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STEM Moments in the Family Context throughout Engineering Design Challenge Activities (Fundamental)

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Abstract

Research on interactions between caregivers and children have long been reported in science museum experiences. However, the interactions between caregivers and children in home environments are rarely investigated. By comparison, research on the experience of the engineering design challenge activities in a family context is even less. This case study aimed to examine interactions of two families in their home as they engaged with engineering design challenge kits that have the potential to support children's foundational understanding of STEM concepts. Using social-cultural constructivism as a lens, about 370 minutes of video data was analyzed. Data coding revealed three types of interactions that facilitated children's understanding of STEM concepts: teaching, build up, and synthesized moments. These three moments were interdependent but included different emphasis of caregivers' and children's engagement. Although there is a limitation of this study to generalize the findings, our results contribute to understand how caregivers and children play with the materials, tools, and their ideas in their home environments and how caregivers used different facilitation approaches without any training prior to engaging with the engineering kits.

Introduction

Conversations between caregivers and children create natural environments for children to play, practice, and learn [1]. Researchers have reported how conversations about science, technology, engineering, and mathematics (STEM) promotes a collaborative process of sense-making of scientific literacy [2], sharing knowledge through explanation and questions [3], and developing academic competency [4]. However, in general, studies that examined STEM-related conversations between caregivers and children take place in museum settings and less than often in-home environments. Moreover, non-verbal communication is rarely investigated in these studies [5].

This qualitative, intrinsic case study aimed to examine interactions of family members in their home as they engaged with engineering design challenge kits that have the potential to support children's foundational understanding of STEM concepts and skills. STEM skills in this study encompass cognitive and technical skills that support children to enhance their competencies in STEM context [6]. The engineering design challenge encourages children to play with STEM concepts and skills in a process of designing, making, and testing. A critical challenge in applying this engineering design process in formal or informal settings is to support educators and caregivers in enacting teaching and facilitation strategies during the activities. To understand the nature of teaching and facilitating in STEM, Haug [7] identified planned and spontaneous teachable moments in terms of knowledge acquisition in elementary science classroom, and Barnes [8] described a process that sparked immediate understanding in mathematics classroom as 'magical' moments [9]. Findings of these two articles capitalized teachers' roles in adopting and modifying students' needs and interest to promote their engagement in science and math. Caregivers tend to take an educator's position in interactions with their children in the family setting. Specifically, with young children, caregivers are primary educators to answer their questions, explain the reasons for their answer, or ask questions [9]. These interactions provide social context for children to collect information and shape conceptual understanding. Researchers investigated various interventions such as questioning [10], explanation [11] prompts [12], and training for science inquiry [13]. Still, less is known how the interplay between caregivers and children through engineering design challenge activities foster children's engagement in STEM concepts and skills. Researchers extended a scope of caregiver-child interaction into home environment and examined a nature of the process of children's engagement in conceptualizing STEM concepts.

Theoretical perspectives

This study is influenced by Vygotsky's sociocultural theory [14] that proposed learning as a social process. He stated that any function in children's cultural development occur "first between people as an interpsychological category and then insider the child as an intrapsychological category" [14]. In other words, children interact with people and materials in the interpsychological context. Children are able to shape a conscious awareness of people and materials and master their actions through the exposure to this interaction. People, especially, the more knowledgeable one, scaffold learning and thinking skills until children are able to complete the task independently. The type of assistance offered by adults in learning context are reflected in what children learn and how they develop sense making. Therefore, verbal and nonverbal interactions between caregivers and children build connections between children's previous knowledge and something they did not know [15].

Methods

Context and participants

A qualitative, intrinsic case study was selected to explore various aspects of developing STEM moments in caregiver-child interactions. The intrinsic case study is conducted to investigate a unique situation [16]. For this study, the unique case is individual caregiver-child interactions to brainstorm, design, make, and improve their own prototype using the provided engineering design challenge kits.

