Chapter 12
Seeds of STEM: The Development of a Problem-Based STEM Curriculum for Early Childhood Classrooms

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Abstract This chapter adds to the body of research on engineering in early childhood education by describing the multiple research components associated with the development of an early childhood engineering curriculum, *Seeds of STEM*. Since very few research studies were devoted to the topic of engineering in early childhood, the *Seeds of STEM* research team was charged with developing many of the tools and instruments to be used throughout the project. The chapter describes the research conducted by the *Seeds of STEM* team in order to establish the framework for the curriculum, the development process, evaluation of fidelity of implementation, as well as the effectiveness of the curriculum. More specifically, the chapter addresses the following questions on curriculum development research: (a) Who should be part of the curriculum development team? (b) What is a successful curriculum development process? (c) What principles should guide the *Seeds of STEM* units? (d) How should the curriculum's effectiveness be measured? and (e) What measures should be taken to ensure fidelity of implementation?

12.1 Importance of Early Engineering

Improving science, technology, engineering, and mathematics (STEM) has become a great concern of researchers, educators, parents, and policy makers (Custer & Daugherty, 2009; Jenniches & Didion, 2009; Katehi, Pearson, & Feder, 2009; Schunn, 2009). The focus on STEM is largely related to issues concerning US competitiveness in the global economy and developing a skilled labor force with the ability to solve problem and address technological issues (CCNY, 2009; NSB, 2007). However, most efforts to improve STEM education in the USA have been

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limited to mathematics and science (and technology to a lesser degree)—all of which have a long history of established learning standards in the K-12 grades (Hsu, Purzer, & Cardella, 2011; National Research Council, 2011). Recently, engineering education has received increased attention at the K-12 levels (National Academy of Engineering, 2006; National Academy of Engineering & National Research Council, 2009; NGSS Lead States, 2013) and engineering education standards have been adopted by many states. There is also increased interest in the part of early childhood teachers and administrators in the importance of STEM education (Lindeman, Jabot, & Berkley, 2013; Moomaw, 2012; Wynn & Harris, 2013).

A child's academic success is largely dependent on a strong foundation for learning. The first five years of life are extremely significant for children's cognitive and skill development. During these years, young children explore their environments and use this information to develop language and construct abstract concepts and theories about the world around them (Bowman, Donovan, & Burns, 2001; Gelman, 1999; French, 2004; Worth, 2010). These early cognitive structures are the foundation for academic learning that includes further development of theories, strategies, and skills and are characterized as being deeply rooted in the child's environment and early interactions (Bowman et al. 2001; Eshach, 2006; French, 2004; Novak, 1977). The richness of the environment, type of interactions, and early experiences are linked to elaborate cognitive structures and better preparedness for further learning. In fact, high-quality preschool education has been found to significantly improve young children's learning outcomes (Camilli, Vargas, Ryan, & Barnett, 2010; Gorey, 2001; Gormley, Phillips, & Gayer, 2008). In addition, children constantly explore and question the mathematical and scientific world around them (Bowman et al., 2001; Brenneman, Stevenson-Boyd, & Frede, 2009; French, 2004; Gelman, 1999; Worth, 2010), making this period of early childhood ideal for introducing concepts in STEM and engaging children in developmentally appropriate activities to begin understanding the world around them.

Early *engineering* education, the E in STEM, involves the systematic process of problem solving, which is important for several reasons. First, children have been described as 'born engineers' (Cunningham, 2009). Engineers are problem solvers, and the engineering design process requires creativity, collaboration, and communication. Children reason, define problems, manipulate, build and test prototypes, apply mathematical and scientific concepts, and share their newfound solutions with friends and family (Christenson & James, 2015). Research shows that when teachers engage in the engineering design process, children increase in their engagement of activities, the number of engineering behaviors displayed, and their persistence in completing activities (Wang et al., 2013). By incorporating engineering concepts into early education, children are provided with developmentally appropriate knowledge and skills to further examine the world (Ackerman & Barnett, 2005; Brenneman et al., 2009).

