Chapter 11
Books, Butterflies, and 'Bots: Integrating Engineering and Robotics into Early Childhood Curricula

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Abstract Although we are surrounded by technology on a daily basis, the inner working of devices like phones and computers is often a mystery to children and adults alike. Robotics offers a unique way for children (and grown-ups!) to explore sensors, motors, circuit boards, and other electronic components together from the inside out. This chapter describes how robotics can be used as a playful medium in early childhood classrooms to learn foundational engineering and computer science concepts. By presenting vignettes from three early childhood classrooms that embarked on an eight-week KIBO robotics curriculum, this chapter highlights how educators with little to no prior engineering experience were able to successfully integrate robotics with traditional early childhood content such as literacy and science. KIBO is a developmentally appropriate robotics kit specifically designed for children ages 4–7 that is controlled with tangible programming blocks—no screen time required. The three classroom teachers worked with researchers from Tufts University and Lesley University to integrate KIBO robotics with the teachers' traditional learning units. The three vignettes will describe the following classroom experiences: using robotics to bring to life the book *Brown Bear, Brown Bear, What Do you See?* in the context of literacy explorations; and in science, programming the life cycles of the frog and the butterfly, and using robots to model the movement of worms through different environments. These vignettes will highlight the very different approaches teachers took to introducing robotics to their students and how they utilized the engineering design process as a teaching tool that can be applied to most subject areas.

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Although we are surrounded by technology on a daily basis, the inner working of devices like phones and computers is often a mystery to children and adults alike. Robotics offers a unique way for children (and grown-ups!) to explore sensors, motors, circuit boards, and other electronic components together from the inside out. This chapter provides another perspective on applying the engineering design process in integrating early engineering education within the classroom. With a focus on technology, this chapter describes how robotics can be used as a playful medium in early childhood classrooms to learn foundational engineering and computer science concepts. By presenting vignettes from three early childhood classrooms that embarked on an eight-week KIBO robotics curriculum, we highlight how educators with little to no prior engineering experience were able to successfully integrate robotics with traditional early childhood content such as literacy and science. KIBO is a developmentally appropriate robotics kit specifically designed for children ages 4–7 that is controlled with tangible programming blocks—no screen time required. The three classroom teachers worked with researchers from Tufts University and Lesley University to integrate KIBO robotics with the teachers' traditional learning units. The three vignettes describe the following classroom experiences: using robotics to bring to life the book *Brown Bear, Brown Bear, What Do you See?* in the context of literacy explorations; and in science, programming the life cycles of the frog and the butterfly, and using robots to model the movement of worms through different environments. These vignettes highlight the very different approaches teachers took to introducing robotics to their students and how they utilized the engineering design process as a teaching tool that can be applied to most subject areas.

11.1 Introduction

Anyone who has spent time with a four- or five-year-old child has undoubtedly been asked the famous "why?" questions about the world around her. *Why is the sky blue? Why do birds fly, but not dogs?* As their environment becomes increasingly technological, children's questions are beginning to include things like "how does a phone work?" and "why do some doors open automatically?" These questions are a genuine attempt for children to make sense of their world and understand how things work. This natural inclination to curiosity, inquiry, and investigation is not only the cornerstone of early childhood development, but is also a key component of thinking like an engineer (Brophy, Klein, Portsmore, & Rogers, 2008; Peel & Prinsloo, 2001).

When introducing the engineering design process to young children, we can begin by satisfying their curiosity through asking questions or posing problems that children are personally interested in investigating (see Fig. 11.1). As the chapters in this book have documented, early childhood is the ideal time to begin teaching engineering concepts because children are naturally inquisitive about the world around them and are motivated to explore, build, and discover answers to their big questions. Educators and researchers are thus beginning to see the importance of teaching engineering at an early age (Bers, 2008, 2018). According to the Massachusetts Department of

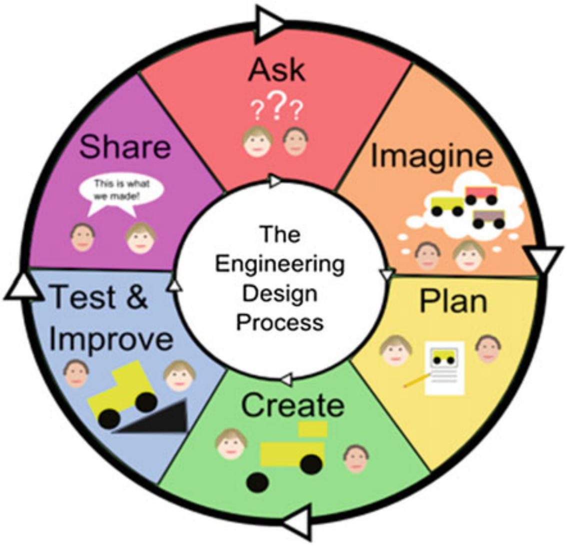

Fig. 11.1 An illustration of the engineering design process (image created by the DevTech Research Group at Tufts University)

Education (2006), the engineering design process refers to the cyclical or iterative process engineers use to design an artifact in order to meet a need. In line with the other descriptions of engineering design presented in this book, the Massachusetts curriculum frameworks refer to identifying a problem, looking for ideas for solutions and choosing one, developing a prototype, testing, improving, and sharing solutions with others. The steps of testing and improving, which require problem-solving and perseverance, are critical for establishing a learning environment where experiencing failure, as opposed to instant success, is necessary for learning (Bers, Flannery, Kazakoff, & Sullivan, 2014; Chap. 9). This is aligned with Dweck's (2006) concept of "growth mind-set." Growth mind-set refers to the belief that basic abilities can be developed through dedication and hard work. By developing this type of attitude through activities like engineering, children are improving their skills for effectively facing challenging situations. (Dweck, 2006). Growth mind-set complements the engineering design process, but it is also applicable to other areas of personal and cognitive development such as dealing with interpersonal conflicts and persevering through challenging coursework.

