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Exploring caregiver influence on child creativity and innovation in an out-of-school engineering program

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A B S T R A C T

Creativity is of increasing importance to the field of engineering. Thus, furthering our understanding of the development of (or barriers to) creativity during childhood and adolescence, and in environments alternative to traditional classroom settings, may hold particular significance and implications for generating creative and cognitive shifts amongst children, and their ultimate interest in the discipline. Constraints on child creative thinking and innovation that may occur by educators and within schools highlight the need to explore alternative environments and individuals, such as caregivers and/or out-of-school contexts. To expand our understanding of the influence caregivers may have on child creativity and innovation, particularly during the critical engineering design phases of problem identification and solution ideation, this study sought to investigate how caregiver involvement shapes the creativity and innovation of children in an out-of-school engineering program. Using conversation analysis to examine caregiver-child dialogue, results demonstrate ways that child ideas, creative thinking, and innovative engagement with various solutions were shaped by caregivers' involvement through four predominant dialogic methods, including (a) directive questioning, (b) restating/reframing, (c) idea blending, and (d) using shared experiences. Insights into specific dialogic methods caregivers employed while engaging with children in out-of-school environments through the engineering design cycle are discussed, further illuminating how such engagement and specific conversational tactics impact children's creative thinking and use of innovation. In so doing, we support the argument that the nature of caregiver engagement and the fostering or hindering of creativity and innovation through conversation ultimately influences children's own engagement and application of engineering concepts

1. Introduction

Creativity and innovation have become important and sought-after skills within disciplines and industries of all types. Organizations have come to value creative thinking and innovation to develop new ideas, products, and processes that contribute to solving

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problems or accomplish goals and tasks (Baruah & Paulus, 2019; Forgeard & Kaufman, 2016). Morrison and Johnston (2003) defined creativity as the making of something new, including ideas, products, art, or even understanding and interpretation. It has also been considered a skill that moves away from norms and identifies new or unusual solutions (Cropley, 2001). Similarly, innovation has been described as the adding of something new or incorporation of changes to a product or process (Badran, 2007). Creativity and innovation are often-linked concepts, with the ability to be innovative dependant upon one's creativity, generation of novel or contributive ideas, and ability to bring those ideas to fruition (Somech & Drach-Zahavy, 2013). Previous research has also identified a connection between creativity skills and the development of other essential thinking and cognitive skills including problem setting and solving, critical thinking, reflective judgement, and the processing and application of information (Newbill & Baum, 2013; Robson, 2014). Within STEM (science, technology, engineering, and mathematics), greater fostering of creativity and novel thinking in children have been called for in order to face rapidly evolving needs and challenges (Kanematsu & Barry, 2016), and to combat what some have identified as a creativity crisis (Kim, 2011). Cropley (2015) identified this rapidly changing environment as a primary cause of increasing needs for ingenuity and advancement in STEM disciplines, education, and processes, particularly for fields such as engineering education. He noted, "Because creativity is concerned with the generation of effective, novel solutions, creativity and engineering are, in essence, two sides of the same coin," (Cropley, 2015, p. 2).

Research has shown that within the context of engineering education, the design stages of problem identification and solution ideation, specifically, present unique challenges and opportunities for children in the development of independent, innovative thinking and the use of creativity in determining appropriate solutions to identified problems (Cropley, 2015; Daly, Mosyjowski, & Seifert, 2014). Gilson and Litchfield (2017) argued that concepts of creativity and innovation are intrinsically linked by ideas, with creativity forming the foundation of idea creation and innovation being required for the successful implementation of such ideas. The generation of concepts and ideas around problem solutions are critical steps that inform subsequent processes undertaken to complete a project including research, testing, and even to whom and where one might go for feedback and redesign (Daly, Yilmaz, Christian, Seifert, & Gonzalez, 2012). An individual's investment in a task or project and innovative efforts often depend on the perceived relevance of the task and individual levels of creative thinking (Barbot, Lubart, & Besançon, 2016; Besançon, Lubart, & Barbot, 2013). As the development of creative ideas and suggestions (i.e., ideation) represents a critical step in the engineering design process, it is important to investigate how children develop ideas and potential influences that may shape their creative, independent thinking.

Despite a growing recognition of the critical role of creativity and innovation within STEM disciplines and industries, the purposeful development of these skills is often neglected or misperceived within typical school and classroom environments (Ahmadi, Peter, Lubart, & Besançon, 2019). Reasons behind this challenge may be varied. For example, in their review of teacher perceptions, Mullet, Willerson, Lamb, and Kettler (2016) noted that barriers to fostering creativity included diverse conceptualizations of creativity, conflation with intellectual abilities, and gaps between educator support for creativity inclusion and the actual use of creative practices and thinking. Traditional teaching approaches and standardized assessments and practices may also contribute to the stifling of creativity and innovative thinking within children in schools (Kim, 2008). Yet research indicates that the years children spend in school overlaps with critical developmental stages in which prominent changes (positive or negative) in creativity and cognitive flexibility may occur (Gopnik et al., 2017; Leggett, 2017). Further, creative and innovative thinking has been identified as a skill that can be learned and is inherent to the development of typical cognitive abilities such as mental flexibility, problem solving, and adaptability to change (Ritter & Mostert, 2017). The development of such thinking skills and abilities can be shaped by various influences and factors a person might encounter as they grow and learn, and contribute to a child's interests, identity, and transformation of information into knowledge (Roth, Conradty, & Bogner, 2021; Thelen & Smith, 1998). As creativity and fields such as engineering have been found to be inextricably linked (Cropley, 2015), furthering our understanding of the development of (or barriers to) creativity during childhood and adolescence, and in environments alternative to traditional classroom settings, may hold particular significance and implications for generating creative and cognitive shifts amongst children in the discipline.