Second, although engineering overlaps with science, technology, and math, which are mostly covered in a typical preschool curriculum (Bagiati & Evangelou, 2015), some skills and concepts are specific to the engineering field (Schunn, 2009). Engineering is a context-based subject with real-life applications, which appeals to a diverse group of students and therefore serves as an anchor for deepening scientific knowledge (NGSS Lead States, 2013). This notion fits well with the call put forth by early childhood and cultural education scholars to develop an early childhood science curriculum that is connected to children's lives and experiences. Context-based activities have been shown to engage and include all learners, thus leading to increased motivation and achievement (Bowman et al., 2001; Lynch, 2001; New, 1999; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). Integrating engineering into the early childhood curriculum gives children the opportunity to examine these everyday concepts and build upon them in a new way (Bagiati & Evangelou, 2015). Research on engineering design projects finds that students show improved problem-solving skills that are critical in dealing with ambiguity and solving open-ended and ill-defined problems (Eshach, 2006) and enhance students' content knowledge and skills in science (Kolodner et al., 2003; Mehalik, Doppelt, & Schunn, 2008) and mathematics (Hjalmarson, Diefes-Dux, & Moore, 2008). For preschoolers, such opportunities can increase persistence in completing activities (Cohen & Uhry, 2011) and better critical thinking and social skills (Stoll, Hamilton, Oxley, Eastman, & Brent, 2012; Tunks, 2009).

Third, stimulating interest and early exposure to engineering as a career requires the practice of engineering (Schunn, 2009). Studies show that engineering design projects enabled more positive attitudes toward engineering as a career (Cunningham & Lachapelle, 2010; Kolodner et al., 2003; Mehalik et al., 2008).

Finally, exposure to different problems and the application of science, math, and technology has the ability to reduce the achievement gap, while simultaneously debunk stereotypes and change attitudes and beliefs toward the STEM fields (Brophy, Klein, Portsmore, & Rogers, 2008). National reports highlight the wide gap in STEM literacy between low-income and ethnic minority American students and their White, middle-class American peers. This disparity is well documented by research from kindergarten to 12th grade, suggesting that gaps in academic and skill development start during the prekindergarten years. These achievement and readiness gaps (in reading, math, science, and approaches to learning) are evident as early as kindergarten and widen as students advance in school (Duncan et al., 2007; Clasessens, Duncan, & Engel, 2009; Federal Interagency Forum on Child and Family Statistics, 2013). Additionally, although girls and boys take roughly the same number of classes in elementary, middle, and high school and are equally prepared to pursue science and engineering majors in college (Hill, Corbett, & St. Rose, 2008; U.S. Department of Education, National Center for Education Statistics, 2007), fewer girls than boys decide to major, are retained, and actually go into these fields (Seymour & Hewitt, 1997; Xie & Shauman, 2003).

Stereotypes of ethnic minorities and women are partly responsible for these disparities (Eccles, Jacobs, & Harold, 1990; Fennema & Sherman, 1977; Jacobs & Eccles, 1985; Swim, 1994). Stereotyping is not uncommon for 3- to 6-year-olds (Levitch & Gable, 2016; Piaget, 1961), and this may lead to a fixed mind-set. Early childhood educators can help children combat stereotypes in the classroom through increased representation of engineers, engineering problems, and engineering occupations (Care, Denas, & Brown, 2007; Sleeter & Grant, 1999), through the language used and the literature selected (Roberts & Hill, 2003; Southern Poverty Law Center, 1997).

In summary, introducing STEM and especially engineering during early childhood education promises to provide young children with the problem-solving skills that will help them address complex problems and better prepare them for success in school and life. Early childhood teachers who teach children to solve problems in a systematic way can also introduce children to possible career opportunities while debunking stereotypes.

12.2 Research on Engineering Education During Early Childhood

Despite the promising evidence that introducing STEM/engineering ideas and practices during the early childhood years supports children's cognitive development and positive attitudes toward learning and inquiry (Eshach, 2006; Evangelou, 2010; Katz, 2010; Van Meeteren & Zan, 2010), there is very little STEM or engineering instruction within the prekindergarten classrooms (Diamond, Justice, Siegler, & Snyder, 2013; Ginsburg, Lee, & Boyd, 2008).

One of the reasons for the lack of STEM and engineering instruction is teachers' low self-efficacy regarding the teaching of STEM, due in part to a lack of preparation and shortage of early childhood STEM and engineering curricula (Bagiati, Yoon, Evangelou, & Ngambeki, 2010; Brenneman, 2011; Greenfiled et al., 2009; New, 1999).

Research on STEM and engineering in early childhood education is also limited. At the time of writing this chapter, only a few research projects engage in systematic study of STEM and engineering during the early childhood years, shedding light on teaching and learning as well as classroom materials and curricula. These studies include the development of the Engineering is Elementary (EiE) curriculum (Cunningham & Lachapelle, 2007, 2010) and the development of a pre-K engineering curriculum (e.g., Bagiati & Evangelou, 2015). Additional early childhood STEM/engineering research themes include robotics activities (Sullivan, Kazakoff, & Bers, 2013), STEM during summer camp (Torres-Crespo, Kraatz, & Pallansch, 2014), and a recent guide of PreK-5 engineering curricula (Sneider, 2014).