The research team offered three consecutive Family STEM Saturday events through two local Boys and Girls Club branches after getting an approval from the institutional review board (IRB). Directors in the Boys and Girls Club disseminated the program information to local underserved families with at least one child in grades 3 - 6. A total of 14 families with 21 children participated in these Family STEM Saturday events and received information about the home engineering design challenge project. Five families with seven children joined the engineering design challenge activities. Preliminary findings from two families or caregiver-child dyads are reported in this paper. Since the pandemic started in the middle of their participation, the kit circulation process changed into a contactless circulation system. The first author delivered kits to the door of participants' home. Caregivers were asked to record their interactions during the engineering challenge activities. They were also asked to finish one kit within two weeks, but that was not required. Additionally, the research team did not force caregivers to finish the kit in one sitting. Depending on families' situations, they could stop their recording in one day and continue recording their engineering interactions on another day. The two dyads in this study completed four to five kits over six months. Each participant was assigned a pseudonym by the research team.

Prior to this study, engineering kits were piloted with underserved families through nine local elementary school libraries [17]. The initial purpose of the kits was to facilitate involvement of underserved families and their children in STEM activities focusing on an engineering design challenge process. Each kit included one instruction card including potential facilitation questions, materials, and tools. School librarians circulated the kits with students in grades 3 – 6. As an extension, our research team developed five engineering kits with different themes based on librarian's feedback: delivering a package using a zipline, designing a tennis shoe, making a paper roller coaster, a rain gauge, and a game joystick. Each kit contained a set of instruction cards, materials, and tools. The instruction cards provided a stepwise guidance of the activity: engineering task, a list of materials, 4-5 inquiry-based steps focused on the making process with photos, kit chats (i.e., questions for caregivers), and links to substantial resources. Caregivers were not provided any training before participating with their child in the various kits.

Sara's family

Sara was a 10-year-old girl. She mainly worked with her mom, Amanda, to complete three kits. Steve, Sara's father, participated in one kit (i.e., package delivery) with Sara. Amanda previously worked at a children hospital as a counseling assistant and more recently ran a gardening club with local children in afterschool gardening programs. Steve worked at a biomedical company.

Roberto's family

Roberto is a 9-year-old boy. He completed four activities with his dad, Khun, who worked in science education at a university and one activity with his mom, Jennifer, who has not worked for any positions related to STEM.

Analysis

About 150 minutes of data from Sara and 220 minutes data from Roberto were collected and analyzed. Two authors employed memoing [16] to identify and organize meaning according to the research aim. Sixty-three episodes were identified using memos. These episodes include verbal and nonverbal interactions that encouraged students to conceptualize STEM concepts and/or practice STEM skills. To identify what STEM skills are, authors used Carnevale et al.'s list [18] of cognitive and non-cognitive STEM competencies. However, these skills do not present all STEM skills (Table 1). According to the synthesis of literature review by Siekmann and Korbe [19], STEM skills refer to "a combination of the ability to produce scientific knowledge, supported by mathematical skills, in order to design and build (engineer) technological and scientific products or services" (2016, p. 45). Therefore, authors used the list by Carnevale et al.'s as a reference but did not set boundaries to identify STEM skills from video data in this study.

	Cognitive	
STEM knowledge	**STEM Skills**	**STEM Abilities**
Production and Processing	Mathematics	Problem Sensitivity
Computers and Electronics	Science	Deductive Reasoning
Engineering and Technology	Critical Thinking	Inductive Reasoning
Design	Active Learning	Mathematical Reasoning
Building and Construction	Complex problem Solving	Number Facility
Mechanical	Operations Analysis	Perceptual Speed
Mathematics	Technology Design	Control Precision
Physics	Equipment Selection	
Chemistry	Programming	
Biology	Quality Control Analysis	
	Operations Monitoring	
	Operation and Control	
	Equipment Maintenance	
	Troubleshooting	
	Repairing	
	Systems Analysis	
	Systems Evaluation	
	Non-Cognitive	
STEM Work Interests	**STEM Work Values**	

Realistic Investigative	Achievement Independence Recognition

Table 1. *O*NET Competencies associated with STEM (Carnevale et al., 2011, p. 8)*

Consequently, open coding was used to interpret each memo with descriptive labels focusing on who, what, and how. The label of 'who' represents who initiated discussion or actions as well as who took a lead. The label of 'what' included what STEM concepts (e.g., conductive materials) and STEM skills were detected during interactions. Additionally, the label of "how" explained how verbal (e.g., questioning) and non-verbal (e.g., eye-contact) interplay between who (caregivers and children) and what (STEM concepts and skills). Next coding step was to review these codes and determine broader categories that illustrate patterns of dynamic interactions based on the research aim to explore caregiver-child interactions that support potential understanding of STEM concepts and skills.