Research conducted in out-of-school learning environments, such as museums, has also shed light on the influence that flexible, curated environments and targeted programming or experiences within them have on caregiver-child dialogue, and the subsequent impact that dialogue may have on learning and engagement. Rogoff, Callanan, Gutiérrez, and Erickson (2016) found that children attending museums with their families blend familiar contexts and experiences from their home or community with what they are seeing and learning in an exhibit. The context and type of hands-on and purposefully engaged learning that can take place in out-of-school settings have also been identified as influential factors in fostering collaborative and fluid dialogue, idea sharing, and interaction between caregivers and children (Callanan, Martin, & Luce, 2016; Haden, Cohen, Uttal, & Marcus, 2016; Willard et al., 2019). Further, programs that purposefully transformed or used every day spaces as mediums for exploratory and informal learning have been found to foster communication between caregivers and children, particularly around STEM concepts, language, and literacy (Hassinger-Das et al., 2020). Varied definitions and general understanding of creativity in education also remain a consistent challenge as many current definitions are centred around adult understanding and professional application which may not be appropriate for adolescent learning (Lassig, 2020). This understanding exacerbates what some have argued is the unequal emphasis on practicality and core subject instruction over the arts and design-based content, subsequently limiting the value of creativity and innovation within and by schools and disciplines (Page & Thorsteinsson, 2017). As noted by Cropley (2015), within STEM and engineering specifically, the rapid rate of change and emergence of new and unforeseen challenges requires creative thinking and innovative solutions to meet evolving demands and needs. Thus, constraints on child creative thinking and innovation that may occur by educators and within schools highlight the need to explore alternative environments and individuals, such as caregivers[1] and/or out-of-school contexts, to learn how creativity and innovation might be fostered in children.

Research by Van Voorhis and colleagues (2013) provided evidence that engagement and involvement in learning by caregivers or trusted adults may have profound impacts on child development and learning, and that this influence is most prevalent within out-of-school contexts. Conversation and dialogue between caregivers and children in a museum setting, for example, has been found to determine what children understand and retain about their experiences (Benjamin, Haden, & Wilkerson, 2010; Callanan et al., 2016). Previous studies indicate that the nature of conversation, such as the use of more additive, open-ended *wh*-questions, between caregivers and children in relation to an event or experience can impact children's recall and memory and is informed by their shared experiences (Callanan, Castañeda, Luce, & Martin, 2017; Fivush, Haden, & Reese, 2006; Haden et al., 2014). Caregiver-child dialogue during an experience has also been found to shape how children perceive their experiences in real time, subsequently impacting what they might learn and retain (Ornstein, Haden, & Hedrick, 2004). This concept is further supported by research indicating that in the context of science education, collaborative behaviour and exchange of scientific ideas and concepts fostered meaningful learning (Barak, 2017; Ben-Zvi Assaraf, 2011).

Creativity and innovative thinking have become increasingly important and sought-after skills (Cropley, 2015; Forgeard & Kaufmann, 2016), especially within STEM disciplines such as engineering (Daly et al., 2014). Yet, schools and traditional learning environments struggle to incorporate or support creativity development within existing curriculum (Kim, 2008). This requires looking beyond school and classroom environments to out-of-school contexts and relationships to learn what may shape the development of children's creative and innovative thinking. The role of caregivers in shaping various aspects of children's lives and development (e.g., speech and language, emotional regulation, academic development) has been well documented (Kiel & Kalomiris, 2015; Rowe, 2018; Sadruddin et al., 2019), however, a dearth of research investigating the extent and nature of their influence on creative thinking within disciplines such as engineering remains. Thus, to expand our understanding of the influence caregivers may have on child creativity and innovation, particularly during the critical engineering design phases of problem identification and solution ideation (Cropley, 2015; Daly, Mosyjowski, & Seifert, 2014), this study sought to investigate the following question: *How might caregiver involvement influence and shape the creativity and innovation of children in an out-of-school engineering program?* In this study we argue that caregivers dialogue and conversation around STEM engineering projects in out-of-school environments, plays a unique role in shaping the development of creative and independent thinking of children. We illustrate how caregivers influence the creative, innovative, and independent thinking of children through directive questioning, restating/reframing ideas or information, blending ideas or concepts with those of their child, and the use of shared experiences or contexts. Investigating these various dialogic methods employed by caregivers provides valuable insight into how caregiver engagement in out-of-school learning environments fosters or constrains creativity and innovation in children. Further, findings illuminate insights for the development of targeted family and community engagement interventions that incorporate instructional and dialogical methods in favour of a positive adult influence on child creativity and innovation within engineering education.

1.1. Theoretical framework

Glăveanu (2018) argued that adult understanding and appreciation for creativity in children is reflected via interaction, and such interaction may influence the development of creativity in a child. In this light, social constructivism provides a framework by which the sharing of information, dynamics, and methods of engagement between child and caregiver might be examined. As Piaget (1936) described, knowledge and understanding are actively constructed by the learner, informed by existing awareness and influenced by the experiences, cultural background, and environmental circumstances of a learner. These elements influence the perspective with which individuals approach a problem or topic and, consequently, impacts knowledge building and learning (Domínguez & Jaime, 2010). The work of Vygotsky (1962) further emphasized the role that social interactions and individuals play within the learning and development process (Bodrova & Leong, 2018). The social constructivist perspective views learning as a result of knowledge sharing, interpersonal dynamics, and collaborative idea exchange (Barak, 2017; Ben-Zvi Assaraf, 2011). Thus, dialogue and social interactions can be considered important factors in the development of independent, creative thinking, as well as how we might learn to value and foster creativity and innovation.

Social constructivism and its contribution to creative and independent thinking has been identified as an influential force in cognitive development. In the context of child development and learning, the complex dynamic systems (CDS) approach further suggests that a developing system is one that incorporates multiple, intersecting components and subsystems (e.g., actions, emotions, other individuals) (van Geert, 2011). As these various components and subsystems interact over time, they change and evolve, subsequently shaping the development of the individual at the focal point of these intersecting systems, such as a developing child (Thelen & Smith, 1998; van Geert, 2011). In the context of learning and engineering education, interactions that children have with adults (e.g., caregivers) and various environments (e.g., the home), can be understood as subsystems that effect change in children's thought processes, learning, identity, ways of engaging in tasks, and expectations (Kaplan & Garner, 2017; O'Connor, 2010). Thus, a complex dynamic systems approach implies that adult engagement through conversation and dialogue interacts with the child's learning environment in unique ways, which contributes to their overall development, thinking skills, and self-concept (van Geert, 2011).

In conjunction with both social constructivism and a CDS approach, Eccles and colleagues' theories of caregiver socialization

[1] Caregivers are understood to be an adult who provides direct and regular care to children.

(1993; 1997) provide further grounding from which the distinct perspectives and social behaviors of caregivers might be examined in the context of an out-of-school learning environment. Caregiver socialization theory posits that the beliefs and perspectives of caregivers are applied via two primary mediums – communication and dialogue, as well as tangible experiences and interactions facilitated by various behaviors (Eccles et al., 1993). The former serves as a channel not only to convey direct messages and caregiver perceptions regarding the task or circumstances at hand, but also the value and importance of the task held by the caregiver. Such communication and the underlying values and beliefs they convey, subsequently impact the behaviors and actions taken by the caregiver in relation to a child (i.e. engaging in specific learning opportunities, actively partnering with their child on a project, etc.) (Jacobs & Bleeker, 2004). Thus, in this study we aim to closely examine the dialogue employed by caregivers that may influence their child's creative thinking and innovation with key design stages of problem identification and solution ideation, within the context of an out-of-school engineering program.

