# The Effects of Rigamajig® Play Materials on Elementary Children's Early Development, Learning, and Interest in STEM

**Final Report to KaBOOM!**

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December 31, 2019

**Acknowledgements**

We are thankful for the participation of the students, their parents, teachers, and administrators at Amelia Earhart Elementary School, Mintonye Elementary School, Murdock Elementary School, and Lafayette Sunnyside Intermediate School in Lafayette, Indiana. The parents, teachers, and administrators were enthusiastic participants, helping in many ways and making it possible for us to observe the children playing with Rigamajig. Key partners in development and consultation on this project were Rigamajig creator and Associate Professor Cas Holman of the Department of Industrial Design at the Rhode Island School of Design and Ngina Johnson, Head Teacher at the Croft School in Providence, Rhode Island. Finally, we are grateful to David Flanigan and Bruce Bowman of the national non-profit organization KaBOOM! for their enthusiastic support of this research and The CarMax Foundation for providing essential funding support, without which this project would not have been possible.

**Abstract**

Researchers at Concordia University and Purdue University filmed and observed elementary children's group play with Rigamajig materials in four 30-minute play sessions over a one-month period. The research objectives were to: (1) document the occurrence of engineering, physical, and social play behaviors as children gained additional experience with Rigamajig; (2) assess similarities and differences in play between boys and girls and children in kindergarten, 2nd grade, and 5th grade; and (3) examine children's interest in STEM-related careers before and after study participation. This observational study included 74 children filmed in their elementary schools during the spring of 2019 and analyzed through December of 2019. Results demonstrated that Rigamajig provided meaningful opportunities for play across each observed behavioral domain. Elementary children engaged in high rates of engineering play behaviors, fine and gross motor physical behaviors, and social competency behaviors across gender and grade level. Important similarities and differences by grade and gender were found. There were no significant gender differences in engineering play and social play, but significantly more gross motor behavior in girls compared to boys. Also, there was frequent gross motor behavior in kindergarten and frequent fine motor behavior in older children. Moreover, there were statistically significant associations between engineering play behaviors and physical and social skills, suggesting that children who engage in more engineering behaviors are more socially competent and employ specific physical skills to accomplish their goals. Although STEM career interest did not increase after study participation, boys and older children were most interested in STEM. It is clear that Rigamajig facilitates unique play experiences across elementary school that include opportunities for meaningful engagement in a variety of developmental and learning areas supporting 21st century skills. Evidence suggests that Rigamajig play materials support social group collaboration and leadership, consistent physical movement, and higher-order thinking skills reflecting early engineering design processes. This study shows that Rigamajig as a child-centered activity with supportive teacher guidance in classrooms, affords children opportunities to practice a broad range of developmental skills (See web-based project lesson plans https://www.rigamajig.com/project-plans/)

## Introduction

Research supports that numerous aspects of development and learning can be understood through children's self-organized thoughts and actions during unstructured and semi-structured play (Lobo & Galloway, 2008). Specifically, children's active manipulation of objects during play is associated with other important behaviors across a variety of childhood domains, such as positive social-emotional behaviors, physical activity, creativity and imagination, and cognition (Bagiati & Evangelou, 2016; Gold et al., 2015; Howe et al., 2002; Stauffacher & DeHart, 2005). Scholars posit that because play provides children with opportunities for enthusiastic engagement and development across multiple domains (Brophy & Evangelou, 2007; Sutton, 2011), it is pertinent to develop holistic teaching perspectives that identify and interpret developmental processes occurring during play (Gold et al., in press), especially in science, technology, engineering, and mathematics (STEM) contexts (Horn et al., 2012). It is thought that observing children's play behaviors from an engineering perspective could be useful in understanding development and early interest in STEM (Bairaktarova et al., 2011; Gold & Elicker, in press). Recent studies identified children's engineering play behaviors in constructive play contexts as important factors associated with physical and social ability and early learning (Gold & Elicker, in press). However, there is little research about engineering play as a part of the curriculum in classroom contexts (Gold et al., in press). This research provided new information about how children's engineering, social, and physical behaviors developed during semi-structured play activities with Rigamajig® play materials, and how development of these behaviors informed knowledge about children's 21st century skills.

In February, 2019 research teams from Purdue University, led by Dr. Jim Elicker, and Concordia University, led by Dr. Zachary Gold and Dr. Nina Howe, were invited to engage in a collaborative research project funded by KaBOOM! and the CarMax Foundation. The overall goal was to systematically study children's play with Rigamajig play materials. The specific objectives of this research were to:

(1) Quantify the effectiveness of Rigamajig in developing children's early interest in STEM-related fields.
(2) Assess the utility of Rigamajig to develop early engineering behaviors and play behaviors that parallel the basic engineering design process.
(3) Document the effectiveness of Rigamajig in developing children's fine and gross motor physical skills and social competency skills.
(4) Evaluate children's Rigamajig play in response to semi-structured play prompts to examine the utility of Rigamajig as a teacher-guided tool in classrooms.
(5) Explore similarities and differences in girls' and boys' Rigamajig play behaviors and between children in kindergarten, 2nd grade, and 5th grade.

The research project began in February of 2019 with the development of the observation instruments and child STEM interest surveys; training, practice, and reliability testing of data collectors; recruitment and orientation of participating elementary school programs and teachers; and recruitment and informed consent with children and families. KaBOOM! provided full sets of Rigamajig materials to four participant elementary classrooms: Amelia Earhart Elementary School, Mintonye Elementary School, Murdock Elementary School, and Lafayette Sunnyside Intermediate School in Lafayette, Indiana. KaBOOM! also provided input and support about study design and implementation through collaborative discussions with Rigamajig creator, Cas Holman, and Rigamajig project consultant, Ngina Johnson.

