# Observing empathy in informal engineering activities with girls ages 7-14 (RTP, Diversity)

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Susan Letourneau is a Senior Research Associate at the New York Hall of Science. She collaborates with educators and designers to develop and study museum experiences that emphasize play, exploration, and creative expression as avenues for STEM learning. She has over ten years of experience conducting interdisciplinary research on children's learning and caregiver-child interactions in science centers, children's museums, and other informal settings.

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Ms. Bennett currently serves as Director of Creative Pedagogy at the New York Hall of Science, responsible for developing and implementing new initiatives that reflect NYSCI's core pedagogical approach known as DESIGN, MAKE, PLAY —a child-centered approach to STEM learning that inspires curiosity and playful exploration, builds confidence with new skills and tools, and fosters creative problem solving and divergent thinking. Drawing on 30 years of experience in informal and formal education, she helps translate this approach into practice by creating professional development experiences for our young museum facilitators and K-12 educators, developing apps to stimulate STEM learning beyond the walls, and designing exhibit and program experiences to inspire our diverse audience of English Language Learners. Prior to NYSCI, Ms. Bennett conducted foundational work in gender equity and design-based STEM education through EDC's Center for Children and Technology, Bank Street College of Education, and Sesame Workshop, collaborating with national and international partners such as IBM, the Australian Children's Television Foundation, higher education schools of engineering, and k-12 educators nationwide to create hands-on design experiences and digital media that invite diverse learners into STEM.

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Yessenia holds a master of public health in community health education from CUNY School of Public Health and Public Policy. She has worked in various areas within public health including respectful maternal care, sexual and reproductive health, nutrition and global health. Her belief that "knowledge is power" has fueled her career choices and led her to join NYSCI as a research and development assistant. She will be using her experience with qualitative research to investigate the impact of STEM learning within NYSCI. Yessenia hopes that her research will work towards decreasing engagement disparities based on gender.

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Katie McMillan Culp is Chief Learning Officer at the New York Hall of Science. She is a developmental psychologist with twenty years experience leading research and development initiatives and applied research studies focused on equitable, high quality teaching and learning for all young people. At the New York Hall of Science, Dr. Culp leads collaborative, multidisciplinary teams to design, develop, implement and study experiences, tools, and media that help highly diverse groups of young people discover their own identities as scientists and engineers. Her research has been funded by the National Science Foundation, the Bill & Melinda Gates Foundation, the U.S. Department of Education and the Intel Foundation. Dr. Culp is a Phi Beta Kappa graduate of Amherst College (1988) and holds a PhD in developmental psychology from Teachers College, Columbia University (1999).

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## Background

Research and policy shifts in engineering education have identified socioemotional skills like empathy as a fundamental and often neglected part of engineering practice [1]-[2]. This work argues that solving complex engineering challenges with societal and ethical implications requires engineers to empathize with clients and colleagues whose perspectives and needs might differ from their own [1]-[4]. Humanistic approaches to engineering education integrate empathy as a core skill and orientation to engineering practice, placing the other people involved in the engineering design process at the center [5]-[6]. This human-centered approach has the potential to strengthen engineering practices while also offering more welcoming invitations into the field for groups of learners, particularly women, who have historically been underrepresented in engineering courses and careers. Research has found that the dominant view of engineering as primarily about "working with things" rather than "working with people" leads many young women to the conclusion that engineering is not for them [7]-[9]. These conceptions of engineering begin to form in elementary and middle school, leading many girls to pursue other, more human-centered fields [10]-[12]. Introducing children to engineering as a profession that involves empathy and care for others can counteract perceptions that engineering is impersonal and technocentric [4], [10], and informal STEM environments in particular can play a role in offering engaging introductions to engineering for girls and young women. Developing engineering experiences specifically with girls' interests and needs in mind can allow informal institutions to create innovative learning experiences that shift whose perspectives are valued, inviting a wider range of identities into the field.