1.2. Methods

This study is part of a larger multi-year project aimed at developing a program for integrating engineering design practices with an emphasis on emerging technologies (i.e., making, DIY electronics) and recyclable materials into home environments of families with a child in grade 3–6. The overarching hypothesis of this larger project centers around the idea that engaging children and their caregivers with the implementation of engineering design practices in out-of-school contexts will positively impact the development of affinity with STEM disciplines. This is supported by our rationale that families play a vital role in their children's path toward entering STEM fields or not. The current study analysed data from the first two years of the program which took place in two locations - a large metropolitan area in the Midwest United States and a mid-sized urban area in the Northeast United States. In year one, we engaged two families in self-identifying a way to improve the life or lives of someone they know, then constructing a prototype and working product by the end of the project. For example, one family wanted to prevent one of their cats from bullying another. Using a microcontroller, they developed a collar that would vibrate when the two cats got close to one another. During year two, the program expanded to include another research site in a different state and community and engaged three more families in the same program process (identifying a problem or issue in their home, school, or neighbourhood that they were interested in engineering a solution for) as the year prior. In both years, each session lasted between 2 and 3 h and took place at a local community organization (e.g., public library, Boys & Girls Club).

1.3. Participants

For this specific study, we focused on five child-caregiver dyads from whom video and transcript data pertaining to the problem identification and solution ideation phases was available. Further, the inclusion of five diverse dyads across two research sites and from two different years of the program allows for the identification of similarities and differences amongst participating families or cases (Stake, 1995). Children and caregivers across both research sites were recruited and selected for participation through established partnerships with after-school programs, community-based organizations (e.g. Boys & Girls Club), school districts, and local libraries. Informational recruitment events were held in the fall terms to provide potential participants with an opportunity to engage with the researchers and learn more about the program. Participating children and their families were racially and ethnically diverse and included individuals who identified as Black, White, or more than one race. Three out of five of participating children identified as female and all participating children ranged in grade levels between first and sixth grade. A total of five participating caregivers were included in this sample, comprised of one mother, one grandmother, and three fathers. These participants expressed varying levels of experience with engineering content, with some having no experience and others having extensive experience (i.e. they themselves are engineers). Pseudonyms for all participating children and caregivers have been used throughout this study to ensure anonymity.

1.4. Data source

Data for this study originated from initial program sessions held in the early months of Spring 2019 and Spring 2020. This data consists of video recordings of children, caregivers, engineers, and researchers participating in facilitated group sessions. Video recordings of family groups and wider classroom settings were collected using stand-alone cameras at each session. Video recordings ranged from 64 min to over 75 min, with an average of approximately 68 min of video data per family. These recordings captured the initial problem identification and solution ideation phases of the engineering design process. All video recordings were initially transcribed using an automated service, with full transcription and cleaning conducted by the first author to ensure accuracy.

1.5. Analysis

Conversation analysis (Clayman & Gill, 2012; Gee, 2015) was conducted to examine and scrutinize the processes, actions, and phenomenon unearthed during the first stages of transcript review and analysis. Gee (2015) described the two primary steps of conversation analysis as (a) the identification of forms of discourse and (b) the description of how those forms of discourse are constructed and delivered to ultimately influence subsequent dialogue or behaviour. Through this analytical process, forms of dialogue and statements between caregivers and children were identified first (i.e., posing questions). Next, responses in further dialogue or behaviour to the dialogue and statements were identified, using directional arrows and notes within the transcript to map such conversation "chains" and their subsequent impact. An example of this process and identification of conversation sequences or "chains" can be seen in Fig. 1. In this example, the use of questions and restating earlier conversation by the caregiver spurs complex, creative thinking by the child, with arrows and notes providing a visual representation of the connected nature of conversation within the brainstorming and ideation process of this dyad. The inclusion of time stamps (e.g., 15:07) further highlight the connection to prior ideas. The instance at 20:42 is an example in which the caregiver brings forth a previous statement made by the child, which shifts the conversation from a robotic arm that would unfold with a press of a button to thinking about how to use string instead.

This process was undertaken by the first two authors. Upon completion of conversation analysis of each transcript, review meetings were held to discuss analysis of each dyad and identify commonalities and continuity of process, such as the identification of specific forms of communication or dialogue used by caregivers within certain portions of data (i.e., targeted questioning or use of previous experiences). Further, where analytical discrepancies arose, discussion and reevaluation were conducted in order to reach consensus, such as determining the type or nature of questioning directed at children from caregivers. Through discussion of such questioning and both the prior and subsequent dialogue, the researchers came to consensus of how to classify such impact. Results of this form of conversation analysis revealed ways in which caregiver involvement in the problem identification and solution ideation process shaped the creative, independent thinking of children and the development of their own innovative engineering solutions.

2. Results

In this section, we present analytical findings from the problem identification and exploration conversation that took place between children and their caregivers in the out-of-school engineering program described above. All participating families presented instances of interaction between children and adults that allowed for careful examination of the ways that caregivers might guide or challenge