Systematic filming of Rigamajig play began at the four elementary schools in early March, 2019 and continued through April, 2019. Observational coding and analysis of children's filmed play behaviors began immediately after filming was completed and continued through December, 2019 over approximately eight months duration. This report summarizes the methods used to conduct this research, the findings of the research, conclusions, and implications for childhood development, teacher practice, and product development and marketing.

## Research Method

### Participants

Children between 5- and 11-years-old were recruited by sending parent letters to all families in four classrooms in the four participant schools. Parents were given a written explanation of the study and a detailed consent form. The sample included 74 children distributed fairly equally among the four participant schools and across kindergarten, grade 2, and grade 5. Retention rates were high. Overall, 84% of children who participated in Week 1 of play remained in the study at Week 4. Due to school absences, some of the eligible children were not present during a few weeks of play observation. Ultimately, 62 children (33 girls; 29 boys) (k = 20; grade 2 = 20; grade 5 = 22) who were observed during Rigamajig play at both the start and end of the study were included in the analyses for this report. Children were racially and ethnically diverse (Caucasian = 58%; multi-racial = 15%, Latino = 10%; African American = 7%; Parent chose not to report = 10%). Additionally, 15% (9 children) were identified by their parents as having a diagnosed disability and an Individualized Education Plan. Family socioeconomic backgrounds were also diverse. Average annual family income was between $30,000 and $50,000. Most parents had some college experience, but no degree.

### STEM Interest Survey

To assess children's interest in STEM occupations, the Concordia and Purdue research teams developed a picture-based survey administered to children before their first Rigamajig play session and after their last play session. The survey was designed so children at each grade level in the study could understand and answer survey items. Children responded to 10 items, each asking them to circle which picture depicted the career they were interested in most. Each of the 10 items presented 3 picture choices, ranked from lowest (0), middle (1), to highest (2), representing which careers were most STEM-related. (See Appendix for a copy of the STEM Interest Survey). Gender-specific surveys were administered, including the same pictures in both genders to ensure boys' and girls' answers were not influenced by the gender of the person in the pictures. Scores were calculated for each child by summing the scores (0, 1, or 2) of their selected pictures to produce a score ranging from 0-20, with higher scores indicating more interest in STEM careers.

### Observation Procedure

Two research observers visited each elementary classroom once weekly for one month to organize and film children's play with Rigamajig in four 30-minute sessions. At each grade level, children were filmed in groups of four to optimize and encourage collaboration. Same-sex play groups were filmed to replicate boys' and girls' typical childhood play partners. The classroom teachers selected the four children for each play group based on their knowledge of children's friendships and who was most likely to work together successfully. The children in each play group remained the same throughout the study period. However, some children were absent for some play sessions, in which case children were either filmed in groups of three, or alternate children stepped in to round out the group at four. In sum, 18 play groups (6 groups per each grade level) were filmed four times across one month, totaling two hours of video-recorded play with Rigamajig per play group.

Play groups were prompted with a specific play objective before each of their four play sessions. Play prompts were designed to be child-directed, open-ended, and to increase in complexity each week as children gained additional experience with Rigamajig. At the start of each session, play prompts and objectives were posted near the play area, so children could remember their task throughout the play session. Play prompts were informed by Next Generation Science Standards.

**Play Prompts**

**Week 1 -- Materials Exploration:**
- Name each of the Rigamajig pieces to become familiar with shape, size, and function.
- Build anything you want together as a team, and work together to figure out how to connect pieces as you build.

**Week 2 – Wave Protection:**
- Imagine that a giant wave from the ocean is about to crash onto the land.
- Make a Rigamajig that you can get inside to protect your group from the wave.

**Week 3 – Lifting a Bucket:**
- Imagine another giant wave is coming and it's about to get everything wet!
- Create a contraption that will lift a bucket above the wave to keep these animals dry.
- Children were provided with a few small stuffed animals to use in their contraption.

**Week 4 – Crossing the River:**
- Imagine your group wants to cross the river and reach the other side.
- Make a machine you can use to move your group to the other side.
- The river was marked on the floor with blue painter's tape.

**Video Analysis Procedure**

Four research assistants observed and documented children's engagement in (a) engineering, (b) physical, and (c) social play over their four play sessions with Rigamajig. Two camera angles were used to ensure each child could be observed throughout the play sessions. The video observer focused on one child at a time and documented all of the engineering, physical, and social play behaviors the child displayed. Observation intervals were 20 seconds: the observer watched the child carefully for 20 seconds, then noted all behaviors that occurred on a checklist that included 5 engineering play behaviors, 17 physical behaviors, and 4 social competency behaviors (see Appendix for the complete observation instrument). This observation process was repeated for each 20 second interval over each 30-minute play session. Therefore, each child was observed for approximately 90 intervals per play session. Over the course of the study period, children were observed for more than 8,000 minutes (134 hours). Because the number of minutes each child was observed in each play session was not exactly the same, we calculated each child's *rate* of play (# of times observed per 30-minutes) rather than the simple frequency of occurrences. Using these *play behavior rates* makes the summary of observed play behaviors in each play session more comparable and understandable.

