Chapter 5
Engineering Peer Play: A New Perspective on Science, Technology, Engineering, and Mathematics (STEM) Early Childhood Education

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5.1 Block Play, Learning, and Engineering: An Introduction

> *It has taken me a lifetime of learning from children to know these things: how to stop the waste, how to channel the precious forces of children.* (Caroline Pratt 1948)

Young children have always playfully and creatively built with materials available, testing and expanding their ideas about the physical and social world (Hanline et al. 2001). Not surprisingly, young children's play with blocks and other loose parts constructive materials has been an important aspect of early childhood education since its inception. Froebel's Gifts and Occupations curriculum for kindergarten prominently featured both adult-guided play and children's free play with blocks (Froebel [1826] 1887). In the early 1900s Maria Montessori's innovative educational materials developed for the *Casa dei Bambini* in Rome included a variety of blocks designed to spark self-directed learning, increasing children's understanding of mathematical and geometric concepts through hands-on manipulation of objects (Montessori [1917] 1971).

These early uses of blocks in educational programs for young children focused mostly on aspects of cognitive development. However, subsequent developments in the early childhood curriculum by pioneer educators broadened the focus of block play to include facilitation of social relations among children and their peers. In the United States, Patty Smith Hill of Teachers College-Columbia University in New York was a passionate proponent of a developmental, play-based approach to

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early education, inspired by Froebel's kindergarten and the child study movement led by G Stanley Hall and John Dewey. Hill believed constructive play was a rich context for both cognitive and social development. Among Hill's many contributions to early years education were "Patty Smith Hill Blocks," a system of large wooden planks and joints that both enabled and required children to work together to build houses or other large structures that they could play inside or upon (Fowlkes 1984). Caroline Pratt, founder and director of the City and Country School in Greenwich Village and a contemporary of Hill, was another passionate proponent of play within the progressive education movement. She invented hardwood unit blocks as a free play material (Pratt [1948] 2014). Pratt conceived of children's play with unit blocks as "an experiment in cooperation that was the foundation for the social relations and ethics that were democracy" (Hendry 2008, p. 7). Unit blocks are still commonly found in preschool classrooms, and we employed them in research described in this chapter.

Block building as a prime arena for developing social language and cooperative peer relations was recognized long ago by American early educators including Hill, Pratt, Dewey, Harriet Johnson, and Lucy Sprague Mitchell. More recently, scholars have emphasized peer interaction and social skills as children negotiate, plan, and cooperate to solve problems in block building contexts (Hanline et al. 2001). In fact, much of the block play literature has been focused in theory (e.g. Piaget 1967) and practice (e.g. Hanline et al. 2001; Verdine et al. 2014a, b) on social and constructivist principles of early learning and development; on the notions that young children actively explore the properties of blocks, and through engagement with materials and social interaction with peers, construct knowledge about blocks, the building process, related areas of learning, and social relationships (e.g. Piaget 1967; Verdine et al. 2014a, b). However, little systematic research has focused on children's specific language use and social interaction processes while playing with blocks. Rogers (1985) observed that preschool peers played in social groups most often when using larger vs. smaller blocks, and that little or no negative social behavior was observed during peer block play. More recently Cohen and her colleagues (Cohen and Emmons 2017; Cohen and Uhry 2007, 2011) conducted a series of studies in which they observed peers' language interactions as they played with unit blocks. They found that children use complex social language with peers, frequent spatial language, and a variety of representational forms when they are engaged in peer play with blocks, in both free play and adult-guided play, compared to solitary play. While such studies provide preliminary evidence for multimodal learning in social block play, it is clear that additional research could illuminate developmental change in block play with peers and the linkages between block play and several areas of social and cognitive learning (e.g. mathematics, spatial skills, executive function; Clements and Sarama 2007; Verdine et al. 2014a, b). Additionally, innovative peer play education perspectives may inform educators' framing of social-constructive peer play in classroom contexts.

