ETE 371 Honors By Contract Research Paper

How Young Learners Understand Mechanical Systems

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Introduction

This research paper explores engineering concepts in early childhood education. Few research studies have been conducted in this area and much is still unknown about young learners' perceptions of engineering concepts such as mechanical systems. In this paper, engineering research in early childhood education will be synthesized and frameworks for teaching engineering in early childhood education will be compiled. Methods of the research completed with preschoolers about the mechanical system of gears will be described. The results will also be presented, followed by a discussion of the results. Based on the results and data, recommendations for teaching engineering in early childhood education will be made. The goal of the research being conducted is to understand how preschoolers perceive the mechanical system of gears. With this knowledge, the best theories and curriculums can be recommended for teaching engineering in preschool classrooms in the future.

Engineering Research in Early Childhood Education

The area of engineering in early childhood education is an ongoing topic for research and is relatively new. When synthesizing the literature to discover the best practices and strategies that yielded positive results, three main themes emerged from the literature. The first theme involves young learners and their natural engineering abilities. The second theme revolves around the materials and implementation of the activity. The third theme includes the types of classrooms and curriculums that worked well to implement engineering activities.

Children are natural engineers and it is the teacher's role to foster student growth within engineering activities and concepts. Students enter preschool with knowledge of the world and how it works (Elisabeth R. McClure, et al., 2017). There are many engineering concepts that students understand before they even begin school. The book, *STEM Starts Early: Grounding*

Science, Technology, Engineering, and Math Education in Early Childhood, by Elisabeth R. McClure, et al. discusses how capable students are of learning STEM concepts in early education and how important it is to incorporate a STEM curriculum as young as preschool. The authors explain children's natural engineering abilities, writing, "While engineering and technology are less common as explicit subjects in the early years, instances of both have been part of early childhood classrooms for decades in the form of fort-building and block play, and in explanations of how to use tools as simple as spoons and scissors" (McClure, et al., 2017, p. 16). Even when engineering is not explicitly part of the curriculum, children's brains still approach the world and tasks from an engineering perspective. It is then the teacher's role to expand on children's natural engineering skills and implement activities into the classroom that allow students to further explore these engineering concepts.

The article, *Engineering Thinking in Pre-kindergarten Children A Systematic Literature Review* by Christine N. Lippard, et al. also agrees with the notion that preschool aged children have an understanding of the ways in which the world works around them before they begin school. The authors further explain, "Recent work from leading psychologists indicates that pre-kindergarten age children are particularly open to taking in information and effective at using that information to formulate hypotheses" (Lippard, et al., 2017, p.455). Not only are children natural engineers at a young age, but they also think like scientists. When given the opportunity, children take in information to form and later test their hypotheses. This information supports the fact that preschool aged children are able to understand engineering concepts and their classroom should allow them to explore, formulate, and test scientific hypotheses.

The articles detailed various ways to implement engineering activities in the classroom. All articles agreed that the most effective way for children to further learn engineering concepts is through authentic and meaningful experiences and intentional instruction. Lippard, et al. writes about the importance of intentionality in selecting materials. Not only should intentionality be used in the selection of materials, but also in the introduction of these materials to the students (Lippard, et al., 2017, p.465). Careful and thoughtful planning of materials is required on the teacher's part to ensure that students will have a meaningful interaction with the materials. Another article that echoes this sentiment is *Revealing the Work of Young Engineers in Early Childhood Education*, by Beth Van Meeteren and Betty Zan. It details a classroom environment and curriculum intentionally created to allow students to explore and further their engineering knowledge. The authors argue that adding materials that promote engineering and design to already existing centers will be more meaningful to children and engage them longer than just a few weeks (Meeteren & Zan, 2010, p.4). The materials added must be intentionally selected to provide an authentic learning experience for students. Oftentimes, common play materials that students are already familiar with are the most authentic and meaningful materials for them to use to design and engineer solutions. One of the simplest materials is blocks. Different sized and shaped blocks can be used with marbles or cars to build structures and ramps. Children playing with blocks are designing, hypothesizing, and learning about engineering concepts.

Frameworks for Teaching Engineering in Early Childhood Education

There are several well-known educational frameworks used to teach early childhood education. Some of these frameworks lend themselves to integrating engineering concepts into the curriculum while others do not. Piaget, Montessori, and Reggio Emilia are frameworks that work well for incorporating engineering practices into the early childhood classroom. Piaget's theory focuses on exploration, hands-on learning, and trial and error. Montessori curriculum also focuses on exploration, along with scientifically designed materials for hands-on, independent experiences. The Reggio Emilia approach focuses on emergent curriculum, stemming from interests of students and those interests turning into in-depth projects.

