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Caregivers' Multiple Roles in Supporting their Child through an Engineering Design Project (Fundamental)

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Abstract

Caregivers are one of the most significant influences in their children's engineering engagement at a young age; however, the roles caregivers can play in supporting their children is less understood. Employing an intrinsic case study on a five-month engineering program conducted in an out-of-school context, we illustrate the multiple and different roles that three caregivers enacted, and the contextual factors of the program that influenced and shaped their role enactment. We observed 12 dynamic, complex, and evolving roles that caregivers endorsed to support their child throughout the engineering design process. These roles were situated within preexisting rules and expectations as caregivers while also developing an understanding of the rules and expectations of an engineer through their social interactions with volunteer engineers and makers. This work contributes to our understanding of how to create environments to enable caregivers to best support their children's STEM learning process.

Introduction

The importance of engineering practices and processes for young children in elementary grades has recently gained traction [1]. Yet, the preparation and support of prospective and practicing teachers in supporting these engineering practices and processes for young children in more formal learning environments are lacking [2], [3]. Likewise, caregivers may not have a thorough understanding of this field, portray common misconceptions of engineering, and are less likely to know the roles they can play in developing and supporting their children's learning experiences as engineers in out-of-school contexts [4]-[6]. This contrasts the roles that caregivers are able to play in math and science activities [7]-[9]. For example, caregivers are able to articulate and exhibit behaviors, actions, and roles in which they use mathematics in everyday contexts with their children such as creating and staying within a prom budget, charting baseball stats, home improvement projects, and cooking [10], [11]. In this paper, we add to this scholarship base by illustrating the multiple, yet different roles that three caregivers enacted over the course of a five-month *engineering* program conducted in an out-of-school context. Our research question was as follows: What roles do caregivers enact with/for their child during a family-based engineering design project? Subsequently, we considered the contextual factors of the program that seemed to influence and shape caregivers' role enactment. Results of our work provide further evidence of the impact of caregiver inclusion in the process of learning engineering, not only on the student(s) involved, but also on caregivers. Findings support the benefit of incorporating familiar adults into the engineering learning process, while providing distinct avenues by which caregivers might acknowledge and value their own unique contributions, particularly within a STEM field that is often misunderstood [4]. Further, the nature and context of learning environments was found to impact caregivers' adoption of various roles and speaks to the value of purposefully designed and supplied environments to facilitate learning.

Related Work

Caregivers play an important role in shaping their children's STEM experiences, dispositions, identities, interests, and practices [12]–[17]. For example, Vedder-Weis [17] highlighted how family negotiations of roles and recognition within everyday interactions around science positioned one child as the science person (i.e., "good" science participant) and another child as the science antagonist (i.e., uncooperative or a hostile science participant). As such, caregiver-child relationships and interactions serve as a resource in their children's learning ecology, a perspective that "foregrounds the fact that adolescents are simultaneously involved in many settings [18, p. 199]."

The studies on specific roles that caregivers enact in informal learning environments to support and promote the development of children's STEM interests and understanding of concepts is "in its infancy" [19, p. 87]. Yet, the actual identification or name of the roles and their descriptions are not consistent. For example, [20] described the role of *cheerleader* as "did not always have a complete understanding of their child's project, but were supportive emotionally of the child through the child's exploration and project completion" (p. 9). A similar description by Yu et al. [21] was labeled as *spectator*; a caregiver that provides encouragement and help when needed. Another difference in role identification was based on the approach and perspective of the research study. For example, [4] defined roles by the ways that caregivers promote awareness and understanding of engineering (e.g., engineering career motivator) while [22] considered caregiver roles through their interactions with children and facilitators during traditional and digital fabrication activities.

Regardless of the differences in role names, descriptions, and approaches, looking across the scholarship on caregiver roles, it is clear that there are multiple roles that caregivers enact and describe when supporting their children in various STEM-related learning environments [7], [20], [23], and these roles can be viewed as a continuum from providing more assistance and hands-on support (i.e., active) to less assistance and hands-on support (i.e., passive) [8], [20]. In addition, these multiple roles do not necessarily require any expertise in a particular concept, topic, tool, and/or discipline [23]. Research illustrates that involving caregivers as a part of their children's learning may actually lead to shifts in their roles as they and/or their children become more familiar and comfortable [21], [23]. For example, [21] noted a change in caregivers' roles as their children became more familiar with a coding kit. When first engaging in a coding kit, caregivers enacted roles that facilitated the learning experience such as setting up a kit (i.e., *logistics supporter*) and/or developing ideas together (e.g., *collaborator*). As children became more familiar with the coding kits, caregivers enacted roles that provided their children with more freedom to explore independently (e.g., *spectator*) and with suggestions and questions to guide their play (e.g., *scaffolder*). As such, we agree with [8] and [24] that the roles that caregivers enact are grounded in their awareness and/or knowledge of their children.