Explicitly teaching these foundational engineering concepts has only recently become an interest to early childhood educators. Science curricula in early childhood classrooms were traditionally more likely to focus on the natural world including plants, animals, and the weather (Bers, 2008). While learning about the natural world is important, developing children's knowledge of the human-made world, the world of technology and engineering, is also needed for children to understand the environment in which they live (Bers, 2008; Sullivan & Bers, 2015). Research and policy changes over the past five years have brought about a newfound focus on STEM (science, technology, engineering, and math) education for young children

(Sesame Workshop, 2009; White House, 2011), with particular emphasis on the "T" of technology and the "E" of engineering.

Amidst this national focus on STEM, and engineering in particular, early childhood educators are now faced with the difficult issue of *how* to implement engineering curricula in their classrooms. One of the major difficulties early childhood teachers face is figuring out developmentally appropriate ways to introduce young children to this often complex discipline (Bers, 2008; Bers, Seddighin, & Sullivan, 2013). Robotics and computer programming initiatives have grown in popularity as a way for teachers to introduce young children to engineering content in a developmentally appropriate way that is aligned with traditional teaching approaches such as the use of games, group work, and playful exploration (Bers, 2008, 2012, 2018). Additionally, robotics allows young children to build, create, and design their own inventions using the engineering design process. Moreover, integrating robotics into the classroom does not necessarily require teachers to take time away from teaching standard curricula; instead, robotics can serve as another entry point for their students to explore content already being taught.

In this chapter, we present three vignettes from a public school in Cambridge, Massachusetts, that recently began a robotics and programming initiative in their early grades (kindergarten through second grade):

(1) integrating robotics and literacy to bring to life the book *Brown Bear, Brown Bear, What Do you See?*
(2) using robotics to program the life cycles of the frog and the butterfly, and
(3) using robots to model the movement of worms through different environments.

These vignettes were chosen to illustrate how robotics can be used to facilitate the learning of foundational engineering content while being integrated into literacy and natural science curricular content. Implications for best practices in the early childhood classroom are discussed.

11.2 Robotics in Early Childhood Education

Robotics and computer programming initiatives are growing in popularity among early childhood researchers and educators (Bers, 2008; Bers et al., 2013; Elkin, Sullivan, & Bers, 2014; Kazakoff & Bers, 2014; Strawhacker & Bers, 2014; Sullivan & Bers, 2015). Recent work has shown how the field of robotics offers a unique potential for early childhood classrooms by facilitating cognitive as well as fine motor and social development (Bers et al., 2013; Lee, Sullivan, & Bers, 2013). For example, robotics can support a range of cognitive skills, including number sense, language skills, and visual memory (Clements, 1999a). New educational robotic construction sets may help children develop a stronger understanding of mathematical concepts such as number, size, and shape in much the same way that traditional materials like pattern blocks, beads, and balls do (Resnick et al., 1998; Brosterman, 1997). Technology can also serve as catalysts for positive social interactions and emotional growth in children (Clements, 1999b). For example, robotics offers a playful way for young children to practice social skills by sparking collaboration and teamwork (Bers, 2008; Lee et al., 2013). Robotic manipulatives invite children to participate in peer-to-peer interactions and negotiations while playing and learning in a creative context (Resnick, 2003).

Robotics engages young children as engineers by allowing them to construct and design with electronic and non-electronic components. It also inspires children to become storytellers by creating and sharing personally meaningful projects that react in response to their environment (Bers, 2008). The discipline of robotics provides opportunities for young children to learn about mechanics, sensors, motors, programming, and the digital domain (Bers, 2010; Sullivan & Bers, 2015; Strawhacker & Bers, 2014). The use of educational robotic kits is now becoming widespread in elementary schools (Elkin et al., 2014; Kazakoff, Sullivan, & Bers, 2013; Rogers, Wendell, & Foster, 2010; Sullivan & Bers, 2015).

Research with programmable robotics in early childhood settings has shown that beginning at age 4, children can learn fundamental programming concepts of sequencing, logical ordering, cause and effect relationships, and engineering design skills (Bers, 2008; Fessakis, Gouli, & Mavroudi, 2013; Kazakoff et al., 2013). When children create programs to make their robots move, they are sequencing commands for their robot to act out. The act of sequencing is foundational for early math, literacy, and planning (Zelazo, Carter, Reznick, & Frye, 1997). Additionally, educational robotic programs, when based on research, child development theory, and developmentally appropriate practices, can foster student learning of engineering such as design skills and methods while engaging in collaboration and other social skills necessary for school success (Clements, 1999a, 1999b; Druin & Hendler, 2000; Svensson, 2000; Lee et al., 2013).

11.3 The KIBO Robotics Kit

The vignettes presented in this chapter utilize the KIBO robotic kit (see Fig. 11.2) created by the DevTech Research Group at Tufts University after years of research funded by the National Science Foundation and now made commercially available by KinderLab Robotics (www.kinderlabrobotics.com). KIBO is designed for children ages 4–7 and consists of both hardware (robotic parts to assemble) and software (tangible programming blocks to make KIBO move). Using KIBO, children are engaged with the engineering design process while they build a functional and mobile robot using wheels, motors, lights, and a variety of sensors. These sensors, intentionally designed to resemble body parts or objects that children are familiar with, include sound (shaped like an ear), light (shaped like an eye), and distance (shaped like a telescope). Additionally, there is a light output module which resembles a lightbulb.