**Observation Measures**

The Concordia and Purdue research teams used structured observation measures to provide comprehensive descriptions of children's play behaviors in three domains: (a) early engineering skills, (b) physical activity, and (c) social competence. Observers were trained using extensive video examples and demonstrated a high degree of reliability on the observation instrument before any video data were analyzed. Each observation measure was derived from instruments used successfully in previous research. Specifically, the observation instrument was a new version of the instrument used by the same researchers in KaBOOM!'s 2013 evaluation of Imagination Playground$^{TM}$ Blocks. The combined observation instrument included a total of 30 individual play behavior categories (see Appendix for categories and definitions). As children were observed, each play behavior was noted as present or absent within each 20-second observation interval.

***Engineering Play Behaviors*** (EPB). Play behaviors paralleling the basic engineering design process were observed using a five-category system initially developed by Demetra Evangelou and colleagues at Purdue University (Bairaktarova et al., 2011). The observation scheme was then further developed by Dr. Jim Elicker and Dr. Zachary Gold in the Imagination Playground$^{TM}$ Study (Gold et al., 2015) and the Engineering Play Unit Blocks Study (Gold et al., in press). The categories are: (1) communicating goals; (2) explaining how things are built/work; (3) problem solving/solution testing; (4) following patterns or prototypes; and (5) use of STEM vocabulary. Summary scores for each engineering behavior category for each child were calculated, indicating the average number per 30 minutes.

***Social Behaviors***. The categories for social play behavior included four observed behaviors developed and defined specifically for this research study. The four social play categories were: (1) expresses positive emotions to self/others; (2) instances of leadership; (3) instances of cooperation or following; and (4) sharing behaviors. We also rated each child's level of social play in intervals using an ordinal scale (Parten, 1932; Rubin, 1989) that included the following categories: (1) unoccupied with the activity; (2) observing but not socially involved in play; (3) engaged in solitary play; or (4) engaged in collaborative play with at least one other child. For each child, summary scores for each social behavior were calculated indicating the average number of behaviors that occurred per 30 minutes. For the levels of social play, proportion scores were calculated representing the percentage amount of the play session that children engaged in each social level.

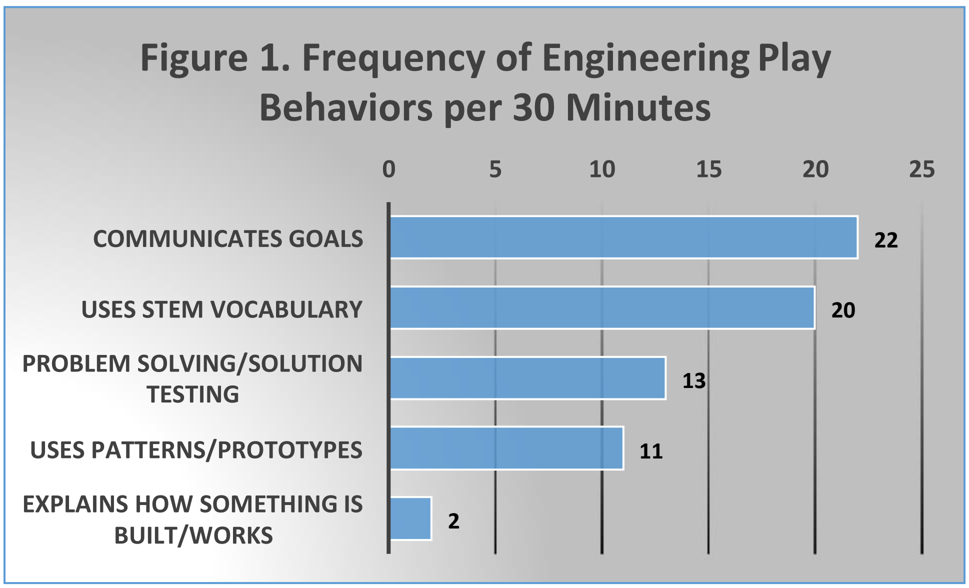
***Physical Behaviors***. Categories for physical play behavior included gross motor movement (11 categories) and fine motor movement (6 categories.) The gross motor categories were adapted from a measure of children's physical activity developed by Gallahue and Ozmun (2006). In this project, we further refined both the gross motor and fine motor behaviors from the observation scheme used in the Imagination Playground$^{TM}$ Study, to best reflect children's physical activity with Rigamajig. Summary scores for each physical behavior for each child were calculated, indicating the average number of behaviors that occurred per 30 minutes. The 30-minute rates of total fine motor and total gross motor behaviors were also computed.

Analyses in this report compared the rates of children's play behaviors and interest in STEM from Week 1 to Week 4 of Rigamajig play. To evaluate associations among engineering, physical, and social play behaviors, the rate scores of each observed behavior at Weeks 1 and 4 were averaged. This produced rate scores representing each child's engagement in each behavior in an *average* 30-minute play session.

# Results

## Engineering Play

***Frequency of Occurrence.*** Children's engagement in engineering play with Rigamajig was plentiful! On average, children engaged in 68 engineering play behaviors per 30-minutes of play, a rate of over two engineering play behaviors per minute. The most commonly occurring engineering play behavior was communicating goals. On average, children engaged in 22 goal communications per 30-minutes. Children also used extensive STEM vocabulary terms. On average, 20 STEM words were used in 30-minutes of Rigamajig play. Problem solving/solution testing occurred an average of 13 times in 30-minutes. Following patterns or prototypes occurred 11 times, and explaining how things are built/work occurred 2 times in 30-minutes (See Figure 1 for frequencies of each engineering play behavior.)