Findings

Analysis uncovered qualitatively three different ways in which STEM moments were cultivated during interactions between caregivers and children. Distinctive patterns of teaching and facilitation were detected among these three categories, but these moments are interdependent within the STEM moments. Collaborative educational environments of this activity formulated reciprocal directions of teaching and facilitation between caregivers and children. The first category is framed as a teaching moment. In this study, teaching moments were built on caregivers' effort to notice children's needs and/or enhance children's understanding. The second category is denoted as a build-up moment. This is an extended form of teaching moments that focused on children's active engagement. Caregivers and children worked through iterative processes of making, testing, improving, and retesting. Caregivers stepped back and encouraged children to find solutions by themselves. Ideas and solutions were negotiated, as well as filtered by questioning and discussion. The third category is described as a synthesizing moment. Children collected and applied information to figure out the problem or gain an understanding of STEM concepts with caregivers' verbal and nonverbal assistance.

Teaching moments

Engineering design challenge activities encouraged caregivers and children to explore STEM concepts throughout the making process. Instructional cards did not explicitly explain what STEM concepts children should learn in the activities. We provide two episodes to illustrate how caregivers used questions to identify children's needs for explanation and clarification of the STEM concepts, materials, or tools, to then utilize this information to expand their child's thinking. For instance, in identifying and understanding material used to create a rain gauge, Khun checked Roberto's understanding using actual examples in their home.

> *Khun*: Do you know what conductive means? It means it allows electricity to flow. Do you know what you're not supposed to stick into…
> *Roberto*: Metal?
> *Khun*: So, aluminum foil is a type of metal, right? But can you use all metals?

Roberto: No, you can't use like copper.

Khun: Why not? Copper's actually one of the best metals for conducting electricity.

Roberto: It is? I just randomly guessed it.

Khun: It's why all the Ethernet cables at our house and electrical cables that go from the basement to each plug in the house. They're all copper. The line that comes from the cable out here to our house, it's copper.

This caregiver explains the concept of electrical conductivity first and facilitates the child's understanding into conductive materials using probing questions. When the child's response does not present clear understanding, the caregiver clarifies the answer and helps the child connect the new concept or word with child-friendly concepts. In this study, the caregivers' direct explanation of the concept tends to entail a subsequent process to ensure the child's understanding. The caregiver, as the more knowledgeable member, guided children's understanding of the concept and involvement in interactions to develop and expand their understanding. As exemplified in the next episode, teaching moments also were built up from caregivers' questions that can induce children to think about advanced concepts. When children demonstrated their understanding properly, caregivers had opportunities to extend children's understanding. The following episode is another example from the rain gauge kit. Amanda and Sara were measuring volume to mark a standardized measurement unit on the cylinder shape cup.

Amanda: So, if you wanted to measure something and have more visual height, what would you want to do for your cup?

Sara: I would want to make it like a tube.

Amanda: yeah, more narrow.

Sara: Yeah, more narrow.

[Sara lay ruler back on the table. Amanda added another 15 mL of water to the cup. Sara about marks cup with sharpie.]

Amanda: Good job. That's right. That's just 15.

[Amanda added another 15 ml of water and Sara placed a line at 180 ml.]

Sara: That's right. Will this actually work do you think?

Amanda: I think so. If it works, I think that will be wonderful to have one. Did it correlate with your unit of measurement and the ruler?

Sara: No. I don't even have to measure it to see that.

[Sara placed a ruler vertically against the cup, glances at the ruler and removes.]

Amanda: So that's an interesting point is if you are measuring inches of rain, it really matters how big around your measurement tool is. I wonder if that is standardized. Because usually they will, the weather will report how many inches we got, but I wonder if their tubes are standardized.

Sara: Yeah, not usually in millimeters.

Amanda: Yeah, but we could measure in millimeter or centimeters.

They agreed that a narrower, tube-shaped cup was better to show the difference between measurement units clearly because the distance between 15 mL is getting closer. Amanda posed a question to check if Sara understood that the cylinder shape cup was inappropriate to measure volume. She built on this idea by asking if the volume correlated with a length of the ruler based on the cylinder-shaped cup. Sara's answer indicated that she already understood this. Then, Sara brought another example that provided an additional question about the standardized measurement unit. Amanda's questions did not only check Sara's understanding, but also led to Sara accessing advanced concepts. Sara practiced data collection and analysis skills through adding the 150 mL water, marking it, measuring volume and distance, and reasoning skills to find a better shape for the rain gauge.