This chapter adds to the body of research on engineering in early childhood education by describing the multiple research components associated with the development of an early childhood engineering curriculum, *Seeds of STEM*. Since very few research studies were devoted to the topic of engineering in early childhood, the *Seeds of STEM* research team was charged with developing many of the tools and instruments to be used throughout the project. The following sections describe the research conducted by the *Seeds of STEM* team in order to establish the framework for the curriculum, the development process, evaluation of fidelity of implementation, as well as the effectiveness of the curriculum. More specifically, the chapter addresses the following questions on curriculum development research:

1. Who should be part of the curriculum development team?
2. What is a successful curriculum development process?
3. What principles should guide the *Seeds of STEM* units?
4. What measures should be taken to ensure fidelity of implementation?

12.3 About *Seeds of STEM*

Teacher (showing a puppet): Good morning, friends! Today we have a special visitor. Its name is Problem Panda, and it needs your help. Do you want to meet our guest?
Children: Yes!
Puppet (in a sad voice): Hello, children! My name is Problem Panda and I have a big problem. I heard that you are learning to solve problems just like engineers, and I thought perhaps you could help solve my big problem. Can you help me?
Children: Yes, we can help you.
Puppet (happy): Oh, thank you! Yesterday, I was getting ready to go and meet my friend and I bought a special present for her—a ring. Somehow the ring fell into a glass of water and was frozen—see? (showing a cup with a ring stuck inside an ice chunk). Now I can't take the ring out—what will I do?
Teacher (to children): Let's put on our 'engineer' badges and help Problem Panda.

The vignette above is taken from a video of a Head Start classroom (3- to 5-year-old children) in Worcester, Massachusetts, testing the second unit of the *Seeds of STEM* curriculum. *Seeds of STEM* is an innovative, research-based curriculum which focuses on teaching preschool children—and their teachers—the process of problem solving. The different units of the curriculum are built around the steps of the engineering design process (EDP). An accompanying character, Problem Panda, presents to the children a different problem in every unit and engages the children in the process of understanding the problem and defining criteria for successful solutions, brainstorming solutions, selecting and testing some of the solutions, creating and revising the solution, and sharing the solution with Problem Panda and other guests. In addition to teaching children how to solve problems, each unit addresses a key concept (core idea) in science. For example, the science focus of unit 2, from which the vignette is taken, is **ice and water, solids and liquids**, and the engineering focus is **brainstorming and selecting testable solutions**. During the first week of the unit, the children engage in multiple experiences about the ice and water, solids and liquids, including stories, melting and freezing experiments, sorting, going on a solid/liquid hunt, and even freeze-dancing. During the second week, Problem Panda asks the children to help him with a problem: get a valuable item (the ring) out of the ice without harming it in the process. With guidance from the teacher, the children practice brainstorming solutions to Panda's problem. The teacher encourages the children to propose different solutions based on children's experimentation with ice

Table 12.1 Seeds of STEM unit description

Unit	Science week	Engineering week	Main problem
1	Introduction to the problem-solving process		Help Panda get out of a box
2	Ice and water (solids and liquids)	Identify problem, brainstorm, sort, and vote on solutions	Panda dropped a ring into a cup of water that froze! Help Panda get the ring out of the ice
3	Habitats	Plan and create models	Panda's friend is coming to visit! Plan a habitat for Sally Squirrel
4	The five senses	Test and improve solutions	Panda wants to play with his friend Design a toy for a blind friend
5	Forces and motion	Share solutions with others	Panda broke his leg! Design a device that helps Panda move
6	Properties of materials	The entire process	Design a container to send cookies to a friend who lives across the river
7	Plant parts and needs	The entire process	Gladys Goat ate Panda's plant! Design a barrier to protect plants
8	Light and shadow	The entire process	Panda wants to play outside, but it is too hot and bright! Design a shade for Panda

and water during the first week, emphasizing that every problem has multiple solutions. The children then define criteria for successful solutions (e.g., not breaking the ring, melting the ice fast) and sort the solutions into testable and non-testable in the classrooms. The children then vote on a solution they would like to test first.

Table 12.1 presents the science and engineering focus for each Seeds of STEM unit.