There are fascinating parallels between the world of young children's block play and the world of adult professional engineers. Children's imaginative and creative constructive play can be seen as a form of problem-focused design, much like the work processes adult engineers use every day. Engineering design typically involves the statement of a goal or problem that needs to be solved by building objects, making plans or prototypes, evaluating results of the initial design, trial-and-error evaluation of built objects, and communication with others about ideas, strategies, the building process, and results (Moore and Tank 2014). Engineering is inherently a social-constructive process, dependent on effective social communication to construct the best version a planned physical structure (Petre 2004). Expert engineering teams, those that produce the most innovative and effective solutions to problems, typically foster innovation by encouraging differing viewpoints and ideas, valuing the discourse involved in sorting out differences, trying different approaches, and comparing alternative solutions (Petre 2004). While much more complex and organized than the discourse in children's peer play, there are striking parallels between processes documented within engineering teams and the language interactions observed among peers in young children's block building (Cohen 2015). In this chapter, we explore the theoretical utility of applying this engineering design conceptual framework to children's social construction in peer play. We ask three research questions:

1. How do young children's peer play processes during block building parallel the design process of adult engineers?
2. How can we observe 'engineering peer play' during young children's typical block play activities?
3. How can we use the 'engineering peer play' education framework to better understand young children's development and apply that understanding in classroom peer play contexts?

5.2 Peer Play and Engineering Design

How do children's peer play processes parallel adult engineering?

At its core, the engineering design process functions much like the scientific method, where scientists ask research questions, make hypotheses and predictions about their questions, test their hypotheses in experiments, and evaluate the experimental results. Fig. 5.1 depicts a standard version of the engineering design process model used in engineering educational programs and research (Moore and Tank 2014). A design problem or goal is identified and *defined*. Peers then discuss, *learn,* and agree upon a constructive approach. They *plan* their building approach, implement and *try* their plan, *test* and evaluate the effectiveness of the plan, and *decide* if changes are needed to meet construction goals. However, unlike the scientific method, the engineering design process is not wholly linear. Success in engineering depends on a flexible design approach involving reflective thought and the possibility that early building ideas and plans will fail. Of paramount importance in this process is the exploration of creative thought to produce innovative solutions to design problems as they arise (Howard et al. 2008) and likewise, the ability to incorporate the design process into

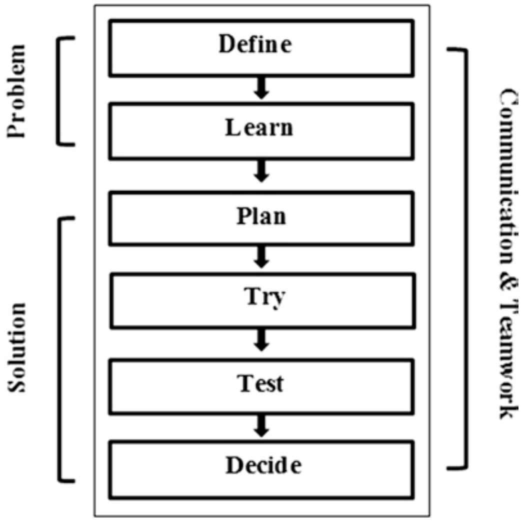


Fig. 5.1 Engineering design process, PictureSTEM, Moore and Tank (2014)

creative thought. This is achieved through iterative cycles of communication and teamwork used to test and evaluate the effectiveness of built structural components, reflecting on and discussing previous design ideas, modifying, adapting, and producing new versions of engineered structures until construction goals are achieved.