Theoretical Grounding

In this study, the term *role* is defined as a set of social behaviors that are characteristic of individuals within a given environment and emerge through our interactions with others [25], [26]. As the term suggests, individuals are provided with a "script" for the parts they play (i.e., theater metaphor). In the context of this engineering program, a caregiver's role as parent or grandparent or aunt/uncle or guardian is enacted in their interactions within the informal learning environment. Likewise, it is likely that caregiver's do not identify themselves as an engineer; therefore, caregivers do not possess a basic set of rules and expectations to define this role. As such, there are several perspectives or schools of thought regarding role theory. This study was guided by symbolic interactionist role theory [27], [28]. This perspective views roles as dynamic, shaped and negotiated as individuals define and understand the ongoing social interactions as a result of what is happening in the current situation. Additionally, individuals enact multiple roles in their lives [29], and within any given situation (i.e., dynamic). Individuals will enact roles that are most aligned with their identities and in accordance to roles that are considered most salient in present social interactions [30]. It can be hypothesized that within this study caregivers will enact roles that are most aligned with their rules and expectations of being a parent within a discipline that may be unfamiliar (e.g., engineering).

Methods

This study employed an intrinsic case study because of our interest in better understanding a case or phenomenon itself and not because the case is representative of other cases [31]. In this study each case is a caregiver-child dyad and the roles that each caregiver enacted while working alongside their child during a program focused on engineering solutions to a self-identified problem. This study is a holistic case study with embedded units or families as we were interested in looking at the same phenomenon, but through analysis of three families focused on three different engineering projects and working alongside different volunteers as part of a program [32].

For this project, we invited families with at least one child in grades 3-6 to engage in engineering design practices with an emphasis on emerging technologies (i.e., making, DIY electronics) into home environments. The first-year of the program included five monthly workshops from January through May. Each workshop lasted approximately three hours and was held at a community-based site (e.g., Boys and Girls Club). Engineers and makers in the community volunteered to attend these sessions, provide support for families, and share their knowledge of engineering and making. Similar to the program structure of Roque [33], these workshops were typically divided into four parts – Meet, Design, Share, Eat. In January, family dyads were given the following short-term design task to expose them to the engineering design process – "Think about something that you can build that might improve the quality of life for someone you know or someone you know about." In February, family dyads were tasked with a long-term design project that would unfold over the next four months. The prompt was as follows - "Think about working on a problem that is something that's personal and relevant to your home or your local community." Most of February was spent defining a problem, thinking about requirements and constraints, and brainstorming solutions that were feasible. The workshops in March, April, and

May were geared toward supporting families in navigating through a non-linear engineering design process specific to their self-identified problem and at an individual pace. Between workshops, families were given tasks to complete at home. These tasks built upon and/or extended what was accomplished in a workshop and the research team provided support as needed. The other part of this program was engagement with engineering kits between each monthly workshop. These kits were framed around an engineering problem and included all needed materials and tools (see [34] for more information). In general, caregivers were encouraged to complete the project alongside their children, but they were not given any directions, rules, or expectations in the role(s) they should take when interacting and engaging with their child during the programs. Unlike studies that are more intentional about supporting caregivers [5], in our cases, caregiver's roles were shaped by preexisting caregiver-child relationships, the nature of their selected project, our programming, and their interactions with their child and volunteer engineers and makers.

Participants

Participants of this study were three child-caregiver dyads. The first dyad was Zac (child) and Una (caregiver). Zac was a 6th grade student who self-identified as a multiracial male who wanted to be an astronomer when he grew up. Una was Zac's mother and bred puppies in their home. Zac explained his project as "help[ing] people in third world countries or people who can't afford electricity in their homes. The solution was to make small solar panels so people would have energy for appliances necessary for everyday living." The second dyad was Walt (child) and Mac (caregiver). Walt was a 3rd grade student who self-identified as a white male who wanted to be a scientist when he grew up. Mac was Walt's father and worked in a law firm. Walt and Mac's project was explained as the following:

> So we have got at home two cats, Sam and Figaro. And they are not big fans of one another. Sam likes to be left alone and Figaro likes to corner her and force her to try to play. And instead she just hisses and runs away. But unfortunately, it causes some problems because he will do things like block the litter box for hours if we are not home and block the food and water, and that is no good for Sam because she does not fight back. She is a little bit older, she is a little smaller that sort of thing. So what we were thinking is that is they both had collars that had little speakers, kind of like a dog whistle but for cats, and little antennas on the collar that, if they were close enough, set off the speaker. And that would cause them to move away from each other and give each other the space they need.