***Across Time.*** Each of the five engineering play behaviors followed the same pattern of occurrence from Week 1 to Week 4 of Rigamajig play. Engineering play behaviors decreased over time. However, the rates at which engineering play decreased were small. Communicating goals decreased from 25 behaviors per 30-minutes to 20. Explaining how things are built/work decreased from 2 to 1 occurrence. Following patterns and prototypes fell from 13 to 7 occurrences. Problem solving/solution testing dropped from 17 to 12 occurrences, whereas STEM vocabulary decreased from 21 to 19 occurrences.

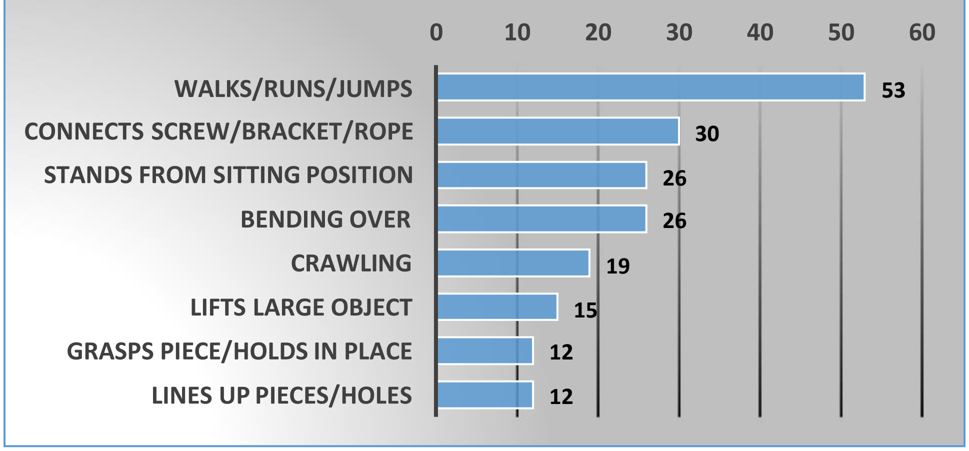
***Gender Comparisons.*** There was no significant difference in boys' and girls' rates of engagement in engineering play. Although boys engaged in slightly more engineering play with Rigamajig than girls (boys = 77, girls = 61), this difference was not statistically meaningful. Analyses of the individual engineering play behaviors resulted in this same trend. Boys generally engaged in more of each of the engineering behaviors, but their rates of engagement compared to girls were only slightly higher, and the differences were not statistically significant.

***Grade Comparisons.*** There were no significant differences in rates of overall engagement in engineering play by grade level. On average, kindergarten children engaged in 61 engineering play behaviors per 30-minutes, 2nd graders engaged in 76, and 5th graders engaged in 68 behaviors. With almost no exceptions, each of the five engineering play behaviors followed the same pattern of occurrence from kindergarten, to 2nd grade, to 5th grade. Engineering play behaviors increased from kindergarten to 2nd grade and then slightly decreased at 5th grade, with 5th graders engaged in more engineering than kindergarten children but less engineering play than 2nd graders. There were statistically significant differences by grade in use of STEM vocabulary and explaining how things are built/work. Children in grades 2 and 5 used more STEM words (k = 16; grade 2 = 22; grade 5 = 22) and more building explanations (k = 0.85; grade 2 = 2.65; grade 5 = 1.85) than kindergarten children. There were no significant differences by grade in communicating goals, following patterns or prototypes, or problem solving/solution testing.

**<u>Physical Play</u>**

***Frequency of Occurrence.*** Physical play behavior with Rigamajig occurred with high frequency. On average, children engaged in 125 gross motor behaviors and 57 fine motor behaviors per 30-minutes of play. The most frequently occurring physical play behaviors were: walking/running/jumping = 53; connecting screws/brackets/rope = 30; standing up from a sitting position = 26; bending over = 26; crawling = 19; lifting a large object/piece = 15; grasping a piece/holding in place = 12; lining up holes = 12 (See Figure 2 for frequencies of each type of physical behavior.)

Figure 2. Frequency of Physical Behaviors per 30 Minutes



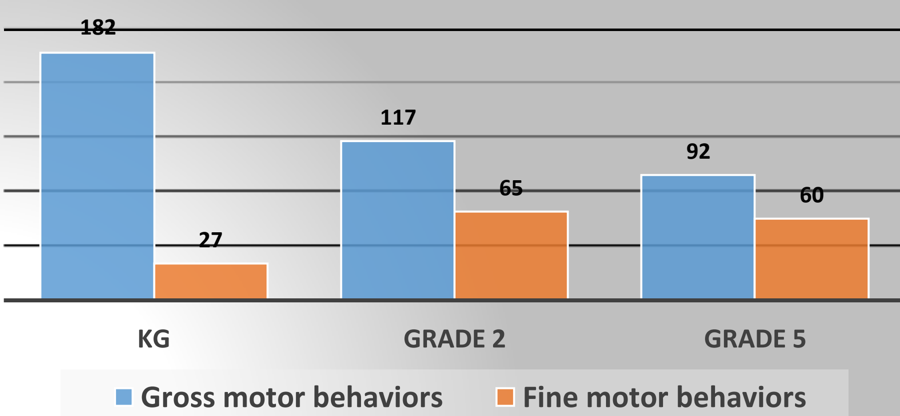

***Across Time.*** For the most part, physical play behaviors followed the same pattern of decrease between Week 1 and Week 4 as engineering play behaviors. Most of the physical play behaviors decreased slightly over time. However, there were four physical play behaviors that increased over time: walking/running/jumping significantly increased from 37 to 69 behaviors; pushing/pulling/dragging objects increased from 10 to 11; swinging or rotating an object increased from 5 to 6;

tossing/rolling/kicking an object increased from 2 to 3 behaviors. Nevertheless, three of the four behavioral increases were small.