In theory, preschool and elementary school-aged children engage in a parallel process with peers during social-constructive play with blocks (Bairaktarova et al. 2011; Gold et al. 2015, 2020a). Figure 5.2 depicts a hypothetical example of children's employment of the engineering design process steps during constructive play. Children *define* their construction goal, to build a castle with two floors and a tower. They discuss and together *learn* that the castle must be tall in order to include the two floors and tower. The children organize a *plan,* where one child will build the floor while the other begins constructing the outside walls. They *try* their plan, building the floor and walls as tall as they can. However, they are met with a construction problem that calls for evaluation and a *test.* The castle is certainly tall enough for two floors and a tower, but there is no second-story floor in their prototype castle to divide the ground floor from the second level. The children *test* an alternative, removing half of the castle wall height and planking a long flat block across the top of two opposite walls. They *decide* this new idea will work, cycle back to the implementation step, and *try* lining up additional blocks parallel to their *test*-block until the first castle level is enclosed by a roof. Then the children replace the wall-blocks previously removed to finish the second floor while preserving the original castle height. The children might subsequently engage in another iteration of the engineering design process as they encounter building challenges while constructing the castle tower.

These children's engagement in the engineering design process depended on their reflective and creative approach to solving the construction problem; the absence of the second level floor. Without evaluation, creative thinking, modification of construction methods, and recognition that the original castle prototype did

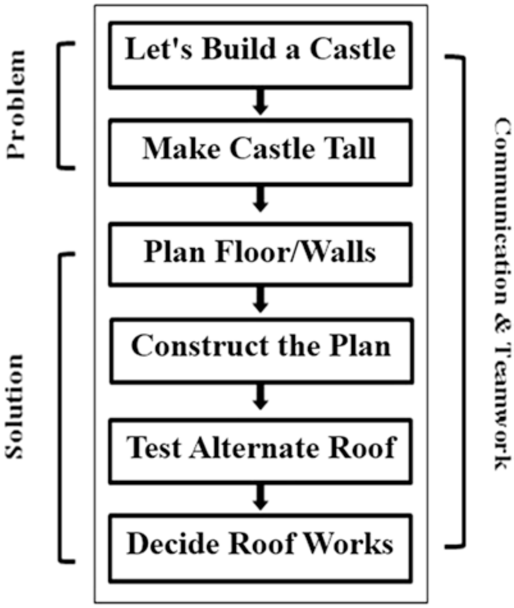


Fig. 5.2 Example of children's constructive play paralleling the engineering design process

not match their representation of the two-floored castle, the children may not have persisted to accomplish their defined building goal. Yet, these peers demonstrated a coordinated social effort to meet their defined construction plan and worked as an engineering team.

Research has confirmed that young children's peer play behaviors, viewed using the conceptual frame of engineering in several play contexts, parallel the design process used by adult professional engineers. Using direct observation methods of children's peer play with blocks and other loose parts manipulative materials, scholars have found evidence of children as young as four years expressing interest in and engaging in the engineering design process through their language and social interaction during peer play (Bagiati and Evangelou 2015, 2016; Bagiati et al. 2010; Bairaktarova et al. 2011; Brophy and Evangelou 2007; Evangelou et al. 2010; Gold et al. 2015, 2017, 2020a). Further, these findings indicate that constructive play with blocks may be a particularly rich context for observing engineering play behaviors and understanding how children employ engineering thinking during peer play.

5.3 Observing Engineering Peer Play with Blocks

What are children doing during engagement in engineering peer play?

The newest initiative in early engineering scholarship has been to systematically describe and categorize young children's engineering thinking into observable language- and action-based engineering play behaviors (Bairaktarova et al. 2011;