Revealing the Work of Young Engineers in Early Childhood Education and *Engineering Thinking in Pre-kindergarten Children A Systematic Literature Review* both cite constructivist classrooms as the optimal environment for implementing engineering materials and concepts. Constructivism can be attributed to Jean Piaget and is the idea that learners do not learn by passively taking in information, but by constructing knowledge from the world around them and hands-on experiences. Scholastic's *Pioneers In Our Field: Jean Piaget - Champion of Children's Ideas* details the main ideas of Piaget's theory which include; hands-on experiences, exploration, and trial and error. These ideas coincide with teaching and allowing students to further explore engineering concepts. In the article, *Revealing the Work of Young Engineers in Early Childhood Education* and *Engineering*, the engineering study took place in a constructivist early childhood program. The authors write, "Constructivist pedagogy is, at its core, all about problem solving and is a natural fit with engineering education" (Meeteren & Zan, 2010, p.2). This pedagogy encourages children to have hands-on experiences with the classroom materials and to learn from their mistakes. Lippard, et al. writes that within constructivist theories "knowledge is acquired when the context is meaningful for the learner" (Lippard et al., 2017, p.455). The materials students are engaging with should be meaningful to them and their learning experience. Moreover, a constructivist classroom provides the framework for opportunities for students to engage with authentic materials and learn in a hands-on way that will promote further understanding of engineering concepts and how to design solutions.

The Montessori curriculum also lends itself to the teaching and learning of engineering concepts. Montessori curriculum has a focus on exploration within the materials in the classroom. Another important aspect of the curriculum is that the materials are scientifically designed and the goal of working with the materials is to learn scientific and mathematical concepts through physical means. Materials used in a Montessori classroom are specific to the program and cannot be found in other classrooms. Some materials that promote engineering concepts and skills include the Pink Tower, the Binomial Cube, Bead Chains, and more. Children are encouraged to independently explore the classroom and play with any materials in the room. The hands-on nature of the curriculum and the scientifically designed materials yield Montessori as a viable option for students to explore engineering concepts and materials.

The Reggio Emilia approach focuses on student interests as the emergent curriculum and is supported by in-depth projects. Scholastic's *The Reggio Emilia Approach* by Alisa Stoudt describes the major principles that this approach is governed by. Stoudt explains that emergent curriculum is created by student interests. The in-depth projects are then guided by the emergent curriculum with the aim to involve the family and community. The teachers act as advisors on the project and help students with their research, materials, and products. This approach lends itself to the exploration of engineering concepts and creating projects around engineering topics. Teachers can supply students certain materials and if a student or the class is interested in engineering concepts such as gears or designing block structures, which they most likely will be, an in-depth project can be structured around the engineering concept. In-depth projects last anywhere from two weeks to an entire school year. With this approach, students will be able to explore engineering concepts and grow their knowledge while engaging in a project brought about by their interest in the subject.

Methods

Data was collected over the course of three weeks. Twelve students were studied ranging in age from three years, three months to five years, one and a half months. The mean age of the students in the study is four years, four months. Each participant in the study individually played with toy gears, consisting of a peg board for the gears and various colored gears. The participants spent ten to fifteen minutes playing with the gear toy. Students were first introduced to the toy gears and permitted to play with them however they liked. After a few minutes of familiarizing themselves with the toy, students were asked to begin by placing two gears next to each other on the board. Students were asked questions about how the two gears relate to each other and how they turn. Then students were asked to place a third gear on the board. They were asked questions about how the first gear connects and makes the other gears turn. Students were also asked what would happen if the middle gear was removed. Once students had tested and answered how the three gears connect and work together, they were able to build whatever they liked with the gears for the remainder of the time. At the end, students were asked to explain what they had made and how it worked.

Results

Student Number	Age	Understanding how the first gear connects to the second gear (turning and stopping)	Hypothesizing what will happen with the addition of a third gear	Understanding and explaining how the gears connect and turn one another	Understanding what happens and how to fix it when the middle gear is removed
1	5 years, 1.5 months	Full understanding and ability to explain	Hypothesis supported	Full understanding, slight trouble properly verbalizing	Full understanding and ability to fix it immediately