***Gender Comparisons.*** Girls engaged in significantly more gross motor physical behaviors than boys per 30-minutes (girls = 139, boys = 106). In particular, girls engaged in significantly more walking/running/jumping (girls = 58, boys = 47), standing up from a sitting position (girls = 30, boys = 22), and bending over (girls = 30, boys = 21). There were no significant gender differences in rates of engagement in fine motor behaviors per 30-minutes (girls = 52, boys = 61). (See Figure 3 for gender differences in frequencies of overall gross motor behavior and individual gross motor behaviors.)

***Grade Comparisons***. Trajectories of physical play behaviors by grade level are very interesting. Gross motor physical play with Rigamajig decreased by grade. Kindergarten children averaged 182 gross motor behaviors per 30 minutes of play; 2$^{nd}$ graders averaged 117 behaviors; and 5$^{th}$ graders averaged 92 behaviors. There was a statistically significant difference between rates of engagement in gross motor behaviors between kindergarten and 2$^{nd}$ grade/5$^{th}$ grade, but not between 2$^{nd}$ grade and 5$^{th}$ grade. In other words, gross motor physical play with Rigamajig significantly decreased after kindergarten and remained the same in 2$^{nd}$ and 5$^{th}$ grade. In contrast, fine motor physical behaviors followed the opposite trajectory. Kindergarten children averaged 27 fine motor behaviors; 2$^{nd}$ graders averaged 65 behaviors; and 5$^{th}$ graders averaged 60 behaviors. As with gross motor behavior, there was a statistically significant difference between rates of engagement in fine motor behaviors between kindergarten and 2nd grade/5th grade, but not between 2nd grade and 5th grade. However, in this case fine motor behaviors significantly increased after kindergarten and remained the same in 2$^{nd}$ and 5$^{th}$ grade (See Figure 3 for gross motor and fine motor behaviors by grade.)

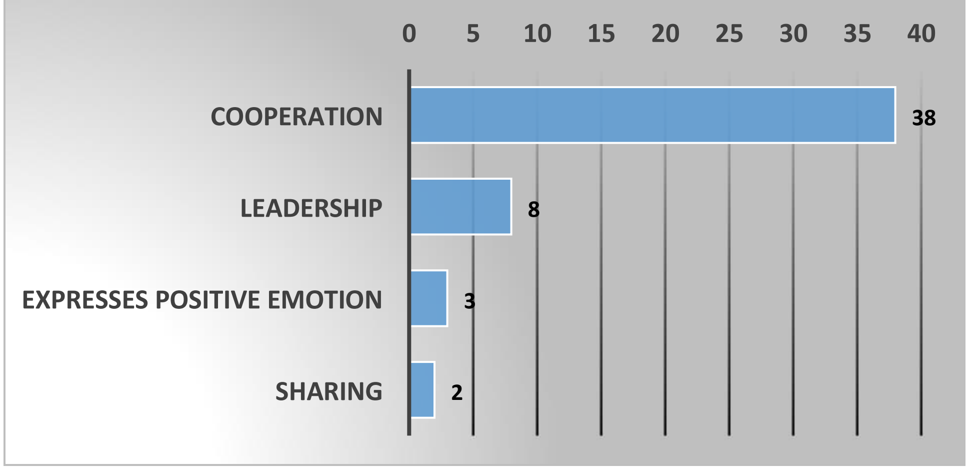
Figure 3. Frequency of Physical Behaviors per 30 Minutes by Grade Level



## <u>Social Play</u>

***Frequency of Occurrence.*** Of the four observed social competency behaviors, instances of cooperation/teamwork and instances of leadership clearly occur often! The average child engaged in 38 cooperative behaviors and 8 leadership behaviors in a 30-minute Rigamajig play session. Expressions of positive emotions occurred 3 times and sharing occurred 2 times per 30-minutes (See Figure 4 for frequencies of each social competence behavior.)

Figure 4. Frequency of Social Competence Behaviors per 30 Minutes




***Across Time.*** Over the one-month study period, rates of engagement in each of the four social competency behaviors remained consistent. Children engaged in statistically similar rates of cooperation, leadership, positive emotional expression, and sharing at both the start and end of the month of observation.

***Gender Comparisons.*** There was a small statistically significant difference in rates of cooperation by gender. Girls engaged in marginally more cooperative and team-based behaviors than boys per 30-minutes (girls = 42, boys = 31). However, rates of positive emotional expression, leadership, and sharing were similar among boys and girls.