Unlike other programming applications and games for children that require the use of iPads and computers, KIBO is programmed to move using interlocking wooden programming blocks. These wooden blocks contain no embedded electronics or

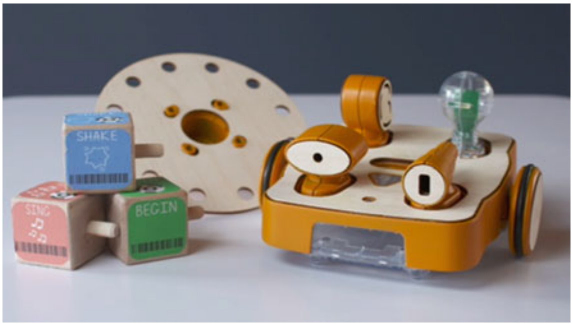

Fig. 11.2 KIBO robotics kit

Fig. 11.3 Programming wooden blocks for the KIBO robotics kit

digital components; it is aligned with American Academy of Pediatrics' (2003) recommendations for limited screen time for young children (Sullivan, Elkin, & Bers, 2015). The robot itself has an embedded scanner that reads the barcodes on each programming block and instantly sends the program to the robot. Similar to other programming languages, KIBO has specific syntax rules to follow. For example, every program must start with a Begin block and finish with an End block. Additionally, in order to create a functional repeat loop (which makes KIBO do actions a certain number of times), one must use the Repeat block, a parameter (either a number or sensor), and the End Repeat block (Fig. 11.3).

In addition to teaching engineering and programming concepts, the KIBO robotics kit encourages creativity and artistic design in young users. The kit contains two art platforms that can be used to personalize robotic creations with arts, crafts, and

Fig. 11.4 Sample decorated art platforms on KIBO robots

recycled materials (see Fig. 11.4). The kit also inspires collaboration and teamwork. KIBO’s programming blocks are tangible so they can be shared easily between multiple children who are collaborating on programming together.

Most importantly, KIBO is fun and easy to use by young learners and adults with little to no technical experience. Children can use the kit to create delightful and silly creations that dance, light up, and make noises. Unlike other toys, KIBO looks and behaves differently every time because children can alter KIBO’s aesthetic appearance with craft materials, change the assembly of motors and sensors, and alter the robot’s actions through new programming commands. The following vignettes illustrate the diversity of identities KIBO can take on from frogs and butterflies to live action versions of popular children’s books.

11.4 School Background

The three vignettes described in this chapter took place at an urban, public school in Cambridge, MA, serving students in prekindergarten through fifth grade. The Massachusetts Department of Education reports that at the time of the curricula, the student population at the school was 32.2% White, 22.9% African American, 20.9% Hispanic, 18.2% Asian, and 5.8% Multi-Race, Non-Hispanic. English was not their first language for over a third of the students (Massachusetts Department of Elementary and Secondary Education Enrollment Data, 2015). The students came from three early childhood classrooms (one kindergarten, one first grade, and one second grade). Neither the students nor the teachers had been previously exposed to the KIBO robotics kit.

A relatively new makerspace had just been built within the school thanks to a technology partnership with Lesley University. The makerspace was created as a way to enhance teaching and learning through technology integration. As part of this initiative, the school had acquired a variety of early childhood appropriate technologies such as BeeBot, iPads, and KIBO for students to explore engineering, programming, and robotics. With this newfound abundance of technological tools available, teachers actively looked for ways to incorporate these technologies as part of their standard curriculum, rather than using them as an "add-on" to the already busy school day. With the help of Lesley staff, they decided to use KIBO as part of pilot curricula in three classrooms before rolling it out throughout all of their lower elementary classrooms. This was an ideal opportunity to try out different strategies and see what worked in the different classrooms.

11.5 Curricula Overview

The curricula presented in this chapter were created collaboratively between the three classroom teachers, the librarian, the art teacher, and researchers at the DevTech Research Group and Lesley University, leveraging each group's expertise. All agreed on three objectives for the curricula. First, the curricula needed to address fundamental engineering, robotics, and programming concepts. This would be accomplished through a variety of small engineering and programming challenges, as well as playing fun games that reinforced the concepts. Second, for the final project component of the curricula, the KIBO content needed to connect to a topic that students were already studying in their classrooms. This could be anything from science and math to literacy, but it would be classroom-specific and determined by the classroom teacher. Third, a component of each class' final projects needed to include the visual arts. Using these criteria, three KIBO curricula were created, tailored to each of the three classrooms.

The curricula were divided into eight one-hour sessions over the course of two months, each taking place in the school's makerspace. The sessions were taught by Tufts University researchers and supported by classroom teachers, Lesley researchers, and the specialist teachers (art and librarian). The first six sessions were devoted to familiarizing the students with engineering and the KIBO robotics kit. Children started by learning about the definition of a robot and an engineer through two physical games, "Jump for Robots" and "Jump for Engineers," where children jumped if they thought they were shown a picture of a robot or something an engineer made, respectively. This led to discussion about how to identify robots and human-engineered creations. To learn about KIBO's different programming blocks, they played another game called "KIBO Simon Says," where children followed the directions on large print-out versions of the KIBO blocks. As children learned more complex syntax to the KIBO programming language, the game became increasingly more challenging with more ways for Simon (the instructor) to trick them. An important topic of the curricula was the engineering design process (see Fig. 11.1), which was taught through a song and referenced during each lesson. Finally, children participated in a sensor walk around the school in order to learn about the difference between senses and sensors, as well as about each of KIBO's different sensors.

