pezalla-Granlund, M. (2008). New pathways into robotics: Strategies for broadening participation. *Journal of Science Education and Technology*, *17*(1), 59-69.

Schreiner, C. (2006). Exploring a ROSE garden: Norwegian youth's orientations towards science: seen as signs of late modern identities (Doctoral dissertation, University of Oslo Norway). Retrieved from https://www.duo.uio.no/bitstream/handle/10852/32331/schreiner_thesis.pdf?sequence=1&isAllowed=y

Schunn, C. (2011). *Design principles for high school engineering design challenges: Experiences from high school science classrooms*. Retrieved from

http://ncete.org/flash/pdfs/Design_Principles_Schunn.pdf

Schulte, C. M. (2011). Verbalization in children's drawing performances: Toward a metaphorical continuum of inscription, extension, and re-inscription. *Studies in Art Education, 53*(1), 20-34.

Shaffer, D. W. & Clinton, L. A. (2005). Tool for thoughts: Reexamining thinking in the digital age. *Wisconsin Center for Education Research*. 2005-(6).

Shaffer, D. W. & Clinton, K, A. (2006). Tool for thoughts: Reexamining thinking in the digital age. *Mind, Culture, and Activity, 13*(4), 283-300.

Smutny, J. F., Walker, S. Y., & Meckstroth, E. A. (2000). Teaching young gifted children in the regular classroom. ERIC Clearinghouse on Disabilities and Gifted Education, the Council for Exceptional Children.

Solomadin, I., & Kurganov, S. Y. (2009). The history of world culture as curricula of the middle and high schools of the dialogue of cultures. *Journal of Russian & East European Psychology, 47*(2), 3–29.

Sone, Y. (2014). Imaginary warriors: Fighting robots in Japanese popular entertainment performance. *Australasian Drama Studies, (65)*, 255.

Spolaôr, N., & Benitti, F. B. V. (2017). Robotics applications grounded in learning theories on tertiary education: A systematic review. *Computers & Education*, *112*, 97-107.

Steffens, M. C., & Jelenec, P. (2011). Separating implicit gender stereotypes regarding math and language: Implicit ability stereotypes are self-serving for boys and men, but not for girls and women. *Sex Roles*, *64*(5-6), 324-335.

Stager, G. (2001). Constructionism as a high-tech intervention strategy for at-risk learners. *Chicago, 22.* Retrieved from https://files.eric.ed.gov/fulltext/ED462949.pdf

Stooke, R. (2014). Producing neoliberal parenting subjectivities: ANT-inspired readings from an informal early learning program. *Journal of Childhood Studies*, *39*(1), 54.

Strawhackers, A., & Bers, M. U. (2015). "I want my robot to look for food": Comparing Kindergartner's programming comprehension using tangible, graphic, and hybrid user interfaces. *International Journal of Technology and Design Education*, *25*(3), 293-319.

Subramaniam, M., Ahn, J., Waugh, A., & Druin, A. (2012). Sci-fi, storytelling, and new media literacy. *Knowledge Quest, 41*(1), 22.

Tindol, R. (2012). The Star-Trek Borg as an all-American captivity narrative. *Brno studies in English, 38(*1).

Tobin, J. (2000). *"Good Guys Don't Wear Hats": Children's Talk about the Media*. Teachers College Press.

Tobin, J., & Hsueh, Y. (2007). The poetics and pleasures of video ethnography of education. *Video research in the learning sciences*, 77-92.

Tobin, J., Hsueh, Y., & Karasawa, M. (2009). *Preschool in three cultures revisited: China, Japan, and the United States*. University of Chicago Press.

Trouche, L., & Drijvers, P. (2010). Handheld technology for mathematics education: flashback into the future. *ZDM*, *42*(7), 667-681.

van Duuren, M., & Scaife, M. (1995). How do children represent intelligent technology?. *European Journal of Psychology of Education, 10*(3), 289-301.

van Eijck, M., & Roth, W. M. (2011). Cultural diversity in science education through novelization: Against the epicization of science and cultural centralization. *Journal of Research in Science Teaching, 48*(7), 824-847.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wagner, T. (2012). *Creating innovators: The making of young people who will change the world*. New York, NY: Scribner.

Weiss, A., Wurhofer, D., & Tscheligi, M. (2009). "I love this dog"—children's emotional attachment to the robotic dog AIBO. *International Journal of Social Robotics, 1*(3), 243-248.

Yin, R. K. (2009). *Case Study Research, Design & Methods 4th ed*.

APPENDIX

TRANSCRIPTION CONVENTIONS

( ): indication of behavior or facial expression

[ ]: added or corrected words to clarify for the reader