Development efforts in museum settings have explored strategies for providing personal and social contexts for engineering tasks that encourage learners to empathize with others as part of the design process — for example by using narratives (e.g., characters or settings that depict clients and their problems) to invite learners to help others with their designs [13]-[14]. Professional engineers frequently utilize narratives to help them empathize with clients and other stakeholders, understand the problems they face, and envision how they might use designed solutions [15]-[16]. With the increasing recognition that empathy is critical for human-centered engineering practices, and in turn, to ongoing efforts to broaden participation in the field, there is a need for additional research on the impact of these types of interventions on children and youth. However, a first step in this effort is developing evidence-based tools and methods for analyzing how children express empathy during engineering design tasks, and how expressions of empathy intersect with and support specific engineering design practices. In this study, we aimed to map this terrain by conducting rich qualitative observations of what empathy looked and sounded like among girls ages 7-14 as they engaged in human-centered engineering design tasks. We used iterative data-driven analyses to develop and refine a set of behavioral indicators for capturing empathy within the engineering design process in this age group [17].

This project drew on three bodies of research: 1) Prior research in psychology and neuroscience that defines empathy as a multifaceted process that includes emotional, cognitive, and prosocial responses [18]-[19]; 2) Humanistic approaches to engineering, which describe how engineers must understand and empathize with their clients' problems, needs, and points of view in order to design solutions that meet their needs [2],[5],[6]; and 3) Frameworks for K-12 engineering education, which describe engineering design practices as a central component of engineering learning in at elementary and middle school levels [20]-[22].

**Research approach**

This work was conducted as part of a three-year design-based research project at a science center in the U.S., which involved developing and testing six engineering activities that used elements of narratives (such as characters or settings) to evoke learners' empathy for the users of their designs. We used a design-based research approach, in which researchers and activity developers collaborate closely to develop and test new educational approaches. In design-based research, initial designs embody theoretical conjectures about how learning takes place in a given context, which are then updated based on ongoing observations as evidence is gathered [23]-[24]. In this project, museum educators and researchers iteratively developed, tested, and refined engineering activities and research instruments to address the following research questions: 1) How do girls (ages 7-14) express empathy in the context of narrative-based engineering activities?, and 2) What impact do expressions of empathy have on girls' use of engineering design practices?

In this paper, we will focus on the iterative development of a framework for documenting aspects of empathy that related to engineering design practices. Other aspects of the study (including the development of activities and design principles, and comparisons of narrative and non-narrative activities on a range of engineering outcomes) are reported elsewhere [25]-[26]. We focused on gathering data about girls' experiences because our primary goal was to develop activities that would appeal to this demographic and center their needs and points of view. Our assumption throughout was that approaches that would be more inclusive for girls might also support other groups of learners who tend not to engage with traditional engineering challenges, although this is an empirical question for future studies.

**Methods**

***Procedure.*** Participants included 245 girls (ages 7-14) who participated in engineering activities at an urban science center in the northeast of the United States during regular museum visits. We focused our observations on girls in order to center girls' experiences throughout the activity development process. Each child participated in either a narrative or a non-narrative version of one of six engineering activities. Narrative versions of the activities contained characters, settings, or problem frames that were designed to evoke empathy. For example, some activities involved sympathetic characters with problems that needed to be solved (e.g., in "Help the Pets," children used simple machines to create a chain reaction contraption that could help take care of a pet; in "Help Grandma," they used repurposed materials to design inventions to help a grandparent with everyday tasks like carrying groceries). Some activities combined characters and settings, as in an activity called "Safe Landing," which invited children to design something to protect an alien or astronaut landing on the surface of a planet. In this activity, the testing station was a 20-foot drop with a space-themed background and landing pad. Other activities involved only a narrative problem frame (e.g., in "Emergency Structures," children used dowels and rubber bands to build a structure that could fit everyone in their group and withstand an earthquake). Non-narrative versions with similar engineering challenges but without the narrative framing were used for comparison. See [25] for a complete list of the activities tested.

***Data*** included *field notes* documenting how activities were implemented (including materials used, facilitation strategies), *observations* of participating girls as they completed the activity (noting the problems they decided to solve, the constraints or criteria they considered, the design ideas they generated, and how they built and iterated their designs), and *semi-structured interviews* with each participant (focused on their descriptions of their design ideas, the problems they were trying to solve, and whether and how they considered the users of their designs).