For a portion of each session, students participated in a specific engineering or programming challenge in order to practice the concept that had just been introduced. For example, during Session 1, children had learned about the engineering design process and how to put together KIBO. Their challenge that day was to assemble a sturdy KIBO robot using motors and wheels along with non-robotic art decorations that would not fall off when KIBO was programmed to shake vigorously. Children returned to the iterative design process to "test and improve" if their decorations fell off or if their motors were not attached properly. Another challenge, during Session 5, was to program KIBO to move along different shaped maps using the Repeat and End Repeat blocks. Children had just learned how to make syntactically correct programs with repeats, so their challenge was to create programs that would make KIBO travel in a straight line, in an L-shape, and in a square using these new blocks to simplify their code.

At the end of each session, time was always allotted for the sharing aspect of the engineering design process. This gave students an opportunity to present what they had created and get feedback from their peers, to discuss what they thought was easy or challenging that day, and to ask questions. Teachers could also use this as a time to informally assess which concepts their students understood and which needed more review. For example, if many children thought using the repeat blocks was difficult and many projects did not have functional repeat loops, this would be a concept that teachers knew they needed to further address. They could either review concepts during this share session itself, or return to it at the beginning of the next class through games and teacher-led demonstrations.

Students worked on their final projects during the last two sessions of the curriculum. The project chosen in each class was unique and based on unique and based on what children were already learning in the classroom. At the beginning of the curricula, teachers had not planned out their classes' final projects. They wanted to get started to see the capabilities of KIBO and how their students used the robot. Each teacher brainstormed a variety of ideas, some which would have been too complicated and others which would have been too simple, and then worked with the Tufts and Lesley University researchers to refine their ideas. During this time, the teachers were learning first-hand about how to use and apply the engineering design process.

The following vignettes describe the experiences of the teachers and students during the two sessions they spent creating their final KIBO projects. The process for creating final projects was similar in each of the classes. First, teachers reviewed the subject content (either the natural sciences or literacy) outside of the allotted robotics time. Then, students were divided into groups of two or three and they brainstormed project ideas that could be brought to life with KIBO (the "planning" phase of the engineering design process). Next, they recorded their ideas in their Engineering Design Journals. They then created their programs for their robot, tested them out, and modified them. Finally, they created artistic decorations for their robots using art, crafts, and recycled materials. All of this hard work culminated with a final presentation of their projects to classmates, teachers, and researchers at the end of the last session.

Fig. 11.5 One group's challenge to get their KIBO from the black sheep to the goldfish

Vignette #1: Brown Bear, Brown Bear, What Do You See?

An important part of the kindergarten teacher's daily routine was reading stories aloud to her students. At the time of the KIBO curriculum, her students had been reading the well-known rhyming book *Brown Bear, Brown Bear, What Do you See?* by Eric Carle. When she was brainstorming final project ideas for the KIBO curriculum, she was inspired by this book which serves as a milestone for many children's lives as emerging readers. She saw the final KIBO projects as an ideal opportunity to integrate literacy, engineering, programming, and robotics.

The biggest challenge this teacher described facing was how to use the robots with this story in a meaningful way. She wanted the project to be structured so that the book could be read along with the kids' final presentations. Additionally, she realized that the structure of the story did not lend itself to much action (which is typically a key component of robotics projects). Each page of the book presents an animal that is asked the question "What do you see?" and it responds that it sees another animal or object. After consulting with the art teacher as well as Tufts and Lesley University researchers, she came up with a plan. Students would be divided into groups and assigned one page of the story; their goal was to program their robot to travel between two pictures on the ground, with each picture representing a character in the story. For example, one group would be given the challenge of programming pages 15 and 16 of the book, so that the KIBO robot would travel from the black sheep to the goldfish (see Fig. 11.5). The pictures of the characters would be set up around the room in the order they appear in the story. Once students successfully programmed their robots to travel from one picture to another, they would be able to add additional actions for KIBO to do to bring their characters to life.

Children used the engineering design process, particularly the stages of testing and improving, as a guide when creating their programs for KIBO. First, children needed to calculate how many Forward blocks they would need to get their robot from one picture to another. This required a period of estimation and trial and error with the robots, which was at time frustrating for the students. The teacher was also challenged with providing the "right" kind of help for her students without simply telling them "it takes 4 Forward blocks." Instead, she scaffolded their learning experience by helping them measure and estimate the distance between each picture using the floor tiles as a visual guide. Eventually, all groups persevered, and as a class, they determined the correct number of Forwards between each picture.

Once students completed basic programs, their teacher prompted them to edit their programs by experimenting with repeat loops instead of using multiple Forward blocks to create a more streamlined program. Children worked to create syntactically correct programs with the repeat loop blocks and number parameters. These complex blocks allowed children to create a more concise program for KIBO only using only one Forward block. Once children successfully programmed their robots to travel from one picture to another and recorded it in their Engineering Design Journals, they had the option to add additional action blocks. Some blocks, such as Turn Left and Turn Right, would make the KIBO robot travel off course, so the kindergarteners needed to experiment with how to ensure KIBO reached its final destination. Additionally, children were prompted to consider how the different animals they were representing might move in order to capture these motions using KIBO's programming blocks. It took multiple iterations, as well as some adult support, for many of the groups to get their robots to move from one picture to the other and capture the essence of the animals from the story.