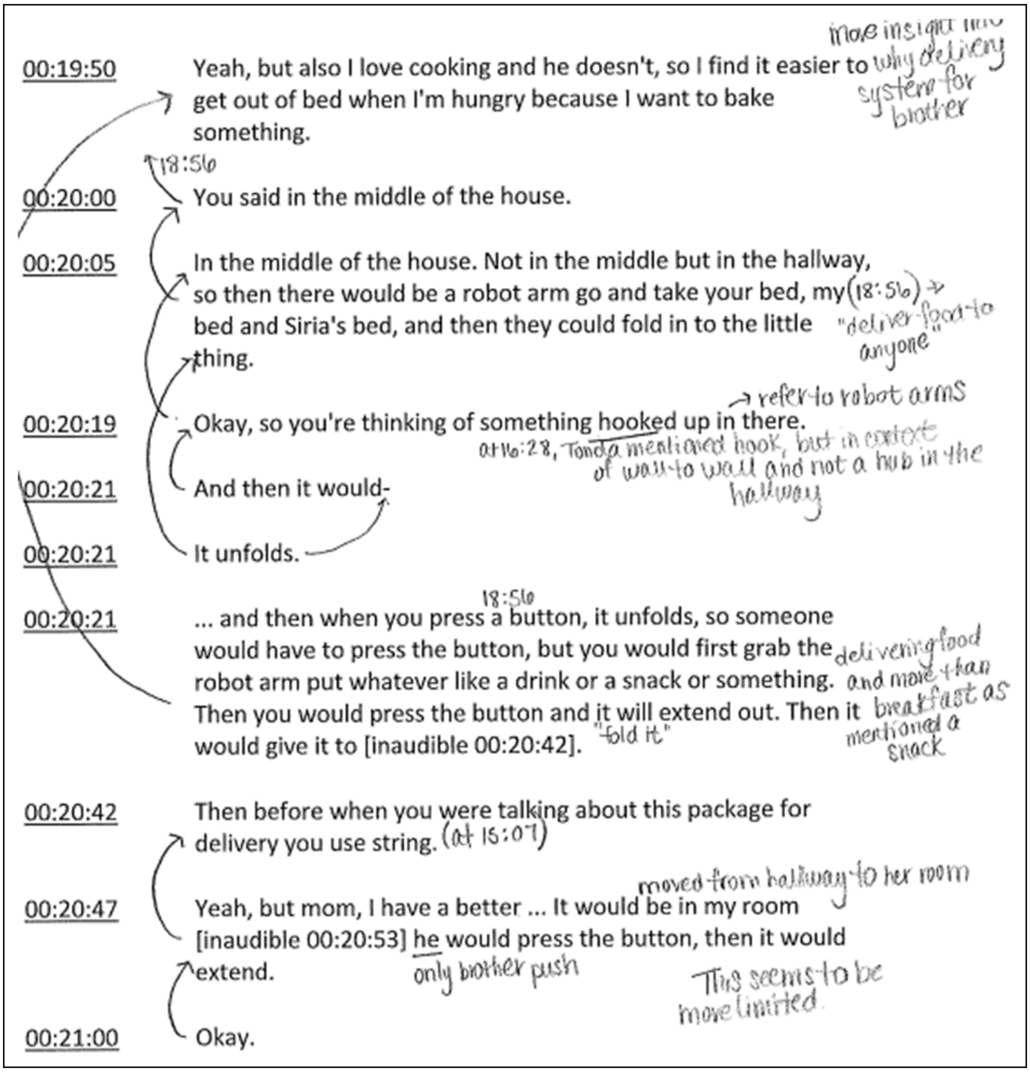

Fig. 1. Example of conversation analysis process.

their children's identification of a problem and potential solutions. Results demonstrate ways that child ideas, creative thinking, and thinking skills (i.e., problem solving, decision making, organizing information) regarding various solutions were shaped by caregivers' involvement through four predominant forms of dialogue. These dialogic forms include (a) directive questioning, (b) restating/reframing, (c) idea blending, and (d) shared experiences. We present each form of dialogue employed by caregivers and include relevant examples from participating dyads that are representative of the available data.

2.1. Directive questioning

The use of directive, nuanced questioning was one dialogic form often employed by caregivers participating in the program. Caregivers were observed using targeted questions and inquisitive response language to varying degrees. In general, the use of directive questioning was used to support or propel child thinking, follow up on their own creative ideas, garner deeper/more complex thinking, and demonstrate encouragement or support for an idea. In other cases, direct questioning was used to reject child thinking and creativity. In these cases, the use of directive questioning as responses to independent ideas generated by children redirected entire projects and centred the thinking and leadership of adults instead of children. An example of *supportive* directive questioning comes from Tanya (caregiver) and her daughter Cindy. In this example, we observed use of purposeful questions and inquisitive language regarding familiar objects and behaviour to Cindy to support her identification of an engineering problem.

2.1.1 Tanya: Okay. Then what other thing ... I've noticed that you spend a lot of time, if it's your individual time in your room doing things with Amy [doll], doing things…

2.1.2 Cindy: Yeah.

2.1.3 Tanya: So, is there- when you're working on those types of projects, is there anything that would make it easier for you or quicker or less frustrating?

2.1.4 Cindy: Something to clean my doll house.

2.1.5 Tanya: Okay.

2.1.6 Cindy: Like the room for Amy.

2.1.7 Tanya: What do you mean by cleaning it?

2.1.8 Cindy: Like organize it. Because when I get into a deep project I take like everything out of one room and then I have to put everything back in and it takes a while.

2.1.9 Tanya: Okay. If you think about that in a larger term, if you got like the ... then you figure that out for Amy's dollhouse. You probably could expand that to a regular size house. Right? Okay, so what's…?

2.1.10 Cindy: Amy's dollhouse would be the prototype, but that's a bookshelf size though.

In this example, nearly all of the language directed from Tanya to Cindy is in the form of questions. Tanya begins by stating her observations of Cindy's time and behaviour (Line 1.1), mentioning her noticing of Cindy playing with her doll, who she has named Amy. The use of specific, directive questioning by Tanya (see Line 1.3) provided Cindy with context and instruction regarding how she might think about identifying her own problem or challenge to address. Further direct questions from Tanya (Line 1.7) spurred more detailed thinking and decisive decision making from Cindy in her explanation (Line 1.8), and also provided Cindy with a concept of modelling to be built at scale later. Cindy even used the term "prototype" in Line 1.10. Use of questioning in this way demonstrated support for and centring of the child's own thinking and conceptualization by providing parameters to bigger concepts and allowing Cindy's responses to questions to dictate subsequent dialogue.

An example of *hindering* directive questioning use with more negative outcomes or a deficit approach to child creative thinking can be seen in Bob (caregiver) and Jackson (child). In this case, Bob reiterated the program steps and process outlined earlier by the researchers, to which Jackson responded by generating two of his own, independent ideas – a "cracked cell phone" and fixing a car. In both instances, Bob responded with questions rejecting Jackson's idea and reorienting his thinking towards a local community problem identified by Bob.

2.1.11 Bob: Cracked phone? What are you going to do with a cracked phone? How are you going to engineer a cracked phone?

2.1.12 Jackson: It's like if someone dropped it and it busted on the floor, it has to be fixed…

2.1.13 Bob: How about walking across the street? Like, how about um, if you wanted to walk across [local street]? You want to build a tunnel that goes over [local street] so you don't have to walk across the street, you can walk over anytime you want and the cars won't mark you. How about something like that?