***Coding and analysis.*** To develop methods for documenting empathy within these engineering activities, our data collection and analyses were conducted in three iterative phases:

First, we used open-coding of field notes, observations, and interviews from the first three activities to descriptively document how facets of empathy identified in the literature were expressed in girls' verbal and nonverbal behaviors, and how they intersected with engineering design practices. We began by using definitions of these categories from existing research that describes multiple facets of empathy [18]-[19]. This work describes affective or emotional components of empathy as involving emotional contagion, compassion, or concern for another person (ie, feeling what someone else feels, or feeling sympathetic toward them). Cognitive facets of empathy involve understanding and/or imagining another's perspective or point of view. This is an analytical process that can take place with or without emotional engagement. Finally, some models of empathy include prosocial behaviors, which involve taking action to help others (e.g., altruism). Engineering design practices were drawn from engineering design frameworks for K-12 education [20]-[22], which describe the design process as an iterative or cyclical process of identifying a problem and building and improving a designed solution. Based on prior studies in informal settings [27], and our own pilot observations in our museum, we focused on the practices of problem scoping, ideation, testing, and iteration. We noted any examples of behaviors or responses in our observations that aligned with these aspects of empathy and engineering design practices, highlighting these instances and describing when and how they were expressed. Three researchers open-coded a subset of the data in this way and discussed examples of each category, iteratively refining the categories and indicators through multiple rounds of analysis and discussion.

Next, we then tested and revised this initial set of indicators by using them to guide observations and interviews in subsequent activities. Researchers gathered field notes, observations, and interviews, and after completing each observation, immediately noted any evidence of the indicators identified in the first round of data analysis. This allowed for more detailed observations of conditions surrounding these indicators, which in turn allowed the categories themselves to be iterated further. Three researchers conducted observations, and discussed the evidence gathered for each category after each testing day, revising the definitions and criteria for each indicator as needed to reach a consensus on how each indicator might be expressed.

The final set of indicators was then used to recode the entire dataset. Three researchers coded a subset of the observation and interview data (20%) and obtained interrater reliability of over 85% across coding categories. Disagreements were resolved through discussion. These categories also guided a summative evaluation across three museum sites in different regions of the US [26].

Throughout this process, disagreements between coders helped clarify the definitions of each behavior, as well as the ways they might be expressed in informal settings. For example, when defining iteration in our activities, we realized that we needed to consider both large-scale changes to the design made after a formal test, and smaller-scale changes made after children tested part of the design or talked with others about how the design should function, as these types of interactions were quite common in our activities and led children to adjust and improve their designs prior to larger-scale tests. In addition, when considering empathic responses such as perspective-taking, we discussed whether these behaviors could involve children referring to themselves, since children were designing for themselves and/or their families in some activities. Although empathy often implies thinking of other people's needs, we ultimately decided that considering one's own needs in an imagined scenario involves the same kinds of perspective-taking that engineers engage in in their work (putting oneself in the situation under consideration to understand what problems one might encounter and what might be helpful), and therefore we considered this to be an indicator of perspective-taking when it was observed. This allowed us to recognize expressions of perspective-taking in younger children in our sample, who are still developing the ability to consider multiple points of view outside of their own [28].

## Results

### *Engineering design practices*

Based on our iterative rounds of observation and analysis, we used the following criteria to identify engineering design practices in girls' behavior:

- *Problem scoping:* Identifying multiple aspects of the overall design problem, considering criteria or constraints that the design should meet.
- *Ideation:* Generating and planning possible solutions to the design problem, including divergent thinking, brainstorming, and considering different forms a design might take.
- *Testing:* This included both large-scale tests of a design's function, and small-scale tests of parts of the design. In activities without formal testing stations, this could take the form of critiquing one's design on one's own or through conversation with others.
- *Iteration:* Revising a design based on evidence generated through a test. We differentiated between low levels of iteration (changing a design once or twice), and high levels of iteration (persistence in making repeated changes to optimize a design).

### *Empathy indicators*

In defining indicators of empathy in these engineering tasks, we focused on how multiple facets of empathy were expressed, and how they intersected with the engineering practices described above. We provide definitions and examples of each category in the context of engineering design practices below, and the indicators are summarized in Table 1.