Although only one hour each week was devoted to working on KIBO robotics in the school's makerspace, this kindergarten teacher worked closely with the art teacher and used non-robotics time during the regular school day for her students to work on different components of their final projects. For example, during art class, children created decorations for their robots. Using tin foil, pom poms, colored paper, pipe cleaners, cups, and other recyclables, children worked in their groups to create sculptures that would sit on top of their KIBO robots. Additionally, during normal class time, the teacher read the book aloud several times in order to familiarize students with the characters and the order in which they appear. This also reinforced a core concept behind both programming and writing: Order and syntax impact the way a story or product is conveyed. Overall, by using non-robotics time, the kindergarten students had additional time during the last two sessions to explore the different programming instructions, plan and test their programs, and document their creations in their journals (Figs. 11.6 and 11.7).

Students presented their final projects to one another and visiting school administrators at the end of the last session. The kindergarten teacher read *Brown Bear, Brown Bear, What Do you See?* aloud as part of the presentation. After reading a page aloud, the corresponding group presented their project. For example, the group who programmed their robot to travel from the black sheep to the goldfish programmed their robot to start moving when it heard a clap (using the sound sensor); then, it moved forward three times, turned its light on, turned right, and stopped. Another group took a more direct approach for their robot to move from the brown bear to the red bird. They created a program where the KIBO robot repeated the Forward block four times and then stopped. Students and teachers expressed having a great time during the final presentations; it served as a celebration of the students' hard work over the course of the eight-week curriculum. In addition to celebrating the

Fig. 11.6 Kindergarten students creating their decorations for their robots

Fig. 11.7 Kindergarten students creating their decorations for their robots

final products, students and teachers had an opportunity to discuss their learning processes and challenges they faced along the way. This provided a meaningful way for children to express their knowledge and expertise of engineering and programming, as well as mastery of the story, as they demonstrated their robots and programs for visitors (Fig. 11.8).

Vignette #2: Life Cycles of the Frog and Butterfly

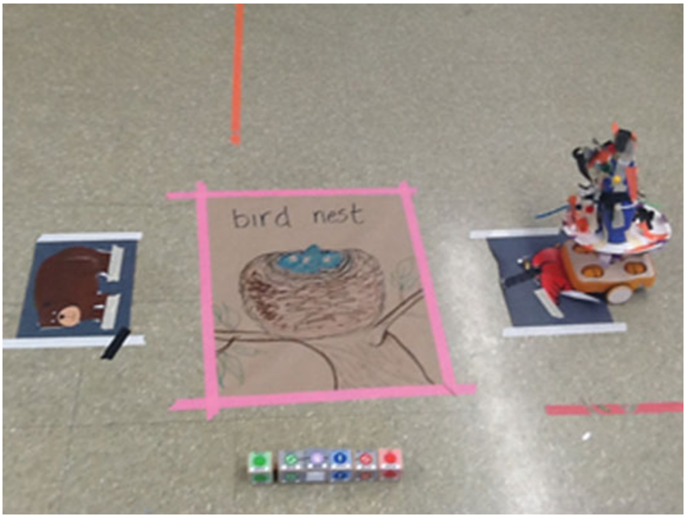

Fig. 11.8 Example final project and robot's program

At the time that the first-grade students were participating in the KIBO curriculum, they were also studying various plant and animal life cycles in their classroom. Their teacher wanted to find a way to bridge together science and robotics, so she had the idea of using KIBO to model animal life cycles. She selected the frog and butterfly life cycles because she felt they could be well represented using KIBO's different action blocks like Shake and Spin. Students were put into groups of two or three and assigned one part of a life cycle. They then were given a two-part task. The first challenge was to program KIBO to perform an action to represent movement during that stage. The second challenge was to program KIBO to move to the next stage of the cycle.

Initially, the teacher was puzzled about how to structure the final project. On the one hand, she wanted students to demonstrate through the programs they created that they understood *all* steps of one of the life cycles. Realistically, she realized it would be difficult to ask students to create four separate programs to represent each part of the cycle due to time constraints. After brainstorming with the librarian, as well as the Tufts and Lesley University researchers, she decided to have four groups recreate one life cycle, with each group focusing one part. For the frog cycle, students would be in the following groups: eggs, tadpole, froglet, and adult frog. For the butterfly cycle, students would be in the following groups: egg, caterpillar, chrysalis, and butterfly. With this idea to have four groups working on a different stage of one cycle, the first-grade students had a unique but feasible challenge: Unlike the projects in the other classes, they would need to coordinate their robots' movements with one another. This would provide ample opportunities for children to utilize the engineering design process as well as practice collaboration.

