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Youth Leadership and Belonging in Technology-Rich Afterschool STEM Programs

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Abstract
In this paper, we share two years of findings from a five-year research project situated in youth-led afterschool STEM clubs. Using a design-based research approach, we examine how these technology-rich learning environments function as both sites of possibility and sites of struggle, where youth negotiate belonging, leadership, and ethical responsibility while engaging with engineering and technology. Integrating engineering education into informal settings for young learners can support students' agency and engagement with STEM. Low-stakes, playful, and informal settings are also opportune spaces for students to temporarily develop a sense of belonging to the space and community, which can support a long-term sense of belonging in STEM. Our study is guided by a Youth Participatory Action Research (YPAR) approach, and here we share our work with STEM after-school programs at two different schools over the last two years. In these programs, middle school students are leaders, activity designers, and peer researchers. In this paper, we explore how youth leaders, across two years of implementation, including weekday in-school design meetings in year one and twelve Saturday design and research sessions with corresponding Monday afterschool STEM club sessions for year two, foster a sense of belonging, equip peers to recognize and act upon ethical considerations, and build community through leadership roles and collaborative artifacts. During the Saturday sessions, the university researcher team worked with middle school researchers to discuss community-identified problems, develop facilitation for in-school peers, and learn prototyping technologies such as 3D printing, circuits, microcontrollers, e-textiles, and laser cutting. The workshops also discussed and critiqued normalized practices in STEM and education. During the Monday after-school STEM sessions, youth leaders facilitated the same activities for their peers at their respective schools. Our data collection approaches included interviews, video recordings, youth-created artifacts, observations, researcher audit trails, and reflections. We analyzed this data qualitatively using a thematic analysis to identify and categorize patterns and answer our larger research questions for this multi-year study: How and in what ways can youth experience belonging in engineering when working in technology-rich spaces? How and in what ways can youth be motivated to prevent harm to people and the environment when engaging in technology-rich engineering activities? How do youth lead the development and maintenance of a technology-rich engineering space? This paper does not report on the complete YPAR approach, which will be shared in forthcoming work, but instead presents a narrative analysis that surfaces insights into the tensions, negotiations, and identities the youth researchers and participants experienced. Our work demonstrates the potential of such approaches in afterschool STEM clubs to position youth as knowledge producers who view engineering as both a technical and human discipline.

Introduction

Unequal Opportunities and a Sense of Belonging within STEM

Despite long-standing initiatives to increase engagement in STEM, there are still barriers to access, recognition, and involvement, especially for young people from historically underrepresented groups [1], [2]. Studies indicate that these gaps are significantly associated with inequitable feelings of belonging in STEM, characterized by feelings of recognition, worth, and legitimacy as a member of a learning community [3], [4]. When young individuals don't feel they belong, they are less likely to see themselves as future engineers or identify with engineering, even when they might have an interest in pursuing it and the potential to succeed. These gaps are particularly significant throughout middle school, an important phase for identity formation and the establishment of enduring STEM trajectories [5]. To address these inequitable perceptions of belonging, learning settings must transcend mere access to knowledge and deliberately foster young agency, acknowledgment, and critical engagement.

Engineering, Ethics, and Harm

In addition to concerns about participation and belonging, there is a growing and imperative interest in the ethical, social, and environmental effects of engineering and technology. Engineering advances can enhance quality of life; nevertheless, they may also cause unintentional harm to communities and ecosystems when ethical concerns are neglected [1], [6]. In response, academics and professional organizations have called for engineering education that emphasizes responsibility, ethics, and compassion alongside technical skills [7]. Early exposure to ethical awareness, especially in informal and youth-oriented settings, can help young learners cultivate a more comprehensive understanding of engineering as a human-centered field. When given the right learning opportunities, young people may understand how their actions affect the environment and society and participate in discourses and related actions about responsibility and harm. These approaches are especially important in engineering tasks that involve significant technology, where design choices can have significant effects on people and the environment.

Research Goal

In this paper, we draw upon data from a larger research project investigating youth-led, technology-enhanced afterschool STEM programs within a Youth Participatory Action Research (YPAR) framework. By emphasizing youth as leaders, designers, and peer researchers, our work examines how a sense of belonging is cultivated through leadership, collaboration, and ethical engagement with engineering and technology.

Furthermore, this research identifies informal STEM contexts as places where youth can critically evaluate and challenge dominant assumptions about engineering and participation. A youth-led inquiry allows participants to engage in engineering techniques while also reflecting on whose knowledge is valued and how engineering may contribute to more inclusive and community-centered outcomes.

Research Questions

As part of our multi-year study, we are answering the following research questions. The findings and discussions that follow further our understanding of the same.

1. How and in what ways do youth experience a sense of belonging in engineering when working in technology-rich learning spaces?
2. In what ways do youth recognize, negotiate, and act upon ethical considerations related to preventing harm to people and the environment when engaging in technology-rich engineering activities?
3. How do youth lead the development and maintenance of technology-rich engineering spaces in informal STEM programs?

Literature Review

Youth Belonging and Identity Development in STEM

Belonging has emerged as an important construct for understanding youth involvement and persistence in STEM education. Rather than being a personal characteristic, belonging is socially formed via participation, acknowledgment, and positioning within learning communities [3]. Youth form STEM identities when they are acknowledged as capable contributors, have meaningful interactions, and have their ideas and experiences appreciated in STEM settings. In contrast, individuals who are positioned as peripheral or invisible are less likely to associate with engineering, regardless of their evident skills.

Research regularly demonstrates that perceptions of belonging in STEM are unevenly distributed. Youth from historically underrepresented groups frequently face challenges to visibility and involvement, limiting possibilities to establish positive STEM identities [8], [4]. These disparities are most harmful throughout middle school, when identities and future academic trajectories are actively formed [5]. As a result, researchers have stressed the need to create learning settings that purposefully promote belonging through relational practices, agency, and chances for meaningful contribution.