2.1.14 Jackson: No. I want to do a cracked phone…

2.1.15 Bob: What kind of cracked phone?

2.1.16 Jackson: Maybe an iPhone 11…

2.1.17 Bob: And what are you going to do with it? Who would be your problem solving, for that?

2.1.18 Jackson: How you fix it.

2.1.19 Bob: Now come up with something else.

2.1.20 Jackson: Why?

2.1.21 Bob: How about the bridge idea?

2.1.22 Jackson: I want to do a cracked phone.

2.1.23 Bob: No. That's not normal.

2.1.24 Jackson: How about cars?

2.1.25 Bob: What about it?

2.1.26 Jackson: It has to be fixed, like, put gas in the engines

2.1.27 Bob: Yeah. That's what's called a mechanic.

2.1.28 Jackson: Yeah. I could do that.

2.1.29 Bob: What are you going to do? Engineer cars?

2.1.30 Jackson: Mm-hmm (affirmative).

2.1.31 Bob: How about we go with the bridge idea?

The use of questioning in this way revealed the nature of the interaction happening, its intensity, and valence. Through the use of "response as questions" as in Line 1.11, Bob revealed his own perspective and thinking around the ideas that originated with his son and his belief that they would not meet the parameters of the program. This was supported by the provision of directions from Bob, in response to Jackson's suggestions and ideas, as in Lines 1.17 and 1.29. Both examples demonstrate Bob's immediate reaction to Jackson's ideas, one about fixing a broken phone, the other a broken vehicle. In both cases Jackson offered suggestions and demonstrated independent thinking and his own method of organizing and interpreting information about relevant challenges which Bob chose not to explore or probe for further thinking or details. Instead, a completely different concept was provided and used to redirect Jackson's thinking in a specific direction.

2.2. Restating/Reframing

Conversation analysis also revealed the frequent use of restating dialogue and caregiver reframing of child ideas, original thinking, and creative suggestions. An example of the dialogic tactic of restating and reframing of information or creative ideas can be found with Mac (caregiver) and Walt (child), particularly as they engaged in brainstorming solution ideas for their identified problem, which was their two cats fighting with one another. To prevent this, they chose to pursue development of a new collar that would make noise or react when the two cats were near one another. In this example, we saw Mac take Walt's ideas and creative thinking and reinforce them through restating Walt's thoughts and ways of organizing information to provide further clarity and explanation. Mac continued to think about, restate, and discuss more practical elements of the project and the actual materials they might need. Walt generated large, complex ideas - encouraged by but continually reframed and grounded by Mac to think about more achievable elements.

2.2.1 Mac: So, what is this?

2.2.2 Walt: This is going to be something that actually spins with the movement.

2.2.3 Mac: Like a little motor to spin it?

2.2.4 Walt: Yeah, so this gets charged faster when the cat is moving a lot.

2.2.5 Mac: Oh, I see. So, it would be a rechargeable battery. So, we do not have to charge it, or replace the battery, the movement, it is like a kinetic charger. It would do more charging if there was more movement.

2.2.6 Walt: [Cat 1] would run away which would charge it.

2.2.7 Mac: So, movement will charge. Okay.

2.2.8 Walt: And since [cat 2] loves to jump around and move anyways, his recharges lots more so both of these are able to get the... So this is [cat 2] right?

2.2.9 Mac: Well this would be both of theirs, because I think it would be the best start to just make two that are identical, and then we will worry about specialization for each one. Because if we found one configuration that worked for all of the cats, and maybe we found a way to turn off the speaker sometime, we could do it for more than just our two cats.

Mac purposefully restated ideas and concepts raised by Walt, as seen in Lines 2.3, 2.5, and 2.7. In this conversation chain, Walt articulates his thinking by referencing "…something that actually spins with the movement," which Mac then restates as "a little motor to spin it." Walt then uses this reframing to clarify his thinking around the use of spinning to charge the device, which clarifies for Mac that Walt is, in fact, thinking of a kinetically charged battery. We often observed Mac working to reframe or restate (as in Line 2.7) Walt's ideas to help in his explanation of the idea they've selected. This allowed Walt a platform to discuss in real-time the various innovative ideas that come to his mind and how they might work as in Line 2.4 or Line 2.8. By reframing children's language in this way, caregivers like Mac are provided with teaching opportunities in which they might turn informal, everyday language into more formal or technical terms.

2.3. Idea blending

Through conversation, the blending of ideas and collaborative mentalities were exhibited. Caregivers and children were observed completing each other's thoughts and actively working to blend elements of different ideas to create novel or more functional solution ideas for the identified problems. The first example is from Kim (caregiver) and Mary (child) as they are discussing how to create an alert system when there is mail in the mailbox. The intent was to minimize the number of times Mary's grandfather checks the mailbox. The transcript begins with an initial question posed by Kim.

2.3.1 Kim: What kind of alert would we need in the house?

2.3.2 Mary: Oh, we should install in the house that reminds you from inside. It could be connected to the mail…

2.3.3 Kim: Or would the mailbox…like blink or something.

2.3.4 Mary: No. It could be like the mailbox is outside and the living room, so there should be something in the living room and then something connected to the mailbox that is like synced. So it can like beep when there's…But how would it know that there's something in the mailbox?

2.3.5 Kim: Oh. That's the problem.

2.3.6 Mary: We didn't think about that. But I was going to say before we thought about that, they're synced together. And then you like see there's something inside the mailbox that blinks. And then when somebody puts something…make like a mailman or mail lady know that there's a switch or something.

2.3.7 Kim: What if there was something with a lid or the mailbox itself was a switch?

2.3.8 Mary: Yeah. The lid is the switch.

[Approximately 34 min later. Mary is sketching out her plan.]

2.3.9 Mary: Oh, we drew the little receiver inside, right? On the window sill? And then there would be a light that would…

2.3.10 Kim: I think a light would be good

2.3.11 Mary: A little light right here…Well, I'm just going to put beep too. It beeps, so I'm going to put beep.

2.3.12 Kim: Maybe it would just beep a couple of times

In this example, we observed Kim suggest an alert system on the mailbox that would blink in Line 3.3. Alternatively, as exemplified in Line 3.4, Mary disagreed and considered an alternative way to alert her grandfather, namely, there would be something in the living room that would beep. Yet, in Line 3.6, Mary took up Kim's idea as she noted that there would be "something inside the mailbox that would blink," subsequently developing a novel, innovative idea that combines both their thinking. We continued to see the blending of their ideas as to whether the alert system should blink or beep 34 min later as Mary in Line 3.11 included both ideas in her drawing. In addition, for the first time, we observed Kim reinforce Mary's idea of an alert system that beeps (Line 3.12); thus, supporting the independent thinking and problem solving thought processes demonstrated by Mary while simultaneously working to collaborate and creatively combine their ideas in such a way that met their agreed upon problem and goals. This family's dialogue demonstrates how the development of creativity is not entirely individualistic, but can be understood as a collaborative or shared endeavour.