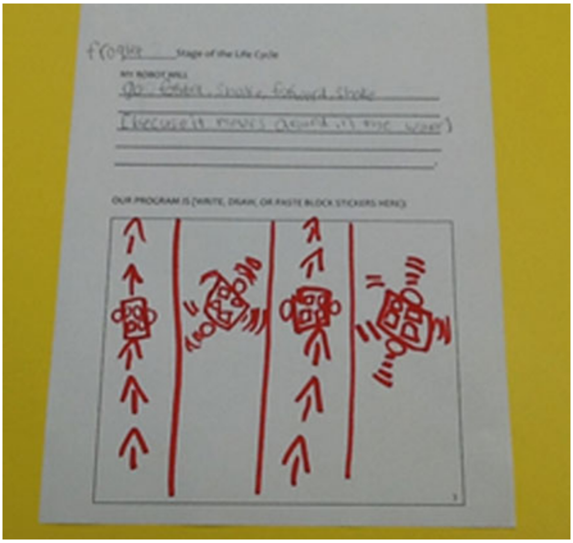

Fig. 11.9 Engineering Design Journal entries

After being assigned to their groups, children spent time reviewing their assigned cycles by watching short videos. The teacher encouraged the students to pay particular attention to the movements they saw at each part of the cycle and consider which of KIBO's programming instructions might be able to represent these movements. For example, the group working on the "frog eggs" noticed that the movement of the eggs in the water resembled how KIBO moves when it is programmed to shake. Afterward, students used their Engineering Design Journals (Figs. 11.9 and 11.10) to plan out their initial programs. The journals were designed so that children could demonstrate their understanding of the life cycle because they needed to write down what happened during their part with words, as well as illustrate the programming blocks or actions that would be used. Since KIBO does not have programming blocks for actions such as jump or fly, children had to creatively decide which blocks they wanted to use to represent these actions. For example, the group working on the froglet part of the frog cycle chose to create the program Begin, Forward, Shake, Forward, Shake, End. One child explained that this program was appropriate "because [froglets] moves around in the water."

Once each group had finished creating their programs, the teacher provided materials for students to decorate their KIBO robots. Unlike the kindergarten class, this was done during robotics time. Each group was given a printed image of how their amphibian/insect looked at their stage of the cycle; they could look at the image for inspiration or incorporate it as part of their decorations. In addition to this, children could use modeling clay, markers, paper plates, and other craft materials. Many groups faced an engineering challenge when it came to figuring out how to attach their creations to their robots. One group had the idea of placing their decorations on a plate and then attaching the plate to KIBO's art platform. After some trial and

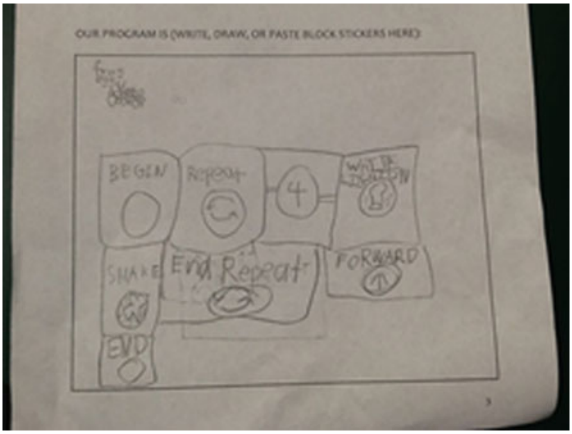

Fig. 11.10 Engineering Design Journal entries

Fig. 11.11 Decorations for the "froglet" robot

error, this group figured out how to keep the plate from falling off the platform and was able to share their idea with peers and teachers. Soon after, the other groups followed their lead. By the end, each group had successfully integrated the visual arts into their final projects (see Figs. 11.11 and 11.12 for sample projects).

Before presenting to the whole class, the four "frog cycle" and four "butterfly cycle" groups had time to practice together, making sure that each robot traveled the correct distance to reach the next part of the cycle. This process took up a substantial portion of the final session, as some groups had miscalculated the distance their robot should travel, while other groups had their decorations fall off when KIBO executed its program. The students helped one another and reinforced the idea that each group's individual programs needed to work in order to accomplish their larger goal. With time to revise and guidance from the adults, each group was ready to share their creations by the end of the last session.

Fig. 11.12 Decorations for the "butterfly" robot

During the final presentations, each group started by explaining what happened during their part of the life cycle. Next, they shared their writing and drawings in their Engineering Design Journals in order to show which blocks they used for their program and how their program represents their respective part. Finally, they demonstrated their program using the robot. After each of the four groups in a cycle had presented, there was time for students to express what they found easy and what they found challenging. Children were given the chance to showcase not only their newfound knowledge of programming and robots, but also their expertise on each aspect of the life cycles. Additionally, children demonstrated their collaborative spirit by working toward the common goal of creating one life cycle represented with multiple KIBOs.

Vignette #3: Worms and Their Environments

The second-grade students had been exploring how worms move through different environments while participating in the KIBO curriculum. As part of their final projects, the teacher wanted to connect KIBO to their unit on worm movement; she posed the following question to her students: How does terrain affect a worm's movement? Students would have to use the knowledge that they had learned in class, their programming knowledge of KIBO, and their creativity to explore this question and depict how a worm's movements changed when traveling through sand, leaves, and rocks. KIBO, acting as the worm, would need to travel along a straight line through at least one of the environments.

Children first spent time reviewing and collecting new research on the characteristics of the three different environments during science time. The teacher suggested that students use their arms and hands to model how a worm generally moves, and then try to adjust that movement based on its setting. She also provided videos and diagrams as alternative options to understanding how worms and their environment interact. Finally, she led a discussion about which terrains would make it easier or

Fig. 11.13 Different worm environments

harder for worms to move. Based on their research, the class concluded that leaves would be the easiest, then sand, and then rock.

Because children were working with technology that could be damaged by sand and rocks, the environments would need to be modeled using materials that would not harm the KIBO robots. An important discussion naturally emerged about what materials could and could not be used around the robots. The children talked about how KIBO's wheels might get stuck in real sand, so the teacher and researchers provided shredded packing peanuts to be used in its place. Rather than KIBO having to drive over many different rocks, which the children hypothesized would possibly break KIBO's wheels, a large rock was used to represent the rock environment; children would have to program their robots to recognize the rock using one of KIBO's sensors and move around it. Finally, the students discovered that leaves would not harm the robots, so the teacher collected real leaves and brought them in for the projects. Before taking out the robots, children spent time examining the objects in each environment in order to help them plan out better programs. Then, the environments were set up around the room so children could reference them while they worked on their robots in their groups (Fig. 11.13).