The *Seeds of STEM* development process offers a unique model of collaboration between Worcester Head Start (WHS) teachers and the research team, representing researchers from Worcester Polytechnic Institute (WPI) and College of the Holy Cross. During the first two years of the project, the curriculum was developed through an iterative process of creation, testing, and revision. Currently, during the third year of the study, the curriculum is being pilot-tested at a different Head Start program. The project is supported by a grant from the US Department of Education's Institute of Education Sciences (IES, grant # R305A150571) and expected to be completed in 2019.

The overarching goal of the project is to support the teaching and learning of STEM practices in early childhood and, as a result, increase students' STEM readiness. The curriculum is developed to achieve two main student learning outcomes:

(1) Children who experience the *Seeds of STEM* curriculum will demonstrate improved ability to appropriately use STEM vocabulary that is integral to the engineering design process.
(2) Children who experience the *Seeds of STEM* curriculum will demonstrate improved ability to conduct each step of the engineering design process, which includes the following: define/explain a problem in their own words, propose multiple solutions to solve the problem, test and improve one solution of choice, and communicate the solution others.

1. **Who Should Be Part of the Curriculum Development Team?**

Education research relies on partnerships between researchers and practitioners to inform practice and enrich the research (Clements, 2007; NRC, 2002). Therefore, a robust collaboration between the research team and the Worcester Head Start program was established.

The *Seeds of STEM* curriculum development team included experts in STEM education, engineering, cognitive development, and diversity, as well as lead teachers from the Worcester Head Start program who provided classroom and pedagogy expertise. The development process was overseen by an advisory board consisting of early childhood, social science, and engineering experts. The team met monthly during the curriculum development period.

We believe that this collaborative development model is crucial for the success of the curriculum. The teachers on the team are knowledgeable about classroom environment, pedagogy, individual children's abilities and interests, appropriate vocabulary, attention span, and family involvement. They are also familiar with the daily schedule, the available materials, and other requirements of Head Start programs around the country. Teachers' expertise, combined with the research team's knowledge in STEM and children's learning, ensured the accurate matching of the curriculum's activities to a real-classroom environment, enhancing feasibility of implementation and curriculum usability by teachers.

To select teachers for the development team, the researchers defined the following selection criteria: (1) having a master's degree, (2) working in Worcester Head Start for more than one year, (3) mid to high scores on all Classroom Assessment Scoring System (CLASS) dimensions, (4) good reviews from the teacher's supervisor, and (5) teachers' interest in joining the development team. Based on these criteria, seven lead teachers from Worcester Head Start were selected for the role of 'Developer Teachers' (DT). The relationship among team members was one of mutual respect. During unit development meetings, the researchers presented the expected outcomes for students and teachers, while the teachers proposed activities, stories, and tasks that lead to such outcomes. Two of the developer teachers also participated in the final revision of the curriculum, to help make it as 'teacher-friendly' as possible.

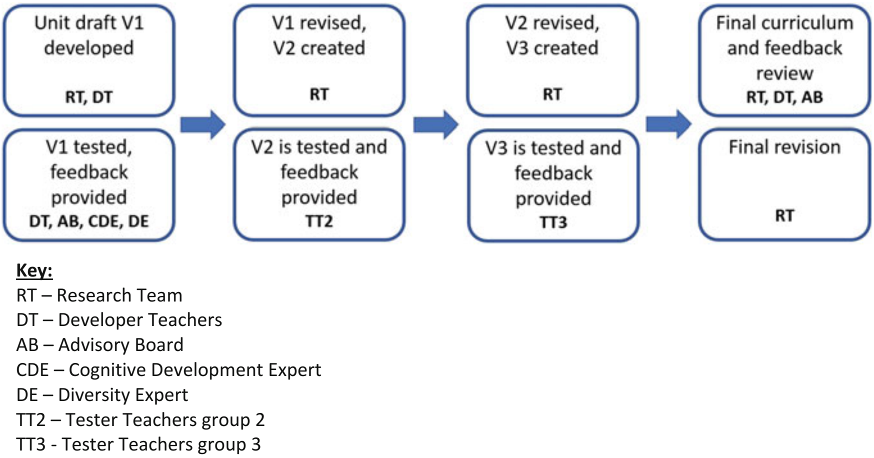

Fig. 12.1 Seeds of STEM curriculum development process

Lastly, the collaboration provided professional growth opportunity for the developer teachers. Several of the teachers presented at state and national conferences and participated in the facilitation of *Seeds of STEM* professional development sessions.