The third dyad was Cindy (child) and Tanya (caregiver). Cindy was a 3rd grade student who self-identified as a multiracial female who wanted to be an artist when she grew up. Tanya was Cindy's mother and had a background in the sciences. Cindy communicated her project as a "remote-controlled delivery robot to help people who can't get out of bed or are sick…I was thinking about someone in a nursing home or something like that. My solution was to build a robot and program it to go to each of the rooms in our house in the morning."

Data Source

The data source for this study was video data of dyads interacting with one another, as well as members of the research team and volunteer engineers and makers, during the monthly workshops. The data was collected through a stand-alone camera directed at each family with the use of a Bluetooth microphone to capture audio. The amount of data collected for each family varied based on their attendance at these monthly workshops. We have approximately four hours of video data from Dyad 1 as they attended January and April together. Dyad 2 attended the monthly workshops with the exception of April. This amounted to about 8.5 hours of data. Lastly, Dyad 3 attended each session for approximately 11 hours of video data. This amounts to a total of 23.5 hours of video data.

Data Analysis

Analysis began by dividing time segments into episodes by design stages embedded within our program – (a) Define the problem; (b) Brainstorm solutions, requirements, constraints, and materials; (c) Prototype; Test and redesign; and (d) Communicate [35]. Next, three members of the research team wrote analytical memos, which allowed each individual to document, articulate, and question their interpretations of the data, free from any risk of making erroneous decisions based on some predefined codes [36], [37]. We noted both verbal and non-verbal acts of communication in our memos, particularly around how caregivers interacted with their child, volunteers, and members of the research team, as interactions are the basic unit of analysis in symbolic interactionism [27], [28]. We provide an example of our memos below from one moment of time in May between Walt and Mac in which they are becoming familiar with the micro:bit drag/drop programming interface [38].

> Author 1: Mac is providing explicit instruction on how to work with the micro:bit. This may be a way to keep Walt focused. Because an alternative view would argue that the adult is doing all the thinking and not allowing student/youth exploration. Within this context/project, having caregivers as the educator is a strength as they know what is appropriate.
>
> Author 2: Mac pointed out phenomena Walt should pay attention to. When he tested their code, he held the micro:bit and pressed on button himself. Walt was watching (hands-off).
>
> Author 3: Dad continues to walk through the coding/downloading process, articulating each step he is taking for Walt's benefit. I suppose the fact that he's taking the lead is likely just for this initial explanatory phase, with Walt likely to take over later to really learn the process.

These memos were placed into an excel sheet by time stamp as each row represented one minute of the video. We utilized the roles identified by Baron and colleagues [7], as well as roles as described by Roque and colleagues [23], as a foundation to build upon as we continually refined and created new roles (see Table 1 for roles). The first author read the memos minute by minute and watched the corresponding video segment to code the data. As an example, consider the three memos above. The caregiver's actions and behaviors were coded as the role of Teacher as Mac is rather descriptive and explicit in his process as we sometimes view in school settings as educators transmit knowledge to students. Mac took the lead as the adult who was more knowledgeable in how to navigate the micro:bit interface. The video also showed Mac in control of the laptop, pointing things out to Walt, while Walt was an observer expected to consume this information. Throughout the analysis, the research team met to discuss the analysis (e.g., the roles) and the cases. These discussions served as inter-rater reliability checks [23], [39] as each member of the research team would note their agreements and disagreements with disagreements being discussed and a consensus reached. As an example, we decided to fold the role of *Questioner* – a caregiver that poses questions to elicit a child's thinking about their project – into the role as *Project Manager* as these questions often moved the project forward as the caregiver was monitoring the child's process, understanding, and progress. These roles as defined in Table 1 were used to code the multiple roles enacted through caregivers' interactions with their child, others in the program, and material. In general, roles were mutually exclusive, but we also coded for instances in which the distinction between roles were difficult to distinguish and were more fluid (e.g., facilitator-project manager).

Table 1. *Coding categories for caregiver roles*

Role	Description
Collaborator	Shared learning experience – ongoing talk/discussion/listening and/or use of material (an exchange). Caregiver may or may not know more about the subject than does child. Balance of power.
Parallel Collaborator	Shared learning experience but in the sense that they are contributing ideas in parallel to one another such as writing down solutions individually or working on two parts of the project but toward the same goal.
Teacher	Taught and instructed the child to do something. Caregiver possesses more knowledge about subject than does child. Transmit expertise to child.
Facilitator	Supported and positioned child as lead engineer. Provided a helping hand. Took direction from child as opposed to giving direction to child as a project manager. Listened to child and took notes.
Learning Broker	Sought learning opportunities for child by networking, searching the Internet, talking to others (e.g., caregivers, engineers, researchers) and used other sources of information.
Social Broker	Mediated social transactions/interactions and the flow of information between people (e.g., child and engineer).