Both children and adults needed to use the engineering design process as they created their final projects. For example, the sand environment was represented with the packing peanuts. When children programmed KIBO to travel forward, the robot would not always go straight because the packing peanuts were slippery and their size obstructed the motion of KIBO. The teacher herself was an engineer as she rethought the way the materials would be best used. After trying multiple solutions and brainstorming with researchers, she decided to cut the packing peanuts into much smaller pieces so that KIBO could move more easily through this environment. By doing this, adults modeled the iterative process of engineering and how to problem solve through a frustrating situation. Additionally, they demonstrated an "everyday" application of the engineering design process.

Once students finished creating and testing their programs, their next challenge was to incorporate the visual arts. With modeling clay and other craft materials, they created models of worms (see Figs. 11.14 and 11.15). However, they were not sure

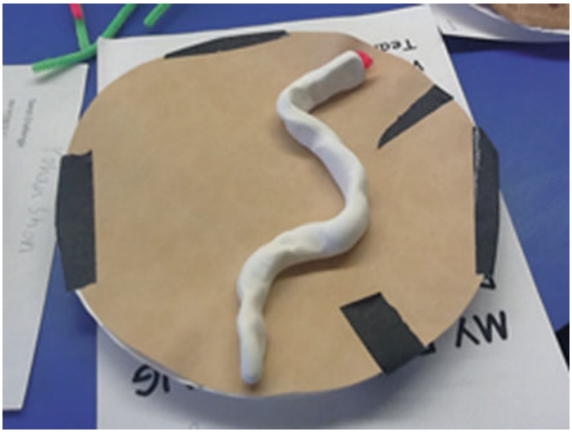

Fig. 11.14 Decorations for the robots

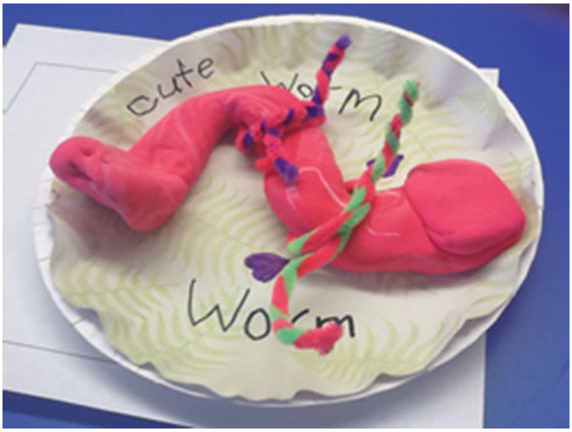

Fig. 11.15 Decorations for the robots

at first how to securely attach their worms to the robots. The teachers took this as an opportunity to demonstrate that engineers often borrow and improve on each other's ideas by sharing the first-grade class' creations and suggesting a similar method of attaching their worms to a plate. This worked well, but students still needed to troubleshoot strategies so that their decorations would not fall off when the robots were in motion.

For their final presentations, each group demonstrated their engineering, programming, and science knowledge as they shared their programs for one of the environments. As they shared, students described their robot's movements and why they were unique for that particular terrain. At the end, students had time to discuss the similarities and differences between the groups' programs based on the environment their robot was traveling through. This was a very unique curriculum experience because students guided much of their own learning. From spontaneously testing out sensors to deeper discussions of the robotic elements in KIBO, the second-grade

Fig. 11.16 Second-grade students presenting their final projects

Fig. 11.17 Second-grade students presenting their final projects

students took their teacher's plan in a personally meaningful direction based on their own curiosity (Figs. 11.16 and 11.17).

11.6 Discussion

These three vignettes highlight the iterative process of creating and implementing a robotics curriculum to not only teach about foundational engineering content, but also integrate literacy and natural science curricular content. For example, the first-grade students needed to draw on their scientific knowledge of how their animal moved during the life cycle before they could effectively represent this with a program.

Similarly, the kindergarten students needed to be familiar with the sequence and story line of the *Brown Bear, Brown Bear, What do you See?* book in order to bring this story to life with robotics. The final projects exemplify the diversity of creations and the integration of robotics with traditional early childhood content.

11.7 Curriculum Development

While designing the KIBO curricula presented some challenges, the team of teachers and researchers were able to successfully implement three unique KIBO curricula in three different classrooms. The teachers themselves behaved as engineers by following the different stages involved in the engineering design process. They asked questions such as: What topic do I want to integrate with KIBO, what do I want my students to learn, and how can I integrate this project with the visual arts? They then imagined what their students might create, and planned out their curricular ideas, collaborating with the specialist teachers and researchers. Then, they tested out their plans as students worked on their final projects, revising and improving the plan as needed. Finally, teachers shared with one another about how the final projects went, and began the cycle again by asking questions about what could be done differently in the future.

Each teacher designed their class' final projects in a way to meet the unique needs of their students. First, each project focused on a curricular topic specific to the classroom. Teachers were given an opportunity to reflect on their current lesson plans and consider which one might be enhanced through the use of a new technology. As a pilot project, teachers did not have previous exposure to KIBO, so they could use this opportunity to explore one topic that they were already familiar with and test out what did and did not work. Additionally, this gave teachers an additional way to reinforce fundamental early education topics in a creative way using a new medium: robotics.