				how the gears connect and work	
2	3 years, 7 months	Understood, but not able to explain at first	Hypothesis supported	No understanding	Understood the third gear wouldn't turn, but needed assistance in order to fix it
3	4 years, 4.5 months	Full understanding and ability to explain	Hypothesis supported	Full understanding, trouble properly verbalizing how the gears connect and work	Full understanding and ability to fix it immediately
4	4 years, 5 months	Full understanding and ability to explain	Hypothesis supported	Some understanding, but explanation is incorrect	Understood the third gear wouldn't turn, attempted a solution that didn't work, second solution fixed it
5	3 years, 10 months	Some understanding, some correct and some incorrect explanations	Hypothesis supported	No understanding	Needed assistance in understanding the third gear wouldn't turn, once understood, was able to fix it immediately
6	4 years, 11 months	Full understanding and ability to fully explain	Hypothesis supported	Some understanding, not able to fully explain	Full understanding and ability to fix it immediately
7	4 years, 8	Full	Hypothesis	No	Full

	months	understanding and ability to explain	supported	understanding	understanding and ability to fix it immediately
8	4 years, 4 months	Full understanding and ability to explain	Hypothesis supported	Limited-some understanding, not able to fully explain	Full understanding and ability to fix it immediately
9	5 years, 0 months	Some understanding, but unwilling/not able to explain	Did not answer	Some understanding, some correct and some incorrect explanations	Some-most understanding and ability to fix it with assistance
10	3 years, 3 months	Some understanding and some ability to explain	Hypothesis supported	No understanding	Wasn't able to fix it immediately, attempted a solution that didn't work before trying a solution that worked twice in a row
11	4 years, 2.5 months	Full understanding and ability to explain	Hypothesis supported	Some understanding, not able to fully explain	Full understanding and ability to fix it immediately
12	4 years, 2.5 months	Most-full understanding and ability to explain	Hypothesis supported	No understanding	Full understanding and ability to fix it immediately

Table 1. Student level of understanding in the four areas measured.

Discussion

The above chart details the four areas students were tested in and how well the student understood and was able to explain each concept. The first area is titled, “Understanding how the first gear connects to the second gear (stopping and turning).” Two gears were placed next to each other and the students were asked to explain what happens to the second gear when the first gear turns and what happens to the second gear when the first gear stops turning. Eight of the twelve students completely understood this and were able to fully explain the concept. The other four students had some understanding, but were not able to fully explain, or had a mix of incorrect and correct explanations. These four students included the three youngest students and one of the oldest students.

The second area is titled, “Hypothesizing what will happen with the addition of a third gear.” Students were asked what they thought would happen if a third gear was added to the first two. Students hypothesized and then tested their hypothesis by adding the third gear and turning all three. Eleven of twelve students’ hypotheses proved to be correct, that with the addition of a third gear, all three gears would turn. One student did not answer this question. This question demonstrated an overwhelming understanding for students three years old to five years old. After the first question and playing with the gears, students understood that when any other gears are added and connected, they will follow the same pattern and all turn.

Area three is the most important concept in understanding gears and has the largest variety of responses. The third area is titled, “Understanding and explaining how the gears connect and turn one another.” Students were asked how turning one gear makes the other gears turn and to explain how the gear works. The responses have been broken into two categories. No student had full understanding in this area yet. Students either had no understanding or had some understanding and ability to explain. Six of twelve students had no understanding of this concept. The other six students had some understanding and ability to explain this concept. None of the three year old students understood the concept, but the ages varied for four year old students who did or did not understand. The youngest student to understand was four years, two and a half months while the oldest student who did not understand was four years, eight months.

Three of the six students had a more limited understanding and explanation while the other three students had a more advanced understanding. Student 11, who had a more limited understanding, was asked how one gear can make the others turn; she answered, "them together get them turning." While she was not able to fully explain this concept, this statement demonstrated that she understood that the gears must be connected and next to each other in order to turn one another. Student 9 had the same level of understanding about this concept. He had created a long line of gears and then a few gears that were not connected to any other gears. When asked why the lone gear would not turn when the others ones would, he answered, "Um, because these (other gears) are not over to the blue (gear)." He demonstrated that he understood that the gears must be connected in order to turn one another and that a gear without any connections will be unable to turn. Students 6 had a similar level of understanding. When asked how one gear could make the others turn, he answered, "Because when it's, when it sometimes, when other things connected to other things they spin." His statement also demonstrated that he understood that the gears must be connected and next to one another in order to turn.

The other three students had a more advanced understanding and a more in-depth explanation, although they still struggled to verbalize the concept. When asked how one gear causes the other gears to turn, Student 1 answered, "Um, those little bumps and they connect to more bumps, and then they start making it move, but if you try to twist them both sides, they'll stop." He was referring to the gear teeth as "bumps" and explaining that if you twist both the first and third gear at the same time it will lock the middle gear in place. His explanation goes beyond just explaining that the gears must be connected, he began to explain and understand how the gear teeth connect the gears and cause them to turn. Student 3 had a similar level of understanding and trouble verbalizing her explanation. When asked how one gear causes the other gears to turn, she answered, "So, so, these all connected to each other and they flap like this so that and they have those little things (gear teeth) so they're moving because they have that thing (gear teeth) and it's rolling and they have that." During her explanation she was pointing and referring to the gear teeth as "flaps" and "things." Her explanation also does not just explain that the gears must be connected, she attempted to explain the role of the gear teeth. Student 8 also had a more advanced understanding, she explained that the gears turn by "scratching." She was referring to the gear teeth, as to her it looked like the gears were scratching against each other and causing one another to turn.