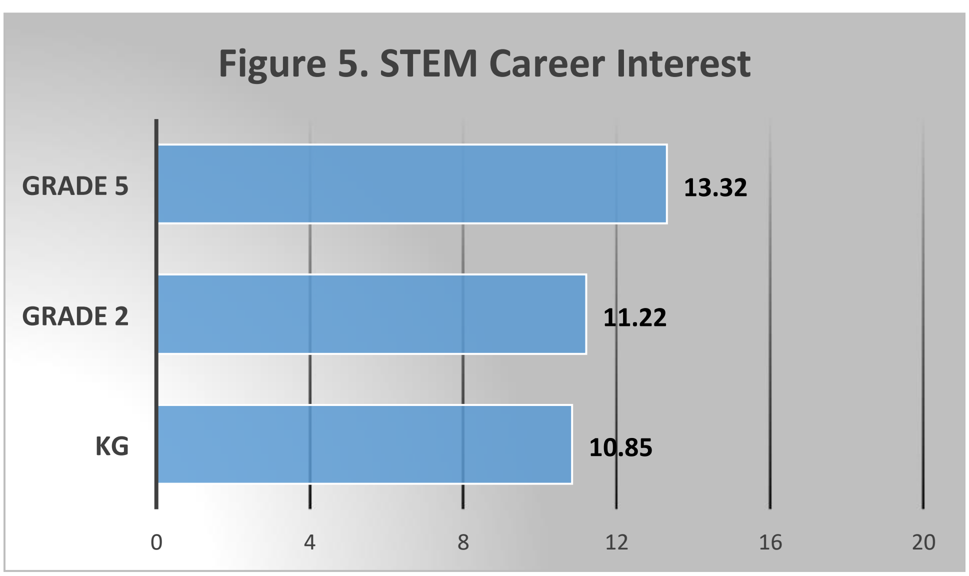
***Grade Comparisons.*** Expressions of positive emotions and engagement in leadership behaviors were similar across kindergarten, 2nd grade, and 5th grade, with most children at each grade level exhibiting between 1 to 5 instances of positive emotions and 5 to 10 instances of leadership. However, there were statistically significant differences in cooperation and sharing by grade. Cooperative behavior significantly increased at each grade. Kindergarten children engaged in cooperative behavior an average of 23 times per 30-minutes; 2nd graders averaged 37 times; and 5th graders averaged 52 times. Sharing also significantly increased by grade. There was no significant difference between kindergarten sharing and 2nd grade sharing, but 5th graders shared significantly more than the other grades (k = 0.66, grade 2 = 1.18; grade 5 = 3.12).

***Level of Social Play.*** Across all children, most of the time playing with Rigamajig was spent collaborating. Nearly half of all play time was spent engaging and actively playing with at least one other child (47%). There were no gender differences in the proportion of play spent at any of the four social levels. However, collaboration significantly increased at each grade level, and solitary play significantly decreased at 5th grade. The amount of time spent observing remained consistent across each grade. Unoccupied (non-engaged) behavior was low overall, but significantly dissipated after kindergarten.

| | **All children** | **Grade K** | **Grade 2** | **Grade 5** |
|---|---|---|---|---|
| Unoccupied | 5% | 12% | 3% | 2% |
| Observing | 18% | 17% | 14% | 23% |
| Solitary | 30% | 38% | 43% | 18% |
| Collaborative | 47% | 33% | 40% | 57% |

**<u>STEM Interest</u>**

There was no significant difference in children's overall level of interest in STEM after playing with Rigamajig for one month. Before Week 1 of Rigamajig play, children's average STEM interest score was 11.97 out of 20. After Week 4 of Rigamajig play, children's average STEM interest score was 11.68. However, there were statistically significant differences in STEM interest when comparing each grade level and gender. Fifth graders were significantly more interested in STEM than 2nd graders or kindergarten children (k = 10.85; grade 2 = 11.22; grade 5 = 13.32). There was no significant difference in STEM interest between kindergarten and 2nd grade. Boys were significantly more interested in STEM than girls (boys = 13.42, girls = 10.46). Additionally, children's STEM interest was not associated with engagement in engineering, physical, or social play (See Figure 5 for STEM interest by grade level.)



**Associations between Engineering, Physical, and Social Play**

***Engineering Play and Social Competence.*** Using total scores, representing the sum of the five engineering play behaviors and the sum of the four social competency behaviors, we tested associations between engineering play and social skills broadly. Engineering play was significantly and positively associated with social competency behaviors. Children who engaged in more engineering play behaviors also engaged in more social competency behaviors. We also analyzed the association of total engineering play with the four social competency behaviors individually. Engineering play was significantly and positively related with expressions of positive emotion, leadership, and sharing, but was not significantly related to cooperative behaviors.

***Engineering Play and Physical Play.*** Although the engineering play total score was not related to the fine and gross motor total scores, there were fascinating significant associations between individual engineering play behaviors and individual physical play behaviors. Following patterns and prototypes was significantly and positively related to: (1) elevating large pieces or parts of the structure and (2) connecting screws/brackets/rope. Additionally, problem solving/solution testing was significantly and positively associated with: (1) elevating large pieces or parts of the structure; (2) swinging or rotating pieces; (3) pushing/pulling/dragging pieces or parts of the structure; (4) lining up holes on pieces; and (5) connecting screws/brackets/rope.

***Physical Play and Social Competence.*** Physical play and social competence were independent in this data. One did not influence the other.