Table 5.1 Engineering Play Behaviors © Gold et al. 2017

Behavior	Definition	Examples
Communicates Goals	Expressing a desired end to achieve a purpose	"Let's build a castle" "I want to put this block on top"
Construction	Collecting and building actions	Stacking or placing blocks, collecting or organizing blocks
Problem Solving	Verbally identifying problems or suggesting solutions	"This will not work, it's too big" "This square block will hold it"
Creative/Innovative Action	Trying a new or innovative approach or idea	Leaning two long blocks together to make a teepee
Solution Testing/Evaluating Design	Testing and evaluating how a structure functions	Rolling a ball to test if a ramp works, saying it does not work
Explaining How Things are Built/Work	Explaining why or how something is built or works	"Let's put the block this way to hold the door on"
Following Patterns or Prototypes	Representing ideas verbally or in structural models	"This tractor is just like the one mom drives at home"
Logical or Mathematical Words	Using math vocabulary or if-then statements	Taller, near, above, square, counting, inside, around "If we use the square block, then we can close the tunnel"
Technical Vocabulary	Using specialized STEM words	Gear, balance, stability, satellite, ramp, engine, factory, robot

Gold et al. 2015, 2017, 2020a). Various observational and statistical methods have been used to explore, define, and group engineering peer play behaviors. We hope to use these seminal measurement studies to establish a foundational understanding of behavioral processes reflecting the way young children employ engineering and related STEM skills during peer play. Bairaktarova and her colleagues (2011) observed preschool children's spontaneously occurring classroom peer play with a variety of open-ended materials. These observations were used to develop an emergent observational scheme, identifying five types of preschoolers' engineering play behaviors. Gold et al. (2015) further developed this engineering play framework into nine observable play behaviors and refined the categories to provide clear operational definitions and examples of each behavior for use in observational coding. Table 5.1 describes the nine engineering play behaviors with examples (Gold et al. 2017). In the current research, we employ our understanding of how peers engage in engineering play and illustrate observed examples for readers.

5.3.1 Research Design and Participants

Peer play examples in the current chapter are drawn from our recent observational study of preschoolers' dyadic play with traditional classroom unit blocks (Gold 2017; Gold et al. 2020a). Participants included 110 preschoolers (62 male; 48 female) ranging from 49- to- 72 months-old ($M = 58.47$, $SD = 4.46$). Children were recruited from 10 preschool classrooms in five rural and suburban counties in the Midwest United States. Classrooms included six Head Start programs, two church-based nursery schools, one public prekindergarten for children with special needs, and one university laboratory preschool. The sample was 77% Caucasian ($n = 85$), but included children from diverse socioeconomic backgrounds (42% of parents' highest level of education was a high school equivalency) and 27 children with identified disabilities (e.g. speech-language delay, autism spectrum disorder, attention deficit and hyperactivity disorder).

Research assistants visited participating child care classrooms to video-record children engaged in same-sex dyadic block play. Children were filmed in separate observation areas, quiet and removed from regular classroom activities ($M = 14{:}53$ minutes of observation). Dyads included only peers from the same classroom. Children were asked to produce and agree to a building plan (e.g., castle, rocket ship, gymnasium), after which they were given a box of 110 unit blocks and filmed in a large open space as they worked together to accomplish their construction plan. Three research assistants then coded children for frequency of engagement in each engineering play behavior (Cohen's $K = .86$).