Resource/Material Provider	Searched for and/or provided physical resources and materials to child in support of project.
Project Manager	Ensured that everyone on the team knows and executes his or her role, feels empowered and supported in the role, knows the roles of the other team members and acts upon the belief that those roles will be performed. This included questions and suggestions that moved the project forward, as well as basic encouragement or advice on topics such as organization or artistic design.
Quality Engineer	Ensured that processes were performed correctly using the right tools, materials and order of operation.
Lead Engineer	Constrained access to resources, materials, ideas, etc. Caregiver was the one in control whether directly or indirectly.
Observer	Not part of the interaction directly through verbal forms of engagement, but an observer and/or silent listener. It is clear that attention is directed toward the interaction (e.g., body language, nods head).
Outsider	Not part of the interaction, but sitting on the periphery (literally or metaphorically). Parent may be doing something totally different while sitting nearby.

Results

We present each case study below in terms of the roles they enacted with/for their child during the program as a progression or a timeline from one month to the next [32]. We acknowledge the complex nature of reducing a case and present the results in terms of snapshots, or the most salient roles [30], with examples to support [40]. In the discussion, we address the two research questions and highlight how caregivers' roles were shaped by interactions with and decisions made by the research team and volunteer engineers and makers.

<u>Zac (child) and Una (caregiver)</u>
Una's participation in the program occurred during the short-term engineering challenge in January and one-month (i.e., April) during the long-term engineering design problem self-identified and further developed by Zac in February and March. The latter limited her understanding of Zac's project, but she enacted roles that supported Zac, and herself, emotionally and intellectually.

In January, during the ideation of a problem and brainstorming solutions, we observed Una taking more of a lead engineering role, in that, through offering a direct suggestion or idea (e.g., accessible swing), she planted a seed that impacted or drove the project. She often presented *her* idea to others while Zac seemed more like an outsider. Intermittent within the role as a lead engineer, we observed Una as a parallel collaborator. Once the idea was implanted and taken up by Zac (as he did not counter), they worked in parallel by writing down their individual ideas and solution possibilities. As the project moved into the creation stage, Una was positioned as an outsider, but not necessarily by choice. As soon as Zac returned from gathering material, a student volunteer at the table asked, "Can I help you? Do you need help?" While being helpful, this limited Una's space to interact with and support Zac. Although Una was positioned as outsider, and accepted this position as outsider as she continued working on another activities, she was an observer and silent listener as she made comments to show that she was present (e.g., "You're doing great son."). We eventually saw a shift in that Zac asked Una for support and her role shifted from that of outsider to one that encompassed multiple roles such as facilitator (e.g., held the cardboard while Zac was observed taping parts of the accessible swing together), as social broker (e.g., explaining project and next steps to engineer) and as parallel collaborator (e.g., making holes in the top of the swing for "chains" while Zac hot glued parts of the accessible swing together).

In April, while Zac began brainstorming, Una situated herself as an outsider as she was curious in handling and discussing the materials and tools at the table (e.g., sewing machine), materials and tools that were for another family's project. This provided Zac with time to think, until Una asked, "show me everything you wrote down". This led to an observed shift in Una's role as she began asking questions about materials and methods for constructing Zac's idea (i.e., solar panels for energy); however, these questions were directed toward the maker at the table instead of including Zac in the questioning process. In this role as learning broker, she was seeking information that would support not only her understanding, but her ability to support Zac. We again see a role shift to that of outsider as Una again engaged with the materials at the table with the maker (e.g., sewing machine, micro:bit) while Zac was in another conversation regarding the solar panels. We see a similar pattern in which Una posed a question, "What are you thinking in your mind? Can you describe it?" She listened and then moved into her role as learning broker – seeking more information from the maker regarding the function and storage capacity of solar panels. She was gaining knowledge, while Zac seemed rather disengaged. Una began to record the information she was learning and created notes. She continued to take notes while the maker offered suggestions regarding his thoughts on the material for Zac's project. At one point, we even observed Una present the maker with the material list she had been writing based on their conversation. She wanted confirmation, but this was her way of supporting Zac. Zac continued to remain passive and silent. Una's roles in April is summarized well by her own statement, "I'm just writing what they're saying so I can explain to it Zac."