Table 1
*Definitions and examples of empathy indicators in the context of engineering design tasks*

| **Empathy Indicator** | **Examples** |
|---|---|
| *Affective responses:* Talking about the client/user's feelings; Expressing concern, compassion, sympathy | "He looks lonely" while looking at one of the pets in *Help the Pets*<br>"That'll make her happy" while thinking about a solution in *Help Grandma*<br>"I feel bad for him! I hope he's ok!" after testing a design in *Safe Landing* |
| *Cognitive Perspective-taking:* Imagining what users want or need, or how someone would use a designed solution | Talking about what it would be like to be in an earthquake while designing a structure;<br>Modeling how grandma would use a device to help her open jars. |
| *Prosocial desire to help:* Expressing a desire or taking action to help the potential user of a design | Reinforcing a dowel structure to protect those inside;<br>Making sure grandma is safe or comfortable while using a design. |
| *Familiarity:* Connecting to one's own personal experiences. Supports other expressions of empathy above. | Thinking about one's own grandparents and the problems they faced or the things they found helpful; remembering one's own pets and their preferences or needs. |

*Affective responses*
Girls who participated in the activities expressed affective or emotional facets of empathy by considering the feelings of their clients/users, as well as how they felt in response. For example, they described how the users of their designs might feel when experiencing a problem (e.g., "It must be frustrating when you can't hear very well."; "He looks lonely!"), or when using the designed solution (e.g., "I thought she would be happy if this was easier to do"). They also sometimes described how *they* felt as designers—expressing concern or compassion, or describing how they might feel if faced with the same problems (e.g., "I'd be really scared if there was an earthquake!"). In our observations and interviews, researchers often observed verbal and nonverbal expressions of these emotions as children first approached the problem, as well as later in the activity when they tested out their designs, and in interviews when children described the problem they were trying to solve.

Link to engineering practices: When children expressed emotional aspects of empathy, they often engaged in mode switching [2]-[3]—switching back and forth between connecting emotionally to the design problem and engaging in analytical problem-solving to design, build, or iterate solutions. This emotional connection encouraged children to persist in solving problems with the materials or optimizing their designs. For example, in Safe Landing, when children watched their character fall down the 20-foot drop, they often expressed emotional reactions of concern and worry for their character's safety, which frequently led them to iterate and improve their designs to make them land more slowly or softly. Likewise, in Help the Pets, the desire to make the pets happy motivated children to troubleshoot problems with the individual props within their chain reaction contraptions.

*Cognitive perspective-taking*

We observed cognitive facets of empathy when girls imagined someone else's point of view (i.e., considering what someone might think about or experience when facing a problem or using a designed solution). For example, in *Safe Landing,* girls might talk about what their characters might see or feel while falling toward the planet. Children also sometimes put themselves in others' shoes by pretending to be the user/client, describing or acting out how designs would be used. For example, in *Emergency Structures,* some younger children pretended that there was an earthquake coming and rushed to finish their structures and get inside. In *Help Grandma,* children frequently physically demonstrated how Grandma would use the designs that they created. In observations and interviews, researchers could determine whether children were thinking this way by prompting them to describe what they were thinking about while building, or to share the reasoning behind their design decisions.

Link to engineering practices: This type of perspective-taking arose most commonly during problem scoping and iteration, when girls defined the problem they were trying to solve and when they were trying to improve on their designs. This resulted in more human-centered design decisions that considered what it would be like for someone to use a designed solution. For example, in *Help Grandma*, one child created an invention to help a fictional grandmother who had trouble opening jars. In iterating her design for a jar-opener, she added an adjustable opening for different sized jars, and padded handles to make it more comfortable to use. In *Safe Landing,* another child added a porthole in her design so that her character could see outside during the journey. Our early analyses defined "user-centered design" as a separate indicator, but in later phases of work, we realized that these decisions actually reflected an intersection of empathy and engineering design practices (i.e., this was how engineering design practices were expressed when approached from an empathetic perspective).

*Prosocial responses*

Girls expressed prosocial aspects of empathy by expressing and/or acting on a desire to help or protect someone with their designs. Sometimes children would express this desire spontaneously before identifying solutions to the problem (e.g., in "Help the Pets," saying "oh no, how can we feed him?", when making iterations to their designs, particularly changes that were meant to make designs safer or more comfortable for someone else (e.g., in "Emergency Structures," reinforcing a dowel structure "to make sure that we survive"). In interviews, questions asking children to describe their designs and their reasoning behind their design decisions were effective at revealing this facet of empathy as well.