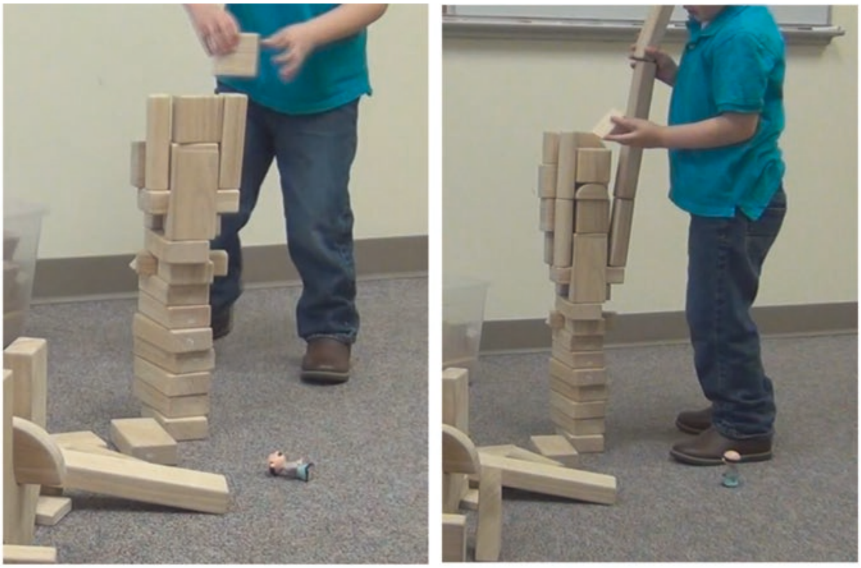
5.3.2 Case Examples

To illustrate how peers engage in these engineering play behaviors and the engineering design process, both socially and constructively, we present exemplars drawn from several engineering peer play dyads. Vignettes include both quotations and descriptions as a contextual reference:

Vignette 1
"Look at my huge tower!"

This engineering design example illustrates the elaborate construction of a tall tower and Child 1's attempt to add blocks while maintaining structural stability. As Child 2 observes just off-camera, Child 1 engages in a problem solving and evaluation sequence that becomes increasingly difficult as blocks are added, with variability in the shape and size of added-blocks creating an imbalance in the structural foundation of the tower. Several steps in the engineering design process occur (e.g. try, plan, test, decide), and several engineering play behaviors are used during this process (e.g. mathematical words ["more pieces", "one more square"]; communicates goals ["I'm going to get one more piece"]; explaining how things are built/work ["I'm going to keep building it so it will be nice and steady"]; solution testing/

evaluating design [“You don’t have to build it so tall”; rebuilding the structure differently after collapse]; problem solving [“See it keeps falling! I told you it’s too tall”]). It is evident in this example that observed engineering play behaviors were utilized as part of the design process to accomplish construction of Child 1’s tower. Equally important are Child 2’s observations and evaluations as key components of the problem-solving sequence, as well as Child 1’s persistence in rebuilding the tower after a failed construction attempt. This vignette represents a social-cognitive peer evaluation process in which one child leads and another observes and evaluates to achieve the construction goal (Fig. 5.3).



Child 1:	“It needs more pieces. I just need one square.”
	“Okay aha! Now look at this new work house.”
	“Hmm. Yes I’m going to get one more piece.”
	[Tower falls] “Uh oh! I’ll try building it again!”
Child 2:	“You don’t have to build it so tall.”
Child 1:	“Yes I do.’ [Tower falls again].
Child 2:	“See it keeps falling! I told you it’s too tall.”
Child 1:	“I’m going to keep building it so it will be nice and steady.”

Fig. 5.3 The engineering design process and behaviors depicted as children build a tower and exchange construction ideas

Vignette 2
"You need a windshield for your car!"

This engineering design example exemplifies a social constructive process in which one child recognizes a pattern in her partner's building and subsequently influences the constructive process and peers' co-learning. Child 1's structure is clearly organized, but it is not evident Child 1 knows what she is building as she adds new blocks and the evolving structure takes shape. Off-camera Child 2 contributes as an analytic observer, recognizing a car-prototype based on the figurine's apparent placement in the driver's seat of a car-shaped block configuration. Child 2's suggestion to add a windshield causes Child 1 to recognize the prototype and use her square block as the windshield her figurine needs. Child 2 then provides additional social encouragement as well as constructive guidance regarding how to place the windshield-block. Child 2 also observes Child 1 leaning over her structure while placing the windshield, and gently suggests caution so she does not inadvertently collapse her house. Several steps in the engineering design process occur (e.g. define, try, plan, test), and several engineering play behaviors are used during this process (e.g. mathematical words ["this is big", "right up", "fall down"]; technical vocabulary ["windshield"]; communicates goals/following patterns or prototypes ["You need a windshield"]; explaining how things are built/work ["Just stand that right up"]; creative/innovative action [using the square block as a windshield]). It is evident in this example that observed engineering play behaviors were utilized as part of the design process during the social constructive verbal exchange between the children. Significantly, Child 2's imaginative perspective-taking and communication fostered the development of Child 1's construction, the social-pretend story associated with her construction, and her understanding of how to physically accomplish the construction goal. This vignette depicts an engineering design process in which the effects of shared peer play experiences help children co-construct knowledge and form ideas about representational forms in their play (Fig. 5.4).