Figure1. *Measuring Volume in Cylinder Shape Cup*

Build up moment: extended teaching moment

Build up moments is an extension of a teaching moment but focused on children's active engagement. Children actively elaborated their ideas, explored and/or used materials, and sought help from caregivers. Caregiver's suggestions did not dominate the interactions but were reflected in children's reactions. Using the following two episodes, the process of child-driven interactions to mold and improve their understanding with their caregivers is described. Sara and Amanda were designing a food dispenser for pets. The engineering task proposed two requirements: training your new puppy to walk without a leash and making a machine to dispense or drop one puppy treat at one time. There were no specific stepwise guidelines with the details of the dispenser such as size, materials, and shape. Sara actively sought to clarify her ideas about placement of the dispenser and its distance from the puppy and elaborated her ideas about the design.

Sara: But we want it like farther out from the puppy so… or no, we just want the puppy to have it, right?

Amanda: Hmmm… how will we dispense?

Sara: That's what I was just saying. So maybe like a popsicle stick or something like or maybe let's just use this as an example. [picked up a cardboard box.] I don't know if I have any bigger ones… no, ok. Just an example like this. Like there would be lining right here.

Amanda: I would say as a dog walker, I would want something that's portable.

Sara: Yea that's why I'm thinking like this and that's more like it. I need to decide on like how my- because this is a pretty small box, right? I would be able to cut a hole mostly easily through here, maybe make a lid or something on the top or a flat or something. But I would want to know like how I could carry this- because I don't wanna- nature walk I don't wanna just be carrying a caramel dip box.

Amanda: I'm with you.

Sara: So, like maybe like a belt or maybe like a bag?

Amanda: Mmm, that's an idea.

Sara enumerated her ideas. Amanda listened to Sara's ideas and reminded her of the basic requirements. Sara's ideas were specified and shaped by Amanda's reminders. Sara's reasoning skills was detected in the logic in her dialogue. On the other hand, build up moments arose with children's suggestions to combine his or her ideas with caregivers' ideas. Roberto listened to and observed his father's ideas first and then suggested that how to improve the prototype by combining his ideas with his father's ideas. The following episode was selected from the making package delivery methods activity.

Khun: I'm gonna make a container too.

Roberto: I think your idea might be better.

Khun: No, I mean. It's just a different idea.

[Roberto put his container into Steve's container]

Roberto: But you still need to get some because it might fall off.

Khun: I can work on that.

Roberto: Maybe we can use this part. We could do something like that. We can make it a little longer if we need to.

Khun: What do you think?

Roberto We could make use rubber bands to tie it.

Whereas Sara directed her making process and created a prototype by herself, Roberto and Khun created a prototype respectively. In the making zipline activity, Roberto and Khun designed a container individually and discussed ideas to make it sturdier. Roberto compared two containers and put his into Khun's. Roberto also suggested how to improve the prototype. In this episode, Roberto demonstrated his creative thinking skills by combining two ideas to create a new idea.

Synthesizing moment based on teaching and build up moment

Synthesized moments represent children's comprehensive conceptual knowledge using collected information from interactions with their caregivers. Sometimes children used information from teaching and/or build up moments. Sometimes children's conceptual knowledge calls for another teaching and/or build up moments. Children's utterances described a process of how they built up and applied their knowledge to conceptualize the STEM concept. The following episode was from Roberto's activity with the rain gauge.

> *Khun*: So lean it over to towards the side.
> [He takes hold of cup and repositions ruler.]
> Now you do realize that…as we go up, what changes as we go up...with this, which would make it [Roberto is marking cup with sharpie] slightly less accurate with like a cylinder like you have in school?
> [Roberto stopped marking cup. Steve removed ruler]
> *Roberto*: Because it like curves up. I mean like at the bottom it's the smallest and then it starts getting bigger and bigger and bigger.
> *Khun:* So then you are not really technically measuring an equal amount. Is that what it's basic?
> *Roberto:* So I have an idea. We can measure the bottom [He picks up ruler and lays across the bottom of the cup.] and see how much it is and then take like all the rest away. And then when we know that number… [He is circling his hand around the top of the cup. He removed ruler from bottom of cup.] and when we get the answer, we can subtract that much from it.