2. What Is a Successful Curriculum Development Process?

Research on curriculum development has shown that an iterative approach to development, in which each unit is developed, tested, revised, and tested again, leads to a high-quality curriculum (Clements, 2007; Diamond & Powell, 2011; Kinzie, Pianta, Kilday, McGuire, & Pinkham, 2009). This approach is in line with the engineering design process (EDP) that calls for engaging in a systematic and repetitive process of testing and revision until the final solution is ready for use.

In accordance with the iterative approach, each unit of the *Seeds of STEM* curriculum was tested and revised three times during the development process by three groups of Head Start teachers: the **developer teachers (DT)** and two groups of **tester teachers (TT2 and TT3)**. Figure 12.1 provides a visual of the entire process.

The first draft of each unit (V1) was developed collaboratively with the developer teachers, with the research team defining the standards and learning outcomes to be addressed, and the teachers proposing books, tasks, activities, songs, and art projects to meet the defined outcomes. Once the first draft was created, each one of the DT tested the unit in their classrooms and provided detailed feedback about the activities, the props, and the engagement of their children with each activity in the unit. During the testing of the first draft, the advisory board met to provide feedback on the unit; feedback was also provided by the diversity and cognitive development experts on the team.

The research team analyzed the feedback from the DT and experts and created the second version of the unit (V2). The group of **tester teachers (TT2)** tested the revised version of each unit in their classrooms and provided detailed feedback similar to the DT. The feedback from TT2 was analyzed and compared with video data from the classrooms and used for the second revision of each unit. Once all units have been tested and revised twice, the development team reviewed all the units together to ensure a cohesive flow from one unit to the next. This step proved to be very important. For example, the character of Problem Panda was only created during the development of unit 3 (earlier versions of unit 2 had a character named 'Mr. Problemo'). Once all units were developed, it became clear that Problem Panda should be present in units 1 and 2 as well. Revisions were made, and the third version of the curriculum (V3) included Problem Panda as a leading character from the first unit.

Once revised, a third group of **tester teachers (TT3)** tested the entire curriculum in sequence (from beginning to end), in order to assess the cumulative learning outcomes for children and the flow of the entire curriculum. The group of TT3 was asked to provide detailed feedback about the clarity of instructions and student outcomes.

Following the third testing and feedback from TT3, the development team and advisory board finalized the curriculum (V4), to be tested in experimental study by teachers from a different Head Start program.

3. What Principles Should Guide the Development of *Seeds of STEM* Units?

Following an extensive review of the literature, the *Seeds of STEM* research team defined a set of eight research-based principles to guide the development of the curriculum and ensure its high quality. The team adapted the Dayton Regional STEM Center's Quality STEM Framework (2011) to meet the standards for high-quality early childhood education. A description of the each of the guidelines follows Table 12.2.

Developmentally appropriate. Head Start classrooms are comprised of children of various ages and often include a wide range of skills, abilities, and language backgrounds (Cabell, Justice, Konold, & McGinty, 2011). To ensure that each unit of the curriculum is developmentally appropriate, the team relied on the National Head Start Child Development and Early Learning Framework (2010), and the Massachusetts Framework for Science, Technology, and Engineering for Pre-K (2014) to define the learning outcomes of the curriculum. The developer teachers proposed activities and tasks that cater to their multi-age and multi-ability classrooms. Through the iterative process of trial, feedback, and revisions, we were able to select only the activities that were proven to engage all children, including children who are dual language learners (DLLs). To increase engagement with the curriculum, the development team created a character, Problem Panda (exemplified by a stuffed animal), that visits the children in each unit to present a new problem.

Culturally responsive. Research shows that cultural contexts affect young children's cognitive, social, and emotional development, as well as their approaches to learning (Bowman et al., 2001; Genishi & Goodwin, 2008). A school's culture may differ greatly from a minority group's home culture. New (1999) called for early childhood teachers to embrace children's home culture and model the coexistence

Table 12.2 Guidelines for high-quality STEM experiences for early childhood classrooms