These are just two examples representing the kinds of reciprocal language and behavioral interactions that occur during young children's engagement in engineering play with blocks. Myriad examples of engineering peer play have been observed revealing the kinds of creative, imaginative, and process-oriented thinking strategies peers use to solve construction problems. However, beyond understanding how peers engage in engineering play, there are larger implications of the engineering peer play perspective within preschool education as a practice. How might researchers and educators use examples, like those described, to inform our understanding of early childhood development and learning, and apply that understanding through meaningful classroom teaching practices?

Child 1:	"This is big!" [Refers to rectangular block as she removes it from the box]
Child 2:	"You need a windshield for your car"
Child 1:	"Oh, I've got a car! [Places square block in front of figurine as windshield]
Child 2:	"You just stand that [block] right up"
Child 2:	"I hope your house doesn't fall down" [Child 1 leans over house].

Fig. 5.4 The engineering design process and behaviors illustrated during pattern recognition and co-learning

5.4 Implications of Engineering Peer Play in Research and Early Education

How can we understand and use 'engineering peer play?'

Observing and understanding how children engage in engineering peer play is applicable in research and practice for several reasons. First, constructive play with blocks is a potentially rich context to observe young children's 'co-learning' engineering with peers and their engagement in social-constructive peer play processes. For example, Gold et al. (2015) described the frequency of preschoolers' engagement in each of the nine engineering play behaviors within several play contexts offering varying opportunities for constructive play. Peers were observed in free play on the traditional fixed structure playground, in the classroom dramatic play area, and both indoors and outdoors with Imagination Playground™ Big Blue Blocks, oversized light-weight foam blocks and attachable pieces designed to foster active exploration and creativity during social-constructive and pretend play. Results revealed that peers engaged in significantly more engineering play in the large foam blocks context, but that children also engaged in high frequencies of engineering play during dramatic play with peers.

As Hanline and colleagues suggest, "Representational play is supported as children take on pretend roles when they play with toy figures and vehicles, along with blocks" (Hanline et al. 2001, p. 224). Play contexts that allow peers to integrate representational objects support creativity and peers' feelings of social competence (Hanline et al. 2001). Consideration of how peers represent various block forms (e.g., following patterns or prototypes, Table 5.1) and integrate pretend play storylines during engineering play, reaffirms that early engineering is both a constructive and social process. Pan, Sun, and Chen (Chap. 10, this volume) also suggest block play promotes high levels of critical thinking. Therefore, we cannot understate the potential value of framing peer block building toward engineering as a method of understanding how children co-construct knowledge of social relationships, peer negotiation strategies, representational forms, and areas of early cognition and learning.

Further, research has demonstrated that engineering peer play is related to many early learning areas and may be inherently valuable in the systematic exploration of early cognitive processes. Gold (2017) and Gold et al. (2020a) found that preschool peers' frequency of engagement in engineering play with unit blocks was associated with mathematical ability, spatial ability, executive function, and planning skills (Gold 2017; Gold et al. 2020a). Applying engineering skills in practice naturally relies on obtained skills in mathematics, spatial reasoning, planning, and children's ability to communicate these skills through social interaction (e.g., verbal engineering play behaviors, Table 5.1). These learning areas have been studied extensively in the early years (e.g., mathematical knowledge, Clements and Sarama 2007; mathematical language, Purpura et al. 2017; spatial ability, Levine et al. 1999). There is optimism that young children's engagement in engineering play in constructive peer play contexts has the potential to influence cognitive development and learning. Moreover, because peers' engineering play is related to a variety of early skills, there are practical implications of engineering play as an early childhood perspective that can be meaningfully applied in classroom peer play contexts.