After Khun explained positioning a ruler beside the cylinder-shaped cup and how it should be less accurate, Roberto applied the difference of volumes between bottom and top of the cup to calculate accurate volume. On the other hand, Sara's synthesizing moment was developed through the hands-on experiment, when Sara made a circuitry in the greeting card using a copper tape, coin battery, and LED light.

> *Amanda*: It looks like you make a kind of grid.
> *Sara*: Yeah, a tiny rectangle with LED light would be. I need to get a positive and negative track. I would like to make this one go to this way and this one go to this way
> [Sara pointed out each corner of the rectangle on the grid and drew the direction of positive and negative using her finger]
> *Sara*: I'm not sure which direction is positive or negative using this coin battery.
> *Amanda*: Do you remember the rain gauge? We made?
> *Sara*: Oh…. I can put the positive in one side and negative on the other because of positive goes this way and negative goes this way
> [She demonstrated direction of current on the circuitry using her finger.]
> *Amanda*: OK. It's cool. Thank you for your explaining. [Eye contact] Proceed. Proceed

Sara's talk indicated that she understood the positive and negative direction of the circuitry. When Sara explained her idea and problem, Amanda reminded her of the similar kit experiment they completed together. Sara conceptualized solutions based on her knowledge from that experience.

Discussion

Importance of caregiver-child interactions in children's development, specifically elementary school years, has been widely and critically discussed. Vygotsky's view of sociocultural learning rationalized multiple directions of influence in caregiver-child interactions. However, little is known about verbal and non-verbal interactions within the engineering design challenge process with elementary students. Still, it is one of the biggest challenges to find ways to support caregivers in informal educational settings. Our findings provide rich narratives to see ongoing interactions with caregivers' influence and children's internalization in the engineering design process.

Findings support Vygotsky's view on the caregiver-child interactions and roles of caregivers to scaffold learning [14]. Children's cognitive growth occurred in caregiver-child interactions and then extended to internalized understanding. Verbal and non-verbal interactions in this study created a social context in which children collected information and formulated their conceptual understanding. More specifically, our findings highlighted children's active engagement in the interactions to clarify, modify, and consolidate their ideas. Caregivers used explanation and questioning in variance to support their children. This is consistent with the more knowledge person's role in supporting children work through the one of Proximal Development (ZPD). Caregivers noticed children's non-verbal language and applied various facilitation strategies using questions or materials to support children's understanding. It advocates benefits of home engineering projects in one-on-one settings as well as caregivers' understanding of their children. Goldstein [20] addressed the importance of co-construction of mind and caring of interpersonal relationships in children's growth beyond the sociocultural theory [14]. A process of three moments in this study might be associated with the process of co-construction of mind. It will be crucial to investigate this association in the next step.

Different paths between two children in three moments touched a critical aspect of ZPD. Sara who was independent learner with natural curiosity actively enacted in elaborating and negotiating her ideas with caregivers. On the other hand, Roberto was creative but tended to listen to caregivers' thoughts first. They expressed different needs and worked through different processes to collect information, develop their ideas, and improve a prototype using ideas. Mercer [21] addressed that every child has a different range of the ZPD between what they can achieve themselves and what they can achieve with assistance. This gap also represents difference between children's capabilities and potential. ZPD. Thus, this argument denies the prevalent assumption of the same range of ZPD for all children. Additionally, there can be multiple layers in ZPD to reach children's potential.

Researchers in studies of the critical moments in classroom also highlighted teachers' roles to respond to students' questions or allow students to explore the contents independently [22, 23]. At the same time, critical moments were initiated by students' questions in spontaneous and unplanned situations in these studies. Children's enactment in the engineering design challenge activities proposed diverse directions in more flexible, spontaneous, and unplanned approaches than typical classrooms, which tend to be guided by more structured situations. Caregivers and children followed the stepwise guideline in the instruction card and used facilitation questions to promote children's understanding. Caregiver-child interactions, however, were not limited by the guidelines and questions. The findings from these case studies raises the following question to educators who are going to conduct family engineering activities and guidelines: To what extent should caregivers be provided with information and facilitation to engage their children in the process of STEM moments?

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