## Discussion

It is clear that playing with Rigamajig offers rich opportunities for school age children to develop and exercise a variety of 21st century skills. One immediate and important finding is that children's rates of engagement in engineering, physical, and social play behaviors with Rigamajig were ***substantively high.*** Across kindergarten, 2nd grade, and 5th grade, the average child observed playing with Rigamajig for 30 minutes engaged in 60-80 engineering behaviors, 125 gross motor behaviors, nearly 60 fine motor behaviors, and almost 50 social competency behaviors. Specific behaviors that occurred most often were communicating goals; using STEM vocabulary words; problem solving/solution testing; cooperation; leadership; walking, running, or jumping; bending over; standing up from sitting; and connecting pieces with hands. These most frequent occurrences were not by chance. To successfully perform various skills in one of the engineering, physical, or social domains, children relied on integrating skills from the other domains. This is supported by our finding that engineering play behavior was significantly and positively associated with various social competency and physical behaviors. When children use more engineering behaviors, they ***also*** employed more physical and social skills. For example, children's behavioral attempts to solve problems and test solutions with Rigamajig were significantly related to elevating, swinging, rotating, pushing, pulling, dragging, lifting, and connecting pieces. Thus, children needed to try out various physical movements with Rigamajig pieces to identify problems in their building plans and figure out how to modify their creations based on their physical experimentations. Likewise, engagement in engineering play was significantly associated with children's social competency skills. Following the play group's Rigamajig plans required using skills in both team-based engineering and cooperative social interaction. For instance, using leadership skills by suggesting a building idea or initiating a new building plan, requires goal communication, explanations, and whole-group collaboration. This is further evidenced by the finding that nearly ***half*** of all the time children spent playing with Rigamajig materials was during social collaboration with other children. Therefore, our findings indicate that playing with Rigamajig not only creates overlap among behaviors in various developmental areas, but also that this overlap accounts for significant relationships between social-cognitive learning processes and physical body movements.

Coupled with the finding that various key behaviors are related, was the finding that engineering play, physical activity, and social behavior tended to decrease in frequency over one month of Rigamajig play experience. This reveals a potential fascinating phenomenon. As children gain additional experience with Rigamajig pieces, why would rates of engagement in these behaviors decrease? Examination of the rates of decrease shows that most behaviors fell slightly over time, with no instance of a large decrease in any one behavior. This suggests that children become more efficient builders as they gain more experience with the Rigamajig building kit, how the pieces work, and how they fit together. For example, a decrease in connecting pieces together with hand screws indicates that over time, children ***no longer need*** several attempts to put something together and take it apart because they already know what they intend to do and how do it. This demonstrates, above all else, that over time children are learning! Over one month, children have expressed many building goals and explanations; they have moved across the classroom floor space to retrieve various pieces to incorporate in their ideas; they have tested out many plans, some of which worked and some that failed; and they have learned as a team how to adjust in their subsequent play sessions to accommodate for previous ideas that did not suit the group's broad objectives. Having learned from previous play experiences, children are more focused, more direct, and more cued in on the specific goals they intend to accomplish. Complementing this result was the finding that a small number of physical behaviors actually increased over time: walking, running, jumping, pushing, pulling, dragging, swinging, rotating, tossing, rolling, and kicking. Each of these behaviors is the kind of movement children do after they have become more efficient builders and thus have more time in their play to move around the play space and use their Rigamajig pieces and its various functional parts. Finally, social competency skills did not change over time. Regardless of whether children spent more time building/learning from their Rigamajig, or moving about and using their Rigamajig, they maintained a high level of positive social interactions. Altogether, using previously acquired skills requires fewer behavioral attempts. Sustained Rigamajig play over time seems to facilitate learning!

Examination of children's engineering, physical, and social play with Rigamajig by age and gender revealed several findings consistent with the developmental literature and several more describing new trends. First, the Rigamajig study is now the third consecutive study by Gold, Elicker, and colleagues showing no significant gender differences in the frequency of engineering play. This is significant because of the false belief that boys are better at STEM-related school subjects than girls, and the reality that men enter STEM occupations more than women do. Consistent with this trend, our STEM Interest

Survey found that boys were more interested in STEM careers than girls were across grades. Although scholars do not yet know why, future research is needed to understand this trend, specifically if these gender preferences are biologically-based, socialized by parents, teachers, and/or peers, or some combination of influences. Nonetheless, our replicated finding that boys and girls engage in similar amounts of engineering play is tremendously promising! It solidifies the empirical data that boys are not actually better at math related skills than girls. It also offers tangible opportunities for parents, caregivers, and educators to encourage girls' early play with building materials like Rigamajig, potentially increasing girls' interest in STEM. Additionally, although we did not find differences in STEM-related career interest before and after playing with Rigamajig in this study, we did find that older children were more interested in STEM than younger children. Increased STEM interest by grade does not necessarily mean younger children are not interested in STEM. Similar to gender differences in STEM interest, this finding may reflect typical trends in identity development. Older children are more likely to be thinking about their adult aspirations and have a greater understanding of the kinds of careers they might be able to pursue. Playing with Rigamajig elicited a wide array of STEM-related behaviors and language that could help children explore their STEM interests and participate in STEM activities at early ages. These interactions may play a part in developing children's future interests. Thus, observing children's interactions with loose parts STEM-related materials, like Rigamajig, could enhance scholars' understanding of early gender and age-related play differences and how these differences influence identity development and adult career choices.

Although there were no gender or grade level differences in broad engineering play engagement, gender and grade differences in specific engineering, physical, and social behaviors inform our understanding of age-related and gender-specific play. In particular, girls and younger children engaged in more gross motor physical play than boys and older children. One possibility is a difference in physical strength between older and younger children. Our video observations revealed several anecdotes of age-related physical differences. For example, younger children needed more frequent trips to the Rigamajig cart to carry individual large pieces than older children, who could carry multiple pieces in one trip. Although it is less clear why girls engaged in more whole-body movements than boys, one potential explanation is that girls build different kinds of structures or engage in different play themes than boys that require additional movement around the play space. Examination of the Rigamajig video data should evaluate this possibility in future studies. Nevertheless, this finding is important because it means that Rigamajig may be used to increase kindergarten-age children's gross motor activity as an alternative to traditional fixed structure playgrounds that do not offer the same opportunities for manipulation of loose parts materials. Additionally, though we found no gender differences in fine motor physical play, older children used more fine motor behaviors. This is consistent with developmental physical trajectories where older children have more advanced control of small muscle skills. Yet, high rates of fine motor movements in young children, specifically connecting screws, brackets, and ropes, illustrate that Rigamajig is a hands-on tool to facilitate fine motor skills development. Finally, whereas the social competency behaviors remained consistent over one month of Rigamajig play, older children were more socially competent and engaged in higher percentages of social collaboration than younger children. While this is consistent with the developmental literature, we still found that kindergarten children spent nearly ***one-third*** of their play collaborating. Therefore, it is evident that Rigamajig is a natural context through which to support children's collaborative efforts and encourage team-based social strategies that promote 21st century skills development.