A second example of idea blending comes from Cindy (child) and Tanya (caregiver). Having earlier selected the challenge of assisting bedridden or mobility-impaired individuals, this family began to discuss specific details about various movement mechanisms for their identified solution, a built-in delivery system or robot. Suggestive language and collaborative back-and-forth between Tanya and Cindy resulted in the arrival of the shared understanding that their prototype requires manoeuvrability, the ability to move independently, and navigate uneven surfaces. In this case, an idea posed as a suggestion (Line 3.13) from Tanya began the conversation.

2.3.13 Cindy: So, it would be the robot moving, it would ... and then the arms. It would have two arms, one for a snack, and one for a drink. I think the one for the snack would have to be a little bigger than the one for the drink. Then it would be ... The one for the snack would probably have to be this big and then it would roam around on the ground. And then it would deliver it to the person.

2.3.14 Tanya: If it was rolling then that sounds like wheels...

2.3.15 Cindy: Yeah, wheels.

2.3.16 Tanya: Then have you ever seen ... I doubt you've seen a tank, but have you ever seen a bulldozer? Let's think about if it's going from our kitchen, there's a tiny little lip that goes down to the hallway. It's like a baseboard, right?

2.3.17 Cindy: Yeah.

2.3.18 Tanya: I'm wondering if they should be the wheels. If you've seen a tank or a bulldozer, it's like it's got wheels, but it's got a strip that goes around it, so it can go up hills. If you have stuff all over your room, it can climb over your clothes.

2.3.19 Cindy: It would have to be able to go up stuff and not get stuck on the carpet, so it's like this.

2.3.20 Tanya: You have to figure out the wheels and I don't know if you can visualize, if you've seen a bulldozer or…

[Two minutes later, conversation around mobility resumes with Cindy more focused on aesthetics]

2.3.21 Tanya: Is that the most practical? Cute, but not…

2.3.22 Cindy: I want it to be cute. I want my robot to be cute.

2.3.23 Tanya: No, and you can do that. I'm thinking more like functional. I'm thinking something that looks functional, like even if it were a box then you could, like you have clamps to keep everything secure, but then if things spill on their sides…

2.3.24 Cindy: It should be like a tray, and then with wheels on the bottom, so it can go over things, and then with sides, and then with a clamp for a drink that you just set the snack on.

Suggestive language and concepts initiated by Tanya in Line 3.14 resulted in Cindy concluding that the robot would have to have manoeuvrability and mobility across various surfaces, including Tanya's original example of "going over" clothes and items on the floor. This sequence demonstrates ideation language from caregiver towards the child regarding the mechanism movement - with Tanya suggesting the specific capabilities that the robot would need for various terrain (Line 3.18) to which Cindy responds affirmatively (Line 3.19) and ultimately makes her final decisions. We observed Cindy take up Tanya's suggestion of bulldozer like wheels and the functionality of manoeuvreing over uneven surfaces, combining that with her original ideas of carrying food or beverages in Line 3.24). Through this dialogue we get a clearer picture of how Cindy is envisioning the project, facilitated by suggestions and ideas posed by Tonya.

2.4. Using shared experiences

The fourth and most prolific dialogic form to emerge from the data centred around the use of shared experiences and/or familiar contextual references. Caregivers were often observed using familiar places or experiences they have had with their children to help frame thinking, spur further ideas, assist in contextualizing problems and organizing information, or guide the direction of projects. This method was employed by every family included in the current study. For example, Kim (caregiver) and Mary (child) employed the use of their family home environment and equipment (Line 4.4) and shared understanding of space to discuss their ideas. The use of real-life examples and suggestions from Kim provides context and seems to help clarify the concept for Mary, contributing to her ability to process information and problem parameters.

2.4.1 Mary: The thing inside would beep or make some kind of noise or something like that. Then put it in the living room like into the wall or something.

2.4.2 Kim: We're going to get into major construction.

2.4.3 Mary: In the living room like a little thing.

2.4.4 Kim: You know how there's that thermometer that sits on the counter? Do you know how it has the remote? Are you aware that goes, that we have hooked on the garage?

2.4.5 Mary: Oh, yeah. Like they're synced, so you do something.

2.4.6 Kim: Right. I wonder if that would be something like that.

Bob (caregiver) and Jackson (child) exhibited the use of familiar places and contexts in the local community to frame their conversation and engagement. In this example, Bob worked to use a place (the park) near their home that Jackson was very familiar with and could help clarify his thinking and identification of problems to address.

2.4.10 Bob: So, we have to find another idea of something that we can do, we come up with. I got a really good one...

2.4.11 Jackson: What?

2.4.12 Bob: How about we build…because we go to the park a lot… How about we build something that the squirrels can play in, or the little chipmunks and stuff can play in?

2.4.13 Jackson: Oh, like a hatch?

2.4.14 Bob: Something we can build with tubes in it, maybe a ball, they can run inside of it and play…put that pencil down… Something they can play in. Is that a problem?

2.4.15 Jackson: Yeah.

2.4.16 Bob: Don't you see them running around. Or we can build something and we can put inside of a tree, or hang it on a tree, so a squirrel can…you know you see 'em run around all the time.

2.4.17 Jackson: Yeah.

4.18 Bob: Something that they can play with, something that has a wheel to it.

Use of familiar home context and family pets as a framework for an engineering challenge and foundation for creative thinking was employed by Mac (caregiver) and Walt (child). The example below shows Mac working to articulate an idea option developed within the familiar home environment that enabled Walt to think in greater detail and organize information needed to complete their prototype.

2.4.19 Mac: So [Walt], you know how the cats at home do not like... and sometimes [cat 1] bullies [cat 2]?

2.4.20 Walt: Well, not really bullying just...

2.4.21 Mac: Chases around a little bit around the corners. So, what if, they each had a collar. And on the collar was a little electronic device, a little speaker, and a little distance detector. Where if they were too close to one another, they would create a little alarm or something on the speaker that would cause the cats to move away from each other. Do you like that idea?

2.4.22 Walt: Yeah, wait it is kind of like a shirt with electronics?

2.4.23 Mac: Kind of, but a collar.

In all five families included in this study, the use of shared spaces, materials, and experiences were employed to influence where certain problems they might address are found, as well as assist in children in framing a problem or challenge in their minds. We see the use of familiar places and common experiences (e.g., going to the park in Line 4.12) used in conversation to guide what children think of as problems, how and when they might occur, and to spur their own thinking and creative solution ideas. In the case of Mary and Kim, we saw Kim reference a familiar object in their home, a counter thermometer, to help Mary understand the remote signal concept she was thinking about. This spurred Mary to reference things being "synced" and fostered further dialogue around a signalling device. Similarly, the use of issues between family cats bullying one another helped Mac engage Walt in thinking about device designs and functions that may help their cats maintain distance. This familiar space and experience with fighting cats provided an entry way for Walt to ask questions and think about various components (e.g., electronic sounds and lights).