<u>Walt (child) and Mac (caregiver)</u>

The multiple roles Mac enacted in January were similar to Mac's roles from February to May. Walt was often offered an opportunity to share his many ideas, conduct research, and "play" with materials (e.g., caliper, micro:bit), but Mac was the one who controlled the materials and tools, and ultimately, the project. This is similar to Sadker and Zimmerman's [8] spectrum between a mentor parent and a peer parent, a caregiver that is focused on the child's learning process to a caregiver that is motivated by the successful completion of the project, respectively. Similar to [8], we would argue that Mac's roles were enacted in order to leverage the strengths, needs, and abilities of Walt through the different stages of the engineering design process. Through the caregiver-child relationship, Mac has an awareness of Walt's trigger points (e.g., spelling errors/writing, use of the word challenge), which we acknowledge as shaping the multiple and shifting roles of Mac.

In February, Mac and Walt spent their time brainstorming possible solutions, as well as thinking through the material, requirements, and constraints of the prototype as they came to this session with their problem already defined – construction of two cat collars to prevent one cat (Figaro) from bullying another (Sam). At the start of the session, we observed Mac enact the role of lead engineer as he controlled the workspace (e.g., where to sketch ideas) and work flow (e.g., listening, but rejecting Walt's ideas). At the point in which Walt explained his thinking around how to integrate noise as part of the prototype, Mac's role transformed to collaborator in that the discussion transitioned to one in which Mac and Walt co-constructed project solutions and ideas through verbal and non-verbal (i.e., drawings) acts of communication. Often, Mac posed questions that were intentional and based on Walt's thinking (e.g., "Let me ask. If the challenge is we are trying to get the cats to get away from each other, what is the purpose of speed or distance travel detector?") Mac's role as collaborator subtly transitioned to project manager as he began making more of the decisions about the prototype, but would sometimes ask permission from Walt as opposed to making the decisions without an opportunity for Walt to counter. We observed an example of this when deciding the size and shape of the device that would be attached to the cat collars. As project manager, Mac continued to guide Walt to think about the various components of the prototype, but also seemed to keep Walt engaged as Walt's attention appeared to be waning. To end this session, Mac's role shifted to lead engineer as he became engaged in a conversation with a member of the research team around the materials, parameters and constraints of the potential prototype. Mac became more and more invested in the process and project while Walt simultaneously became more and more disengaged.

In March, the session began with Walt communicating the problem and solutions to Anya, a volunteer engineer. Mac supported Walt through observing/listening (i.e., observer) and posing questions that helped Walt articulate his thoughts (i.e., social broker). As Anya continued to engage with Walt, Mac's role shifted to resource/material provider as he left the table in search of materials for the prototype. As Mac returned with the materials, we observed him eventually divide the prototype into two parts, and each worked on one part – Walt in conjunction with Anya searched for a sensor while Mac played with the material for the prototype. Therefore, Mac enacted the role of parallel collaborator; yet in this role, there was limited interaction with Walt. When Walt took a break, Mac's role shifted to a learning broker as he and Anya engaged in conversation around sensors, circuitry, breadboards etc., which also seemed to morph into a learning experience that was more collaborative between Anya and Mac as neither was more knowledgeable on the materials. As Walt came back from his break, Mac again left the table and endorsed the role of resource/material provider. This role shifted to observer as Walt was provided opportunities to engage with the materials, then to parallel collaborator as Mac again focused on the materials (e.g., breadboard) and Walt was asked to conduct research. Near the end of the session, when Walt 'checked out,' Mac's role shifted to lead engineer in that he continued to move the project forward without the support of Walt.

In May with the introduction of the micro:bit and interface, Mac was a learner broker, which soon shifted to that of teacher, transmitting knowledge around the circuitry, microcontrollers, and block coding to Walt. He provided examples and explicit instructions around the code and how it would work on the micro:bit display. We continued to see this interplay of learning broker – teacher for about 20 minutes. As they settled in, Mac gave Walt some agency in exploring the micro:bit and app interface while he began construction of the cat collars (i.e., parallel collaborator). Mac continued to give Walt things to explore (i.e., project manager), which also maintained his role of parallel collaborator. At the point in which Walt became frustrated, Mac's role transformed into that of lead engineer as he gained control of the laptop - "Because I literally have only two hands, and there's only one computer in front of me." Similarly, Mac's language changed so that he was explaining what he was doing to Walt as opposed to providing general instruction of how the micro:bit worked. As an example, "Okay, so we can't do two. So, I have to change the logic. So I need an if-then else statement." Walt was an observer at this point. Further, we observed moments in which Mac was doing the work of two people, waiting on a download while also constructing the two cat collars. Mac's role as lead engineer continued for most of the session apart from testing in which his role was that of collaborator as this was a two-person job and he needed Walt to help with testing the receiver-sender function. At the end of the session, when each child communicated their problem and demonstrated their working solution, Mac served as a social broker by posing questions to Walt in an attempt to focus his thoughts for those in the room to make sense of the problem and solution. In other words, Mac facilitated the flow of information between Walt and others in the room.