Link to engineering practices: A prosocial desire to help supported initial phases of problem scoping and ideation. In interviews, when describing the problem they were trying to solve, girls often described being motivated by wanting to help someone. In addition, this facet of empathy also appeared while children made additional iterations to their designs that focused on ensuring the safety and well-being of clients/users. In a later evaluation, some children extended this to include prosocial consideration of larger societal or environmental issues (e.g., sustainability, protecting ecosystems/habitats).

*Familiarity*
Both the design-based research as well as the summative evaluation found that girls often identified with the users of their designs by making a connection to their own prior experiences. This was different from simply using prior content knowledge; instead, this indicator was evidenced by children referencing personal experiences or memories, or relating some aspect of the problem either to their own lives or those of their friends or family members. For example, in the activity focused on helping grandmothers, children often mentioned their own grandparents and the kinds of things that they needed help doing, or the kinds of solutions that had helped their grandparents in the past. In prior research on empathy, familiarity is considered a mediating factor that supports one's ability to empathize with others [16]. Thus, although it is not an aspect of empathy per se, we included it as a relevant indicator of empathic engineering experiences.

Refining these behavioral indicators allowed us to iteratively develop activities that evoked empathy in ways that bolstered engineering learning for girls in our target age group. Our design-based research showed that the narrative versions of the activities were effective in evoking multiple facets of empathy [25], and when girls expressed at least one indicator of empathy, they stayed longer and demonstrated more engineering practices [26]. Although our focus here is on describing our observational methods, these findings highlight the value of rigorously documenting empathy alongside engineering practices in order to develop more inclusive and human-centered approaches to engineering education.

## Implications

This research study investigated how 7-14-year-old girls express empathy within the engineering design process. We brought together prior research on empathy, engineering education, and museum practice to document multiple facets of empathy and their role in supporting specific engineering design practices, such as problem scoping, ideation, testing, and iteration. Using a qualitative and data-driven analytical process, we focused on understanding empathy as an integral part of the engineering design process for children in elementary and middle school, a critical period when children begin to form conceptions of engineering as a field. Our ultimate goal was to generate evidence to inform the development of inclusive activities that presented engineering as an empathic and human-centered endeavor.

By providing tools for capturing both empathic thinking and engineering design practices in this age group, this study could allow educators and researchers to design and study interventions that are targeted toward the intersections between these two processes. For example, educators may use these indicators to develop engineering activities that evoke one or more facets of empathy, to notice expressions of empathy in their students, and to scaffold empathic approaches to solving engineering problems. Likewise, researchers may use these indicators to explore what qualities of engineering activities can support specific empathic responses, how expressions of empathy might vary across age groups, cultures, or settings, and the impact on other aspects of engineering learning (such as engineering knowledge, materials fluency, habits of mind, engineering identity, etc).

Although we focused our efforts on understanding and supporting girls' experiences with these activities, given their persistent underrepresentation in the field, our assumption throughout was that educational approaches that supported girls' learning might also support other groups of learners who also tend to be less engaged by traditional engineering challenges, although this is an empirical question for future studies. Further research could explore whether and how narratives can be broadly appealing to a wide range of audiences across genders and backgrounds, and whether the impacts of narratives on empathy and engineering learning vary for different audiences.

In sum, reframing engineering tasks to prioritize empathy for others can create more inclusive entry points into engineering for many learners, and particularly girls, by redefining whose ideas and perspectives are valued and relevant. Empathic approaches can make engineering more accessible and appealing to young women by offering opportunities to solve engineering problems in order to help others [4], [8]. Critically, our research suggests that fostering empathy can more deeply engage girls in engineering tasks, while also supporting critical engineering practices (such as problem scoping) that can be difficult to support in more constrained educational settings that lack a personal or social context. In these ways, our work supports the conclusion that empathic approaches to engineering education can welcome girls' perspectives and encourage all learners to cultivate the skills and habits of mind that are necessary for solving complex real-world problems.

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