Therefore, another key implication of engineering peer play is its practical utility in classroom settings. Encouraging teachers' recognition and facilitation of STEM behaviors in peer play environments during the early formation of peer relationships could improve children's engineering skills, other related areas of learning (e.g. mathematics, spatial ability; Gold 2017; Gold et al. 2020a), and foster children's early interest in science, technology, engineering, and mathematics (STEM) as a future career. In a study involving 10 classroom teachers, Gold et al. (2020b) implemented and evaluated a feasibility intervention to field test engineering play as a teaching tool for the first time. The intervention facilitated teachers' understanding of: (1) the engineering design process; (2) how to identify engineering processes in children's peer play; and (3) how to facilitate children's engineering play behaviors during constructive peer play with blocks. Results revealed that teachers were engaged and motivated to implement engineering skills with students and effectively supported and facilitated engineering peer play (e.g. noticing and supporting children's engineering behaviors, back-and-forth conversation, building with a child, encouraging children's block-building conversations). We also found preliminary evidence that when interesting building play materials are introduced into the classroom and teachers participate in training about early engineering play, preschool children's peer play is enhanced, increasing their engagement in planning, design, construction, and engineering thinking.

Therefore, scholars and educators might utilize the engineering peer play perspective as: (1) a method of understanding peer social constructive play processes; (2) a potentially valuable peer play context in which to improve children's development in several learning areas; and (3) a tool to frame children's interest and engagement in STEM processes in the early years.

5.5 Conclusions

Since the 1980s, opportunities for unstructured and semi-structured play in schools in the United States have been steadily reduced in favor of increased efforts to meet state standards focused on discrete academic skills, and this trend toward less time for play has recently extended downward into the pre-kindergarten years (Miller and Almon 2009). Some scholars argue there is a need to revisit the potential associations between play-based education in early childhood classrooms and aspects of children's learning and development (Nicolopoulou 2010). Scholars have suggested that because play provides young children with opportunities for enthusiastic engagement and challenges across multiple developmental areas (Gold 2017; Gold et al. 2020a), it is pertinent to develop early childhood educational perspectives that identify learning processes occurring during peer play, especially play in STEM. Direct observation of children's peer play using these perspectives will allow researchers and educators to further understand the behavioral processes that can influence young children's social development and school readiness (Bairaktarova et al. 2011; Gold et al. 2015; Gold 2017).

Research on engineering play as a framework for peer play and development is limited. In their recent review, Lippard et al. (2017) identified only 27 studies related to 'engineering thinking' in preschool. The majority of these studies either measured a construct theoretically related to engineering, without direct measurement of engineering, or assessed engineering thinking in less-traditional play contexts such as robotics. As we develop valid and reliable ways to observe engineering-related thinking and play, particularly with young children, scholars have been observing and gaining understanding of early engineering skills in facilitative peer play contexts, such as constructive play with blocks (Gold 2017).

The early research has indicated that the engineering peer play perspective may be useful in understanding young children's learning and development (Gold et al. 2015, 2020a; Gold 2017). Some play contexts may motivate young children to interact, experiment, and actively practice engineering skills in ways that foster STEM learning and encourage use of previously developed STEM skills (Brophy and Evangelou 2007). Framing and focusing on children's engineering-like behavior during peer play could be efficacious in encouraging children's early interest in STEM and motivation to engage in STEM learning outside of traditional early STEM instructional contexts.

Engineering play as a framework for peer social learning and collaboration is still in the early stages of research, but there is an abundance of potential knowledge to be gleaned about early engineering thinking and application in educational contexts. Although more measurement research is needed, including refinement of the existing engineering peer play measure and examination of other potentially important related factors, such as children's language ability, the field has taken an important first step in exploring potential use of the engineering play framework in early education constructive peer play contexts.

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