The main reason that no student had a full understanding in this area was because they were unfamiliar with the vocabulary related to gears. Students did not know the word "gear teeth." When asked to explain how the gears work, students called gear teeth "bumps," "flaps," and "things." Some students used the words "rolling, " "moving together," "twisting," and "scratching" to describe how the gears turn instead of the more conventional verbs like "turning" or "spinning." This lack of vocabulary caused the students trouble in verbalizing the concept and explaining what they were thinking.

The last area is titled, "Understanding what happens and how to fix it when the middle gear is removed." Students had three gears set up in a line and were told to remove the middle gear, they were asked what happens to the third gear now that the middle one has been removed and how can they make the third gear turn again. Seven of twelve students had a full understanding of why the third gear no longer turned and were immediately able to add the gear back into the middle to fix it. Of the remaining five students, each had some understanding of the concept but needed support to complete the task. Two students understood why the third gear no longer turned, but they needed assistance in fixing the problem. Another student needed support in understanding that the third gear no longer turned, once he understood that, he was able to add the gear in and fix it immediately. The other two students first attempted a solution that did not fix the problem and make the third gear turn again. When their first solution did not work they both attempted a second solution which did work. Student 4 understood that the third gear would not turn and constructed a plan to fix it. Along with the gears and peg board, there are also rectangular connector pieces to build the gears upward. He used the connector pieces to build up and connect the first gear to the third gear. Once they were connected, resembling a bridge, he attempted to turn the first gear, with the rectangle connector piece latched on to both gears, it was impossible for either gear to turn. He realized this solution did not work, took it apart, and attempted his next solution which was to put a gear in the middle of the two. Student 10 also attempted a first solution that was not successful. When attempting to make the third gear turn again she placed the gear, not in the middle, but on the other side of the third gear. She tested her solution by turning the first gear, but nothing happened. Seeing that it did not work she then moved the gear into the middle, tested it and it worked. She then immediately repeated this process with another set of three gears.

Recommendations for Teaching Engineering in Early Childhood Based on the Results

The first recommendation is about teaching vocabulary related to gears. If a gear lesson is to be taught in the classroom, or if students will be playing with gears during center or activity times, then gear vocabulary should be explicitly taught. Students cannot properly explain their thought process if they do not know the correct words to do so. Words that should be explicitly taught if gear toys will be used in the classroom include; "gear," "gear teeth," "connect," and "turning." Once students are taught the proper words, they will have less trouble verbalizing their findings than when they are searching for the correct words to explain their thoughts. Another recommendation is for preschool classrooms to have gear toys available to students during free play time. If students choose to, they can play with the gear toy. Through the research it became clear that student understanding was gained and previous beliefs were changed through their hands-on experience with the gears. Allowing students the option to play with gear toys on their own accord will increase their understanding of the concepts through their manipulation of the gears.

Supporting young children in their learning of engineering concepts requires a certain kind of curriculum, theory, and beliefs. Piaget's theory and a constructivist classroom are recommended and are best suited for teaching engineering concepts, especially those related to gears. Hands-on experiences, exploration, and trial and error are the main ideas of Piaget's theory. Engineering is also about these main ideas. Students playing with a gear toy fit into all three of Piaget's categories. The students are involved in a hands-on experience, they are exploring gears and what they do, and they are making mistakes and attempting solutions to fix them. Constructivist classrooms support authentic and hands-on learning experiences. Allowing students to engage with engineering materials and concepts in a constructivist classroom will promote understanding of these concepts and allow students to discover and understand them themselves.

Conclusion

Preschool students, as young as three years old, are beginning to understand engineering concepts and must be supported in doing so. Through the research it was found that students aged three years old to five years old had at least a preliminary understanding of gears and how they work. Some students had a more advanced understanding of gears and the ability to give more in-depth explanations. All students had trouble verbalizing their thoughts and findings due to their lack of gear related vocabulary. If students are interacting with a gear toy, then they must be taught the proper vocabulary. It is important that the teaching, materials, and classroom are conducive to further exploring and understanding gears and other engineering concepts. Moreover, a constructivist classroom using Piaget's theory is the most opportune environment for students to explore and understand these concepts.

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