3. Discussion

The primary aim of this study was to contribute to greater understanding of ways caregivers in out-of-school contexts might shape the creativity, innovation, and independent thinking of children during the engineering design stages of problem identification and solution ideation. These represent points in engineering practice in which creativity and innovation play critical roles (Daly et al., 2014). In line with previous findings by Van Voorhis and colleagues (2013), we found that several primary methods of dialogic engagement were employed by caregivers that shaped children's creative thinking and innovation in relation to initial stages of the engineering design cycle – identifying and problem and creative solutions. We identified four dialogic forms that caregivers employed that shaped the independent and creative thinking of their children. These dialogic forms were observed across all families included in this study and were predominantly positive in nature. That is, the forms of conversation used by caregivers more often than not supported and encouraged their children's thinking, engagement with STEM concepts and the engineering design cycle, and exploration of innovative solution ideas (Hassinger-Das et al., 2020). Some forms of dialogue, however, were at times employed in a more negative manner that was seen to stifle the independent thinking of children and ultimately, their use of creativity and innovation. Namely, the use of directive questioning and inquisitions counter to children's original thoughts and ideas were found to be used as a way of maintaining control or an adult-centric form of engagement with the program. Collectively, however, caregiver engagement through dialogue and conversation appeared contributive in various ways to their children's engagement and thought processes around engineering design problems and solution options (Benjamin et al., 2010; Callanan et al., 2016).

We consider our findings around caregiver directive questioning to be noteworthy. Specifically, that the nature of questioning truly matters. Specific questioning from caregivers provided greater context, information, or clues to children without telling them exactly what to do. This form of conversation and engagement provided children with an understanding of their caregivers' perspective or line of thinking without being told what to think. The successful use of questions to motivate and support more complex and innovative ideas in children lends support to previous research noting questioning as a motivational tool and key to general content learning (Black, 2001; Haden et al., 2016). Further, how and when questions were employed by caregivers appeared to help spur deeper thinking in children and encourage greater creativity by almost "forcing" them to articulate their thoughts and the process they used to identify various solutions. This may be understood as a subsystem within a child's learning ecosystem, that contributes to the shaping of their self-concept and understanding within novel content areas and cognitive development (van Geert, 2011). Consistent with other studies, pedagogical questions from adults seemed to prompt deeper and more complex thinking, as they provided leeway for greater exploration of ideas and broader learning than direct instruction (e.g., Fivush et al., 2006; Yu, Bonawitz, & Shafto, 2019). Questioning can also be seen as a hinderance, however, in that it calls into question the validity of children's ideas or can be used to reorient child thinking to the ways of the caregiver. As seen in certain cases in this study, non-pedagogical questions (i.e., rhetorical) were employed by caregivers in a nature more akin to direct instruction. This mode of direct questioning provided immediate redirection and shifts in projects but limited their children's own exploration and further learning (Yu, Landrum, Bonawitz, & Shafto, 2018). Use of questioning in this way appeared to bring adult thinking and ideas to the fore, rather than listening and purposefully focusing on child-developed concepts or thinking. It is possible that this form of questioning and caregiver-child interaction is derived from more traditional forms of instruction, which may be the only experience of participating caregivers. As noted previously, practical instruction and focus on core content and standards places parameters on the value of creativity and innovation in schools (Page & Thorsteinsson, 2017). Caregivers themselves demonstrate this form of problematic practice and provide a more directive, leading method of questioning that may have the aim of getting things done, rather than encouraging independent and creative thinking. This may ultimately limit child agency and independence in engaging with the tasks or concepts at hand, subsequently limiting their own ideation and the need for or use of creativity.

The use of restating or reframing of information by caregivers were also found to be impactful engagement tactics. This form of dialogue appeared to provide clarity and context in thinking for children. Further, this tactic remained a supportive method for inserting adult knowledge and experience, without diminishing or altering the independent thinking of children. Glăveanu (2018) argued that adult understanding and appreciation for creativity in children is reflected via their interactions which can then shape their children's use and development of creativity. The reframing and restating of information by caregivers represent this form of interaction, working to blend adult understanding and appreciation for creative thinking in children through their reiterating and validating of child creative ideas. Kaplan & Garner (2017) suggested that this form of engagement by adults represents psychological and social-cultural perspectives that compose elements of complex dynamic systems of development. This method of interaction can contribute to children's identity and self-concept as independent thinkers and "do-ers" of engineering, while still providing autonomy in creativity thinking. Caregiver use of reframing also appeared as a medium through which child ideas might be grounded in reality or connected to concepts or ideas that are similar and realistic, helping frame the independent thinking, learning, and retention in real time (Ornstein et al., 2004). This form of adult dialogue and active listening continued to support children's original concepts and creative thinking around problem solutions. As noted by Weger Jr, Castle, and Emmett (2010), reflecting or restating a child's idea or thinking through paraphrasing or reframing can help make clear that the caregiver understood what the child was trying to say and validate their thinking and ideas. At the same time, this conversation tactic provided a pragmatic framework from which they might brainstorm solutions, materials, next steps, or look for inspiration from existing ideas and concepts.

Study results also demonstrated how collaborative conversation and idea blending contributed to and fostered creative thinking and novel ideas or concepts that can be taken up by children. The purposeful positioning of children supported the equitable exchange of ideas and the blending of concepts. Caregiver use of this dialogic method echoes Eccles and colleagues' (1993) positing that the beliefs and perspectives of caregivers applied via dialogue and interactions can facilitate or foster certain behaviors. This method of idea blending shows the power that comes from preexisting, intimate familial relationships and how those can be leveraged to work as a team, understanding and learning from one another. Indicative of the nature of complex dynamic systems operating in a developmental context, this collaborative interaction shows how subsystems and factors a child is subjected to can contribute to the development of novel and independent thinking, concurrent to children's self-concept, creativity, and problem-solving self-efficacy (Thelen & Smith, 1998; van Geert, 2011). Further, through that close social relationship came the blending of ideas or concepts resulting in divergent thinking and the creation of something novel and equally interesting and applicable to both adult and child (Ritter & Mostert, 2017). Similar to previous research, the demonstrated idea blending and collaborative learning contributed to children growing their understanding of concepts and practices (Barak, 2017; Ben-Zvi Assaraf, 2011). It was through dialogue and a back-and-forth of ideas and thinking introduced through interaction with their caregivers that created more meaningful learning experiences and the creation of new, creative ideas and fostered critical thinking and problem solving (Newbill & Baum, 2013). The collaborative, social aspect of the learning environment was found to be central to the engagement and learning process experienced by both children and caregivers.