1. Developmentally appropriate	Seeds of STEM learning experiences provide children with books, videos, materials, and tasks that are appropriate for their cognitive and language development
2. Culturally responsive	Seeds of STEM learning experiences are designed to reflect diversity of gender, ethnic background, and physical abilities while allowing access and emphasizing children's own culture
3. Application of the engineering design process	Seeds of STEM learning experiences engage children in an **open-ended, multiple solutions problem-solving task** which requires them to follow the **engineering design process** (i.e., defining the problem, brainstorming, researching, creating, testing, improving, and communicating)
4. Integrity of the academic content	Seeds of STEM learning experiences are content-accurate, aligned with the relevant **content standards,** and **foundational skills** of **Science, Technology**, **Engineering**, and **Math** as articulated in pre-K standards and frameworks
5. Quality of technology integration	Seeds of STEM learning experiences are **hands-on** in nature and require children to use variety of **tools** to solve each problem (e.g., scissors, scales, computers, rulers, hand lenses)
6. Connections to Non-STEM disciplines	Seeds of STEM learning experiences help children connect STEM knowledge and skills with standards from early literacy, art, social, emotional, and physical education
7. Real-world connections and STEM careers	Seeds of STEM learning are driven by a real-world phenomena, which are familiar and relevant to the children's life inside and out of the classroom When applicable, quality STEM learning experiences introduce different STEM careers and help children understand the roles of people who work in STEM disciplines
8. Nature of assessment	Seeds of STEM units include formative and summative authentic embedded assessments. The variety of activities allow children to demonstrate their understanding in different ways and allow teachers to record children's mastery of learning outcomes

of different cultures. This allows children of minority cultures to value their home culture and the school (majority) culture and learn to celebrate the differences in people's identities. Cultural-based education recognizes the language, experiences, values, and knowledge of children, their families, and their communities and includes elements of children's home culture into the daily curriculum (Dubosarsky et al., 2011). The *Seeds of STEM* curriculum addresses cultural responsiveness by using books, images, and scenarios that represent a diversity of cultures, allowing children to identify and feel included in the units, while learning to respect other cultures. In addition, research suggests that parent–teacher collaboration supports student learning, and parental involvement is associated with academic and social competence (Powell, Son, File, & San Juan, 2010). To build on these findings, each unit plan includes extension activities and home-connection ideas for engaging the family with the topic of the unit.

Application of the Engineering Design Process. The research team strongly believes that the process of problem solving is the heart of STEM education, and therefore, the process should be taught explicitly through the curriculum. The problems that are presented to the children should be open ended and allow for multiple solutions. To support the curriculum's mission of teaching children how to solve problems, and with full understanding that the process may be too abstract for young children, *Seeds of STEM* engages the teachers in creating a visual aid of the problem-solving process. The visual, which looks differently in each classroom, is introduced during the first unit and being referred to multiple times in every unit of the curriculum. The teachers created the problem-solving visuals during a workshop, using vocabulary words and images that fit their students' understanding. It was important to the research team that every classroom team will create their own visual, thus increasing the ownership of teaching the process. A few examples of teachers' visuals are found in Fig. 12.2.

Integrity of academic content. Based on the authors' experience of conducting STEM professional development workshops with P-12 teachers, often times STEM projects are designed as 'add-on' experiences, for example 'egg drop' or bridge-building challenges, without making clear connection between the STEM challenge and the instructional core ideas (academic standards). The *Seeds of STEM* problems and tasks are aligned with science, math, or literacy standards, in order to make connections between STEM (engineering in particular) and the rest of the pre-K curriculum and prepare children to become problem solvers in any subject. As described earlier, each one of the *Seeds of STEM* units is aligned with NGSS core ideas, as well as the Massachusetts Framework for Science, Technology, and Engineering for Pre-K, and the Head Start Framework. The problems presented to the children require them to apply the science and math concepts for creating successful solutions.

Quality of technology integration. A common misconception held by educators (and the general public) narrows the definition of technology to digital technology. However, the technology integration principle calls for using tools, any kind of tool, that children find useful in solving the problem. These tools may include scissors, a scale, child-sized hammer, marker, measuring tape, spoon, camera, as well as a computer or tablet for research. Teachers who follow the *Seeds of STEM* curriculum

Fig. 12.2 Teacher-created visuals of the problem-solving process

consider the tools that children can use safely and include a plan on teaching the children how to use these tools.

Connection to non-STEM disciplines. Integration is a key to STEM education and the curriculum reflects that by using non-STEM context, such as books, videos, stories, and social studies topics, to generate problems. A study involving kindergarten students found that integration of science and literacy increased children's motivation and engagement in science (Samarapungavan, Mantzicopoulos, & Patrick, 2008). William Wolfson's *Engineering Lens* method (http://www.integratingengineering.org/index.html) for integrating engineering practices with literacy was used by the research team during the development process. There are several advantages for the integration of STEM with literacy: first, greater engagement from teachers, who are very comfortable with literacy activities. Second, this approach may help overcome common stereotypes (i.e., engineering is building). Third, using books as a context to start the problem-solving process allows for the choice of books that represent real-world relevance and involving a diverse population of characters. Fourth, adding books as the context for problem solving assists with daily lesson planning since it is expected to address literacy daily.