Cindy (child) and Tanya (caregiver)

Tanya's roles throughout this project can be summarized in her words, "I really liked being able to just focus on taking a step back and trying to be an observer unless I was asked for help." Even in March, when Cindy asked for support, Tanya asked a researcher if that was okay as she did not want to overstep her boundaries, caregiver-child boundaries within this project that were not clearly defined by our research team. However, with the introduction of computer programming into the project, Tanya's role shifted to that of observer and outsider as she was less able to contribute and support Cindy. Below, we present Tanya's roles between February to May when her and Cindy engaged within their self-identified problem – a remote-controlled robot that would deliver food and other materials (e.g., medicine) to individuals who cannot get out of bed.

In February, Tanya's role was one that was hybrid – project manager-facilitator – two roles that were seamless in her discussions with Cindy as they defined a problem and brainstormed solutions. We saw Tanya asking questions around the project and moving it forward (i.e., project manager), but her questions were framed in a way that provided Cindy a space to share her thinking and take ownership or lead of the project (i.e., facilitator). Example questions include

(a) "What if there was someone who...couldn't get out of bed? So how would that work?" (b) “What do you think about that?” and (c) "What would be important about what we're putting the items in?" Tanya listened without any interruptions and her responses/questions built upon Cindy’s thinking or pushed her to think differently. She tended to view Cindy’s ideas as valid. There were also times in which Tanya’s responses/questions built a connection between the current task and Cindy’s prior experiences. For instance, “I like the idea of different heights. I'm envisioning something similar to what you built for Amy [Cindy’s doll] when you had that plastic egg on a string.” This hybrid role was consistent throughout February.

At the start of March, Tanya had a very limited role (i.e., observer) because a volunteer maker was present and trying to gain an understanding of Cindy’s project as his purpose was to offer his expertise to the project. This lasted for approximately 30 minutes. Even when the work shifted to Cindy beginning to prototype the tray that would help the robot to carry items, Tanya was an outside observer as she sat on the periphery, but by choice. This choice positioned Cindy as the lead engineer and owner of the project. As Cindy continued to prototype the tray, Tanya took a more active role. We observed Tanya as facilitator because while Cindy took the lead in measuring and cutting out prototype materials, Tanya offered encouragement and help, but allowed Cindy to maintain control over what happened during this process. As in February, Tanya continued to be a project manager/ facilitator through her questioning approach (e.g., “Let's see what's the next step you were thinking?”; “Is that going to be the right height? Is that going to be enough space you think? You got to have it to be enough space for the bowl.”) We also observed a few times during the prototype stage when Tanya was the quality engineer as she questioned Cindy on the “rightness” of something such as where items should be placed on the tray for balance. We only observed Tanya in the role of lead engineer when Cindy asked for support in using the box cutter to cut out two circles. As time progressed, Cindy was encouraged to ask the maker about the coding program that would control the “robot” (i.e., Roomba). Tanya then became a parallel collaborator as she continued to prototype the tray Although they were in different rooms with no interaction, they were both doing something in relation to the project. Near the end of March, Cindy began testing the robot’s movements and making changes to the code. Tanya’s role during this time was an observer and outsider, respectively. Tanya was relegated to a different role because she did not have the knowledge in coding to support Cindy, as she has previously done.

In April, the goal was to construct the support for the tray to sit atop the Roomba. During the initial creation of the food tray support, Tanya’s roles were fluid in the sense that one flowed into another. We observed moments when Tanya was a facilitator as she held PVC pipes while Cindy measured and cut them. She was a quality engineer as she pushed Cindy to think about the reasonableness of her conversions from centimeters to inches. She was a teacher in that she showed Cindy how to read the measuring tape with precision. She was an observer as she allowed Cindy room to do calculations by hand. And she was a collaborator in that they worked together to remove Velcro from the base of the tray. As work on the prototype progressed, Tanya’s role became more of a facilitator as Cindy knew what needed to be done and only asked for support when needed, such as for holding the PVC pipes in place or adding materials for stability. In other words, Tanya's support as facilitator was that of a helping hand. Near the end of the session, Tanya became an observer in that Cindy worked with a research team member on testing the robot in the hallway. Again, this highlights how the technical aspect of the project transformed Tanya's role from one that was more interactive to one in which she was on the periphery looking on.