Results also demonstrated the significant influence that the use of familiar contexts and shared experiences have on caregiver-child conversation and, ultimately, the thought processes and creativity demonstrated by children. The recollection of familial engagement, experiences within out-of-school environments, or the use of familiar spaces to help spur thinking and engagement was used often. We observed this across all participating families with some using neighbourhood environments and others using family homes and the needs therein of specific family members as conduits for fostering collaborative and fluid dialogue, idea sharing, and interaction between caregivers and children (Callanan et al., 2016; Haden et al., 2016). The ubiquitous use of this tactic lends support to the argument that out-of-school contexts allow for a more tangible, and applicable, thought process in line with previous research by Rogoff et al. (2016) who noted a marked blending of familiar contexts and experiences from home or community with concepts and practices being learned. Use of known environments and shared experiences helps to take really big, creative thinking often originating from the child and hone in on something that is not only achievable, but also useful and relevant to themselves or others in their immediate environment.

While distinct from one another in certain ways, each dialogic tactic highlighted in the current study serves to demonstrate caregiver influence on children's engagement with the engineering design cycle. Previous engineering education research has shown that the design stages of problem identification and solution ideation, specifically, represent fertile ground for the development of independent, innovative thinking and creativity (Cropley, 2015; Daly, Mosyjowski, & Seifert, 2014). As ideas serve as the bond between creativity and innovation, the influence of caregiver interaction on child ideation as seen through direct questioning, restating, blending of concepts and ideas, and use of shared experiences or places ultimately fosters or constrains children's use of creative thinking. This impacted use of independent, creative thinking amongst children as they identify problems and generate creative solution ideas holds implications for their subsequent engagement in other stages of the engineering process, including research, testing, and redesigning (Daly et al., 2012). Further, caregiver dialogue and interactions that support child creativity and independent thinking demonstrated a correlation with important cognitive skills such as problem solving and information processing (Newbill & Baum, 2013). Identifying a relevant challenge or issue, processing key information, and creating ideas to solve them represent key steps in the engineering design process. This study lends further empirical insight into how children's ideas are developed and the nature of external and contextual caregiver influence on their ideation process. Further, findings of this study demonstrate the relevance and utility that can come from the engagement of caregivers in the engineering design cycle, specifically in out-of-school contexts. The use of conversation regarding shared experiences and familiar locations, in particular, was shown to be an applicable and effective method for expanding creative thinking in children.

Results of this study support previous research demonstrating that through dialogue and conversation within caregiver-child interactions, caregivers do in fact wield particular influence, positively and sometimes negatively, on the creative, innovative, and independent thinking of children. In addition, findings show how this influence occurs through distinct and often implicit forms of verbal interaction and lived experience. Data garnered from this work provides valuable insight into ways caregiver engagement and out-of-school learning environments support (and possibly detract) from the fostering of creativity and innovation in children during critical initial stages of the engineering design cycle. The examples of dialogic tactics used by caregivers in this study also contribute greater insight into ways family and community engagement interventions or programs might evolve. For example, knowing that the nature and valence of caregiver questioning impacts children's thought processes and engagement, the incorporation of more specific instructional and dialogical guidance for caregivers may be included to facilitate children's independent innovation. The purposeful positioning of caregiver and child within their home environments and encouragement to use familial funds of knowledge, too, may support expanded creative thinking in children, as well as the relevance and applicability they find in engineering concepts and practices.

As is typical with studies of this kind, limitations exist, are acknowledged, and offer opportunities for future investigations. One limitation of this study is the limited number and homogeneity of caregiver-child dyads. More nuanced information may be identified by including more diverse family structures, intersectional identities, and out-of-school contexts in which families may engage in creative thinking and utilize innovative, culturally relevant design practices. This study is a part of a larger, ongoing research project that has continued to collect and analyse data that centers caregiver engagement and out-of-school environments within engineering programming. We now have a greater quantity of diverse families from whom our future research might draw insight and develop understanding of how they engage with engineering design, materials, and with one another. Further, future research should continue to explore the forms and nature of caregiver-child interactions and dialogue, particularly within out-of-school contexts. Focused studies that hone in on particular types of dialogic tactics (e.g., use of questions, timed questions, etc.) could be undertaken to further evaluate how particular conversational forms influence children's understanding and engagement with their own creative, independent thinking during specific activities. Such investigations may shed further light into ways that conversation and dialogue concurrently support key cognitive skills and abilities in children like mental flexibility, critical thinking, and problem solving. This information may prove particularly useful in the development of future training or professional development programs for both educators and parents, providing best-practices in family engagement or adult-learning, that centers the unique role and influence of caregivers. Finally, longitudinal investigations building from the findings of the current study would illuminate the long-term impact that caregiver engagement and conversation have on children's perceptions of creativity, innovative thinking, and their comfort with and use of such practices in other areas of their lives or education.

4. Conclusions

In seeking answers to our research question, valuable understanding is gained of dialogue enacted by caregivers in out-of-school contexts and the way it influences child creativity, ideation, and engagement. We provide insights into specific dialogic methods caregivers employed while engaging with children in out-of-school environments through the engineering design cycle. How such engagement and specific conversational tactics impact children's creative thinking and use of innovation was also illuminated. In so doing, we support the argument that the nature of caregiver engagement and the fostering or hindering of creativity and innovation through conversation ultimately influences children's own engagement and application of concepts (Van Voorhis, Maier, Epstein, & Lloyd, 2013).

In the context of STEM and engineering education, this influence on creative thinking and innovation holds particular significance as they remain critically relevant skills within such disciplines (Cropley, 2015). Concurrently, implications for the development of targeted interventions or programming centring family and community engagement are garnered. Findings from this study provide more nuanced information regarding the type of support or training one might provide to caregivers and methods they might employ in engaging in STEM dialogue with their children. Further, the practices highlighted in the current study provide an opportunity to push back on the dampening of creative thinking or self-concept in children as they age through elementary school. Programs and practices such as this offer a unique way for children to think about themselves and their environments in a way that fosters their creativity and self-efficacy in creative thinking. Through close observation of the timing and nature of caregiver questions or their use of well-known environments or objects, we begin to better understand how dialogue is mobilized to uniquely influence child creativity, learning, and engagement in STEM disciplines.

CRediT authorship contribution statement

Peter Knox: Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Amber Simpson:** Conceptualization, Investigation, Formal analysis, Writing – review & editing, Supervision. **Jing Yang:** Investigation, Writing – review & editing. **Adam Maltese:** Conceptualization, Writing – review & editing.

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