Second, the teachers adjusted the difficulty of the projects' goals based on the grade level of the students. For example, the second-grade teacher gave students the opportunity to create up to three projects, one for each of the worm environments. Additionally, she specifically designed the rock environment so that students would need to use a distance sensor, which is one of the more complex concepts of KIBO for children to understand and program. In contrast, the kindergarten project was much more straightforward. Children were asked to get their robot to travel in a straight line from Point A (one picture) to Point B (another picture). They were encouraged to experiment with repeat loops, but they could also successfully complete the program using basic programming blocks. Then, only once groups demonstrated that the robot traveled to Point B could they add extra instruction blocks. By adjusting the difficulty, students were able to successfully create personally meaningful projects.

The teachers discovered that creating appropriate curricula within the allocated time was not always as straightforward as expected. They learned how important it is to embrace not always knowing the "right answer," as well as to iteratively problem-solving along with their students. Over the course of the curricula, they had to adjust their initial approaches to the final project based on observations of their students and their past teaching experience. They needed to choose a focus for the final project that could translate well into the physical capabilities of KIBO, as well as keep their students engaged. Not all teachers use their initial curriculum idea. For example, the kindergarten teacher originally chose a different story instead of *Brown Bear, Brown Bea*r for the basis of her curriculum. However, after rereading the story, she realized that the lack of plot would make it challenging for children to make creative and personally meaningful projects. She therefore had to go back to the drawing board and select a new book, which ended up integrating nicely with the robotics component. This teacher learned the value of changing an idea when it does not quite fit with the capabilities of the technology. She learned that technology has the power to bring literacy to life in a new way that is exciting for students. For the first-grade teacher, she noticed that having each group create four programs, each one representing a portion of the life cycle, would be too time-consuming and challenging, so she adjusted the goal to have students demonstrate mastery of one part of one cycle. This teacher learned about the unexpected time constraints that come with using complex technologies like robotics and how to adapt an initial curriculum idea to fit within the technological constraints.

11.8 Students' Learning

Children embraced the engineering design process as they went through the curricula. They had to plan out their programs in their Engineering Design Journals, test each program iteration, revise it multiple times to make it better, and then share it with others. They also engineered creative solutions to each of the challenges. The second-grade students could not have KIBO travel through a rock environment as it would have damaged the robots, but they were able to get the same point across by representing it with one big rock. For the first-grade classroom, students could not actually make their butterflies fly or their frogs hop, so they had to find other ways to represent these actions with KIBO's programming blocks. In the kindergarten classroom, students had to imagine what movements their book characters might do since it was not specified in the story.

Focusing specifically on programming, students mastered the syntax and rules of KIBO's programming language. Each grade experimented with sensors and advanced programming concepts in order to create more interactive and engaging projects. For example, kindergarten students created programs using repeat loops to minimize the number of Forward blocks that they would need for their programs. Additionally, they learned multiple ways to assemble sturdy and functional robots using motors, wheels, sensors, and lights. Their mastery of robotics was demonstrated at the end of the unit when each group had a functional KIBO robot and a syntactically correct program to share. During the presentations, each group was able to articulate their reasoning behind their programming and construction choices, as well as demonstrate their robots in action.

Not only were the students exposed to fundamental programming and engineering concepts and the intended final project topic, but they also engaged with a variety of other traditional and non-traditional school subjects. Every class incorporated the visual arts through their robot decorations created using craft and recyclable materials. Also, all groups had to use estimation, measurement, and counting to calculate the distance and direction they needed KIBO to move when creating their programs. Beyond traditional early childhood classroom subjects, students practiced collaboration by working in small groups, developed their presentation skills through sharing their work, and exercised perseverance in the face of challenging activities. As one teacher stated, the children were "all learners engaged in the project. There weren't outliers anywhere because they all found something that they were good at within the project and it make them feel really confident."

11.9 Conclusion

The engineering design process was a powerful concept that guided student and teacher learning through the curricula. While each teacher took a different approach to the final KIBO projects, all were generally successful at introducing the engineering design process, robotics, and programming with the support of Tufts and Lesley University researchers. It was helpful to allow teachers to draw on subjects they were already comfortable teaching (i.e., the natural sciences or literacy) as a bridge to implementing robotics for the first time. These vignettes illustrate how easily KIBO integrates with a variety of early childhood curricula and skills that children are naturally learning at that age. Additionally, it shows how KIBO can incorporate multiple subjects at once. For example, children may explore mathematical concepts such as estimation to program their robots while they engage in dramatic play imagining their robot acting out a famous story.

It is easy to see indicators of the children's success with KIBO in these vignettes—they were able to successfully program their robots and present complex work by the end of the curriculum. It is perhaps more difficult to see the learning process that the *teachers* engaged with throughout this experience. Much like the students immersed themselves in the engineering design process, the teachers also engaged with this iterative process of learning and experiencing failures before achieving success. Not only were they new to KIBO and faced with the challenge of mastering a new technology, but they were also new to designing integrative curricula tying in technology, engineering, and traditional early childhood content. These vignettes show the benefit of scaffolding the teachers' learning experience when embarking on a new technology initiative. In this case, this was done through support from the Tufts and Lesley research team, but it might also take the form of professional developments or collaborating with a school's technology specialist.

Looking forward, this school is now equipped with three early childhood teachers who are ready and capable of continuing engineering education in the early grades on their own and supporting new teachers joining this initiative. One teacher commented, "I was so excited about it [KIBO] I decided to share it with my colleagues. I gave them the opportunity to be the learners and had a little professional development with them so that they would feel comfortable and be able to overcome that barrier of being afraid to use it to being excited to use it. By the end of it, they were all saying they were really excited and can't wait to give it a try next year." Whether or not these young children grow up to be engineers, they have gained the problem-solving, collaboration, and perseverance skills necessary to excel in literacy, science, the arts, or any other area they may pursue in the future.

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