In May, Cindy and Tanya were tasked with laying tape on the floor to represent the movement of the robot in their home. They were to demonstrate how the robot would traverse their house as a demonstration for other families. Tanya's role was clearly that of project manager as she often asked about next steps and clarification about the project as opposed to facilitating or asking questions about Cindy's ideas. As they began to work together in laying the tape, Tanya's role shifted to quality engineer as she was concerned with the path being straight and done to scale (e.g., "And then again, you know how you want to make sure you're going in a straight line. You want to make sure, because right now you're not going in a straight line.") As Cindy continued to lay tape, Tanya's role again shifted to project manager. In this role, she was leading Cindy's thinking, but not taking lead of the project based on her own thinking. Cindy was still the one laying the path. As Anya, a volunteer engineer, became more involved with the dyad, Tanya transitioned from a facilitator supporting Cindy's laying of the path, to an observer who was no longer needed due to the presence of Anya, and then to outsider as she was observed cleaning up and organizing materials. As the prototyping process moved to coding, something Tanya was less familiar with, she continued to be an outsider and observer.

Discussion

Utilizing symbolic interactionist role theory, we illustrated the multiple, yet different roles that three caregivers enacted over the course of a five-month *engineering* program conducted in an out-of-school context. Through our research, we observed 12 roles that caregivers "played" to support their child throughout the engineering design process (see Table 1). There was not a clear pattern in how these roles differed across the design stages for a single case or for the multiple cases, highlighting the dynamic, complex, and evolving nature of roles through social interactions. We contend that these roles were situated within the rules and expectations of being a caregiver while also developing an understanding of the rules and expectations of an engineer through their social interactions with volunteer engineers and makers throughout their self-identified engineering problem.

To make sense of these roles, we created a graphic (see Figure 1) that highlights caregivers' level of impact on the project; their influence on their child's decision making. This was based on two components, the active-passive nature of the support in terms of verbal and/or non-verbal support and the interactions between caregiver and child (i.e., more-less). As implied, verbal support is exhibited through discourse or language-in-use such as questions and suggestions [41]. Non-verbal support is displayed through hands-on support as opposed to non-verbal cues such as observing their child. In the figure, the center hemisphere indicates the highest level of impact on the project (i.e., caregiver in position of power) and the outside hemisphere indicates the lowest level of impact on the project (i.e., child in position of power).

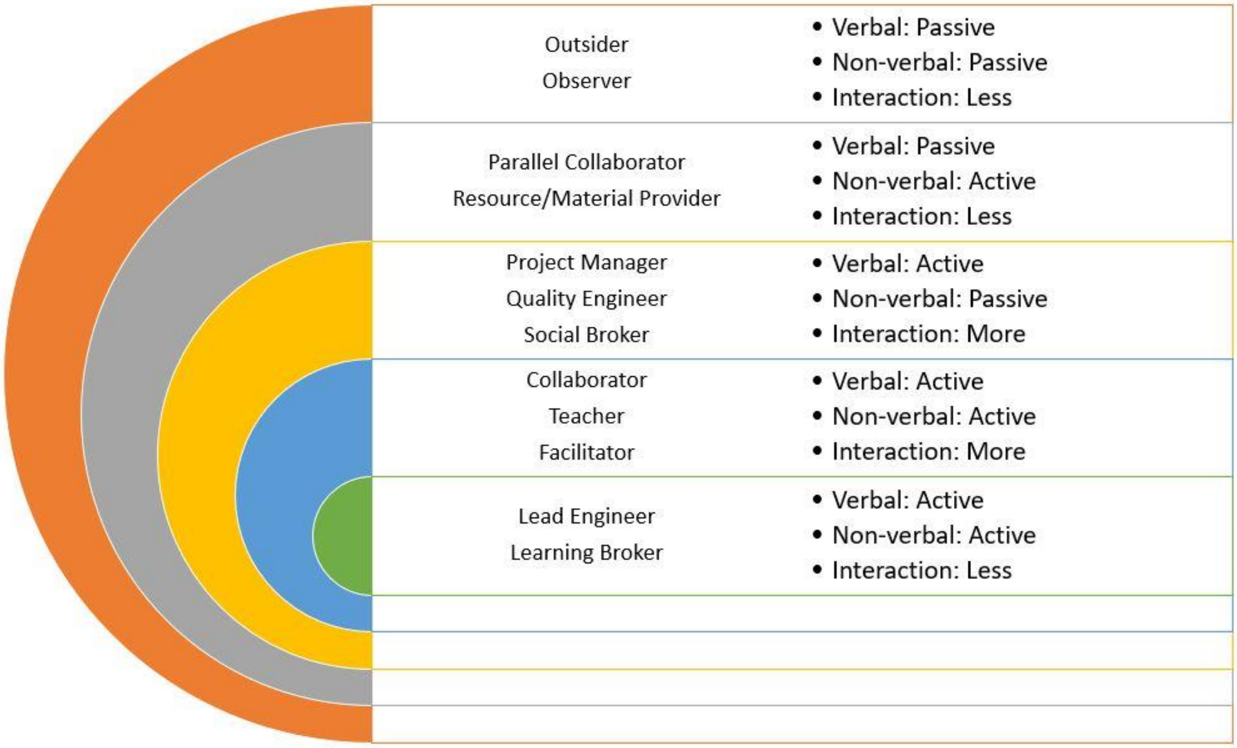

Figure 1. Caregiver Roles in terms of Mediation.