**What Can I Do with These Findings?**
**Implications for Teachers and Play Facilitators**

This evaluation of elementary children's group play with Rigamajig over one month improves our understanding of how children play, what children learn, and how Rigamajig may be used to support early education and development:

1. Small group play with Rigamajig offers rich opportunities for school age children to develop and exercise a variety of 21st century skills: engineering thinking and construction, physical skills, and leadership and collaboration within a peer work group.
2. Children need adequate time, space, and freedom in order to gain the most from Rigamajig materials. In this study, the play spaces were found within the elementary schools in various places: maker spaces; a corner of the library; the music room when not in use; or other unused school spaces. Play can take place outdoors when weather permits. In the study we provided spaces at least 25 ft. by 25 ft. in area.
3. Adult play facilitators were encouraging, but not directive. They offered a play prompt at the beginning, which typically was a problem the group could solve by designing and building a structure or contraption. They did ***not*** tell the children what or how to build. When the group stalled or got stuck, the facilitator asked open-ended questions to help the children identify their problem and offer possible solutions and ways to move forward. If play became raucous or unsafe, the facilitator reminded players of the safety or courtesy rules. (See web-based project lesson plans for suggestions about non-directive play facilitation ideas https://www.rigamajig.com/project-plans/)
4. Having enough time to think, collaborate, and build is important. The play sessions in this study were 30 minutes, which often was not enough time for the groups to fully work out and realize their construction plans. Providing at least one hour of uninterrupted time is recommended, or opportunities for children to return to their creations over the day or week to complete them.
5. Think about the optimal composition of play groups. In the study, we limited the groups to same gender children, with four students from the same grade level. This allowed us to study age-related variations in play, uncomplicated by cross-gender attitudes and interactions. Clearly, we found that girls displayed as many or more engineering, physical, and social competence skills as boys. But we encourage facilitators to experiment with groups of different sizes and composition, including mixed-age and mixed-gender groups, to see what happens.
6. Think of ways that you can integrate or blend academic objectives from different subject areas using Rigamajig play materials. Hands-on science, technology, engineering, mathematics learning (STEM) opportunities abound within Rigamajig play, especially if the teacher or facilitator is alert to the possibilities. As they play, students are highly motivated to think, collaborate, experiment, and build, and the alert educator will find

ways to discuss and extend these learning opportunities. (See web-based project lesson plans for connections to NGSS science and other academic standards https://www.rigamajig.com/project-plans/). Likewise, extended learning in language arts, creative arts, and social studies can easily happen with Rigamajig as a motivational "springboard!"

**Implications for the Rigamajig Product**

1. In the context of our study results, the Rigamajig building kit offers children an innovative kind of play experience. Specifically, Rigamajig materials facilitate a holistic experience, successfully using the inherent design of the pieces to support STEM skills, engineering development, physical activity, and social collaboration.
2. The web-based project lesson plans offer a foundation for using Rigamajig in classroom settings, focused on framing Rigamajig play in child-directed semi-structured contexts with limited teacher interaction and open-ended possibilities (https://www.rigamajig.com/project-plans/)
3. As Rigamajig is further developed and marketed, it is important to consider how most schools, educators, and adults are likely to use Rigamajig and for what purpose. This is especially important in the context of federal and state education standards and how schools envision Rigamajig as a tool to meet STEM education initiatives and requirements. It is equally important in the context of other curricular standards elementary principals are required to follow. With significant amounts of time in public school systems focused on academic outcomes and "teaching to the test," how can Rigamajig fit within schools' current education frameworks, which in many ways can be restrictive?
4. We recommend several ideas for future Rigamajig development and initiatives to maximize impact in schools and with children:
    a. School administrators often require teachers to evaluate child learning outcomes in nearly any activity. This is true with regard to new STEM initiatives because schools want to demonstrate to government agencies and funding sources that STEM programs are "working." We recommend development of a simple student assessment tool for teachers to document behavior and language use as they observe children's Rigamajig play.
    b. Try to find out how schools are currently using Rigamajig. Is it informal free play, or do they incorporate Rigamajig into structured lesson plans developed for other educational purposes? Where do schools organize the play sessions? Is it after school, during formal school lessons within classrooms, or during designated "free play" time in specific play rooms? This information may be gathered in survey format and will be useful to formulate next steps.
    c. Gather additional scientific data on Rigamajig and child development outcomes, and include teachers as study participants. The most effective way to increase Rigamajig exposure and promote awareness among schools, states, and legislators, is to demonstrate that Rigamajig improves multiple developmental and learning outcomes for children using innovative methods not offered through other mediums. This study is

a significant first step. Dr. Gold will retain the video data to analyze in future research projects and provide additional scientific information. One important step is formal evaluation of the effectiveness of the Project Plans using experimental methods. This may be done as a future complementary study to the current project.

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