In addition to integration of STEM with literacy, the *Seeds of STEM* curriculum includes arts, music, and physical activities. The children go on a force hunt (forces and motion), shadow hunt (light and shadow), and solid/liquid hunt (ice and water) around the school and end many of the daily activities with 'freeze dance' that helps emphasize some of the concepts through kinesthetic learning.

Authentic assessment. Since the *Seeds of STEM* curriculum is centered on STEM practices, authentic assessments that are embedded in the unit would measure children's mastery of learning outcomes. Each unit plan includes formative assessment tasks that ask children to explain, demonstrate, or design a solution to a problem. The teachers document children's learning by scribing their explanations on the plans. The teachers also record children's demonstration of the problem-solving steps and use of vocabulary in context. Since young children may show evidence of transfer of the learning during other parts of the day, each unit includes a checklist of learning outcomes and the teacher is able to record evidence for learning—such as using the unit's vocabulary or demonstrating a key skill—throughout the day.

The repetitive nature of the curriculum, and the emphasis of the problem-solving process, engages the children in solving problems with different contexts. The last unit of the curriculum also serves as authentic summative assessment, allowing the teacher to evaluate children's mastery of the curriculum's learning outcomes.

4. **What Measures Should Be Taken to Ensure Fidelity of Implementation?**

Following the completion of the development process, the *Seeds of STEM* curriculum is being tested in 17 Head Start classrooms to assess its effectiveness in meeting the defined student outcomes. In order to evaluate the extent to which the curriculum was implemented as intended, the team developed measures to gauge the fidelity of curriculum implementation (FoI). The team defined the problem-solving steps and the way these steps are being introduced and followed as the critical components of the curriculum, and developed two methods to evaluate *Seeds of STEM*'s FoI: teacher surveys and observation form.

(1) Teacher survey. During the pilot study, intervention teachers complete a survey for each unit they teach. In the survey, the teachers provide feedback on the activities they taught and describe modifications they made during implementation, including changes to pedagogical strategies or in materials used. Teachers also report the level of engagement that their students present in each unit's critical component.
(2) FoI Observation form. Each *Seeds of STEM* unit is being videotaped by the classroom teachers. The video recordings are analyzed using the FoI observation form. The form development process was initiated by aligning the critical components with the following areas of curriculum implementation: materials and resources, duration of activity, format of activity, conceptual accuracy, use of vocabulary words, teacher's efforts to engage children, student participation,

and teacher's efforts to promote inclusion. These areas were then compared to the FoI elements found in the literature: adherence, duration and exposure, quality of delivery, program specificity, and student responsiveness, as well as with the categorization into structural and instructional components (Century, Rudnick & Freeman, 2010; O'Donnell, 2008). Through an iterative process, the areas were narrowed, and indicators for each area of implementation were refined. An initial seven-point scale was later revised into four categories: no evidence, low fidelity, medium fidelity, and high fidelity. An iterative process of developing detailed range descriptors for each area of implementation/indicators is now complete. In developing the range descriptors, the team worked through examples, examined sample videos to see if the range descriptors captured the information accurately, and modified range descriptions accordingly until an agreement was reached. The goal of this process was to create FoI descriptors that include concrete and observable actions, behaviors, and language.

5. **How Do We Measure the Curriculum's Effectiveness?**

The *Seeds of STEM* curriculum will be considered 'effective' if children who participate in the pilot study demonstrate the following goals: (1) improved ability to use the problem-solving vocabulary in context and (2) improved ability to conduct each step of the engineering design process.

The first step in developing the assessment was to clearly define the learning outcomes for each unit, as well as for the entire curriculum. To do so, the research team reviewed three sets of education standards: The Next Generation Science Standards (NGSS), the Massachusetts Framework for Science, Technology, and Engineering for Pre-K, and the Head Start Framework. Analysis of these frameworks resulted in a defined list of problem solving practices for young children, which became the curriculum's learning outcomes. In addition, a list of key problem-solving vocabulary words was defined and embedded in each unit (Table 12.3).

Assessment of curriculum effectiveness (in the form of mastery of learning outcomes by the children) is conducted formatively, during each unit of the curriculum, and summatively, during unit 8.