As noted in the introduction, there was also an interest in understanding how contextual factors of the program seemed to influence caregivers' role enactment as these have implications for how to design the learning environment and learning experience for families to engage in creative production [42], co-creation [43], and to empower caregivers to overcome their negative feelings (e.g., inadequacy, embarrassment) and lack of competence in supporting their child(ren) in STEM activities [6], [44]. As stated by [23], "It is not enough to merely enable parents and children to create together" (p. 669). One, the inclusion of volunteer engineers and makers were a key part of the program as they had an expertise (e.g., Roomba, renewable energy) that members of the research team did not necessarily possess. Their presence shaped the caregiver's roles, sometimes in unfavorable ways – observer (Tanya), outsider (Una), and lead engineer (Mac)- as these roles diminished caregiver-child interactions. On the other hand, the presence of volunteer engineers and maker encouraged caregiver and child to work together; therefore, the shifting the roles of caregivers to one more favorable. For example, Una's roles shifted from an outsider to a collaborator when a volunteer engineer asked her to hold a piece of cardboard for Zac (as described above in January session). We contend that volunteer engineers and makers may benefit from professional development regarding the facilitation of learning and ways to engage family members as a collective. This includes understanding ways to support caregivers and children as co-learners when both lack knowledge needed for the project (e.g., programming language). The intent would be to not position caregivers as outsiders, but to empower them to be learning brokers alongside their child.

Two, the introduction of and/or access to materials and resources served to shape caregiver's roles (e.g., lead engineer, outsider). For example, Tanya's role shifted to an observer or an outsider when Cindy was engaged with coding the robot. Likewise, the absence of materials and resources may have afforded caregivers a space to enact what may be considered more supportive roles (e.g., facilitator, project manager) as they were able to focus on their child's actions, practices, and behaviors within the design process. This has implications for when materials and resources are introduced within the engineering design process, as well as our language of how the materials and resources are to be used between caregiver-child. For example, utilizing a strategy from complex instruction [45], we can establish expectations around the materials by stating "Neither of you have all the abilities needed for the project, but you each have something to contribute. Listen carefully to one another and share the materials as you are important resources for one another."

Three, we concluded that the pressure of time and feeling a sense of urgency in having a functional prototype to demonstrate at the end likely shaped caregivers' roles to those most salient in similar situations and interactions [29], [30]. Time and a product-driven mentality has been noted as a tension in similar environments that strip the opportunity for children to explore, create, and innovate[46], [47]. Again, our language as a research team and how we set-up each session should establish and reinforce the idea that their projects extend beyond the life of the sessions to their home environments. This can be reinforced through situating our language within an engineering design process. We could further utilize the experience of the volunteer engineers and makers as many of their design challenges and projects occur over a period of many months, if not years. We acknowledge that these factors are based on our perspective as researchers and developers of the community-based project, and not necessarily factors that caregivers perceived as having a negative influence on their roles. For example, while Una more often interacted with the maker than Zac during the April session, this was a role she enacted to learn more about solar panels to support Zac at the conclusion of the session. This is the role that Una felt comfortable enacting in the moment.

Conclusion

This study supports current evidence and sheds further light on the unique and often fluid roles that caregivers may play in their child(ren)'s experiences with and engagement in engineering design processes and activities. The diversity of roles assumed by caregivers throughout a planned program varied and was found to be highly contextualized, often influenced by multiple elements (e.g., program structure, materials, physical environment). Results of this study lend guidance to the construction and running of future engineering-focused programs, as well as the benefits and challenges that may come with the inclusion of adults and influences external to the child-caregiver dyad. Future research that includes added facilitation and guidance for volunteer engineers and makers, as well as more measured or explicit exposure to and use of materials throughout the program, may continue to provide more detailed information on the type of roles caregivers adopt. Through a more refined program process and structure, the specific impacts these caregiver roles (and their fluctuating nature) have on a child's learning and understanding of the engineering design process may be better understood.

Through this research, what became clear is that caregivers can and do play a significant role in their child's learning and identity within the engineering design process. Through deeper understanding of these varying roles, more might be learned about how to better facilitate caregiver engagement with the field of engineering and reinforce the engineering knowledge and processes that are already undertaken in their home or community, often unbeknownst to them. As researchers look to the future, this work may contribute to more impactful methods of incorporating parents and caregivers into the STEM learning process and the facilitation of the unique roles that child-caregiver relationships play.

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