Formative assessment methods. Two main methods of formative assessment are being employed as part of the *Seeds of STEM* curriculum: (1) a teacher checklist and (2) a rubric for coding observational data. The teacher checklist includes the specific outcomes and vocabulary words associated with each unit. Pilot teachers are asked to keep the checklist handy in the classroom and check if they notice that one or more children correctly use a vocabulary word or show evidence of mastering a step in the engineering design process. The checklist includes a space for comments, and teachers are able to provide the context and evidence for their marking. The rubric for observational data is currently in development. The rubric includes detailed descriptors that provide observational evidence for learning outcome mastery, in the form of expressive language, gestures, and student work. Specific activities within each unit include formative assessment questions and tasks, to be evaluated by the research team using the rubric.

Table 12.3 Seeds of STEM learning outcomes

	Outcome	Definition	Assessment	Outcome addressed in unit
1	Identify a problem	• Articulate a problem and its implications	• Formative • Summative	1–8
2	Ask questions	• Explore issues related to the phenomenon and problem	• Formative • Summative	1–8
3	Obtain information	• Use first-hand interaction with objects and organisms, media, and books to gather information • Collect and document information (using senses and tools, including technology, to gather information)	• Formative • Summative • Artifacts	2–8
4	Analyze information	• Discuss the meaning and value of information for solving problems • Articulate processes and relationships	• Formative • Summative	2–8
5	Brainstorm and propose solutions	• Draw on self and others' knowledge and observations to come up with multiple solutions	• Formative • Summative • Artifacts	2–8
6	Choose a feasible solution	• Review and organize the ideas • Classify potential solutions into: ordinary, innovative, and magical • Predict outcomes and anticipate difficulties	• Formative • Summative	2–8
7	Plan to execute solution	• Develop a plan for the design of the solution using simple materials/equipment • Investigate materials as needed	• Formative • Summative • Artifacts	3–8
8	Design/build a model of the solution	• Work with others to select and use materials to build the solution	• Formative • Summative • Artifacts	3–8
9	Test solution	• Implement the design • Gather data on the effectiveness of the solution	• Formative • Summative	4–8
10	Evaluate solution	• Assess the effectiveness of the solution in solving the problem • Identify limitations of the solution	• Formative • Summative	4–8

(continued)

Table 12.3 (continued)

	Outcome	Definition	Assessment	Outcome addressed in unit
11	Improve solution	• Address limitations by modifying existing solution or developing a new solution • Retest and evaluate modified solution • Repeat steps 9–11 as necessary	• Formative • Summative	5–8
12	Constructing explanations	• Look for and describe patterns and relationships between the solution, limitations, and the problem, focusing on cause-and-effect relationship • Draw conclusions based on evidence	• Formative • Summative	All
13	Share findings	• Communicate the entire problem-solving and design process • Articulate findings and conclusions to peers and teachers	• Formative • Summative	All
14	Vocabulary	Understand and use in the context of the following words: engineer, problem, solution, brainstorm, choose, plan, model, create, test, improve, share	• Formative • Summative	

Summative assessment methods. The last unit of the curriculum will serve as summative assessment. While the first five units introduce and guide children through the process of problem solving, units 6 and 7 allow the children to practice the entire problem-solving process, and finally unit 8 presents a novel problem and allows for authentic assessment of children's transfer of learning. Trained observers will use a cognitive coding rubric to assess seven dimensions based on the outcomes checklist (describe/recognize information, identify problem, obtain information/ask questions, brainstorming, solution planning, solution creating and testing, sharing findings). This rubric allows the coder to record both the frequency of a behavior, such as asking a clarifying question, and the level of sophistication within each dimension. The rubric also allows the coder to record how often target vocabulary words are repeated and used correctly in a novel context.

A second summative assessment was developed to evaluate children's recognition of vocabulary words and the steps of the problem-solving process. This individual assessment was developed as a short computer game which asks children to identify pictures of problems and solutions, sequence images of a problem-solving story, and identify a picture for each vocabulary word. Every child in the intervention and control classrooms will play the 'game' before and after experiencing the full *Seeds of STEM* curriculum.

This chapter described the extensive research associated with the development of the *Seeds of STEM* curriculum. The authors hope that the information about the development team, the iterative development process, the curriculum guidelines, evaluation of fidelity of implementation, and assessment of the curriculum effectiveness will add to the body of knowledge about STEM and engineering education research during the early childhood years.

The chapter was initially written during the curriculum development process and revised to include information about the pilot testing of the curriculum. Currently, the *Seeds of STEM* project is in its third year, and several of the research instruments are being finalized. For the most up-to-date information and publications, please visit the project Web site: www.seedsofstem.org.

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