Informal STEM Education and Community-Based Learning

Informal STEM learning contexts, such as afterschool programs and community-based workshops, offer unique opportunities to foster belonging and identity development. These spaces frequently feature voluntary involvement, flexible frameworks, and lower performance expectations, allowing youth to engage in STEM activities that promote curiosity, experimentation, and social interaction [9], [10]. Informal environments, as opposed to conventional classes, may value connections, cooperation, and collaborative problem solving over standardized outcomes. Informal STEM programs can function as communities of practice, where learning occurs through involvement in shared activities and, over time, increases in responsibility [11], [12]. Instead of individual success, these communities foster a sense of belonging via mutual participation and shared purpose. Prior research has found that sustained participation in informal STEM programs can boost confidence, foster growth in interest, and promote long-term engagement, especially when learners are positioned as contributors rather than passive receivers of content [13].

Youth Leadership and Participant Roles in STEM Programs

Youth leadership is a promising means of encouraging equity, belonging, and agency in learning contexts. Leadership-oriented methods position youths as designers, facilitators, and decision-makers who actively change the norms and practices of learning environments [14], [15]. When youths are given leadership duties, they acquire chances for recognition, voice, and accountability, all of which are essential components of belonging [16]. Youth leadership has been linked to increased involvement in informal STEM settings. Youth can engage in engineering as a collaborative and relational activity by leading activities, mentoring peers, and contributing to program design [17], [18]. Youth in leadership positions may also shape the social organization of learning environments, influencing who participates, what ideas are valued, and how information is shared.

Ethics, Harm, and Accountability in Engineering Education

There is growing recognition that engineering education must encompass the ethical, social, and environmental impacts of engineering and technology. Engineering breakthroughs can provide significant advantages; yet, they may also result in unforeseen detriments when social and ethical factors are neglected, frequently disproportionately impacting individuals from minoritized groups [1], [6]. In response, academics and professional groups have urged for engineering education that combines technical knowledge with ethics and social responsibility [7]. Studies in justice-oriented STEM education indicate that youth can confront ethical issues and evaluate the consequences of engineering choices on individuals and the environment [21]. When youths are helped to recognize potential dangers and reflect on their responsibilities, they may learn more about engineering as a field that is grounded in caring for others and community health. These perspectives align with harm-reduction strategies that emphasize reducing negative effects while promoting moral awareness and shared responsibility.

Technology-Rich Learning Environments and Youth Agency

Makerspaces and fabrication labs are examples of technology-rich learning environments that allow youth to engage in hands-on engineering design using technologies such as 3D printers, microcontrollers, circuits, and e-textiles. These technologies encourage iterative design, experimentation, and collaborative problem-solving, allowing young people to turn ideas into actual products [23], [24]. However, researchers emphasize that access to technologies alone does not guarantee equal participation or meaningful learning [25]. The social structure of technology-rich spaces, who leads activities, what ideas are valued, and how choices are made, are crucial in developing teenagers' senses of belonging and agency [26]. Participatory and youth-led techniques are thus critical to ensure that technology-rich settings promote inclusive, ethical, and community-oriented engineering practices.

Methodology

Research Design

This study was carried out at two middle schools in a gateway community public school system in the US Northeast and integrated into existing afterschool STEM clubs. A combination of Design-Based Research (DBR) and Youth Participatory Action Research (YPAR) guided the larger study, allowing for exploration in an authentic learning setting and shaping successive iterations of the multi-year project in partnership with youth researchers who lead iterations of change in their learning contexts [27], [28].

The program has seen some changes in scheduling over the last three years, but essentially during a ten-twelve week session, youth leaders work weekly with university-based researchers to learn about the project, amend the research approach to cater to their areas of interest, and develop their leadership and facilitation abilities. Back at their respective clubs, during the first several weeks, student leaders hold collaborative discussions with their peers about STEM belonging, the societal role of engineers, and ethical concerns related to harm in engineering and technology. In the following weeks, youth leaders plan and improve upon STEM activities to implement in their afterschool clubs, paying special attention to facilitation approaches that pay attention to power and inclusivity, and social and environmental ramifications of engineering and technology beyond technical tasks.

Throughout the program, youth leaders lead co-designed, technology-rich engineering activities with their peers in their afterschool STEM club. These activities included a paper-airplane design challenge related to air-travel emissions awareness; a Scratch game design addressing trash cleanup and ocean pollution; and TinkerCAD and 3D-printing challenges focused on localized problem solving and designing for others (for example, hallway-flow redesigns and a 3D-printed "trash hoop" attachment). Youth also created sensor-based prototypes with micro:bits, such as a stairway direction-management display, a hallway crowd-monitoring system using an ultrasonic sensor, and a water-quality activity that uses a turbidity sensor and LED indicators to determine whether water is safe to drink.

These sessions provided a low-stakes, collaborative setting that supported hands-on engineering work, peer leadership, and reflection on responsibility, harm, and sustainability in technology-rich engineering practices.

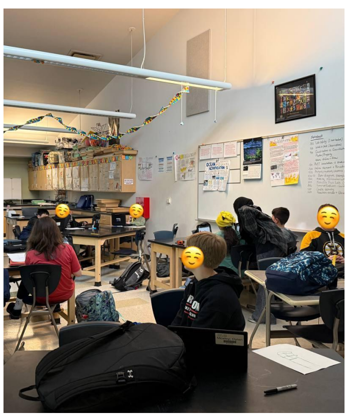
	
After-school STEM club session	Youth leaders meeting session

Figure 1. Youth engagement activities

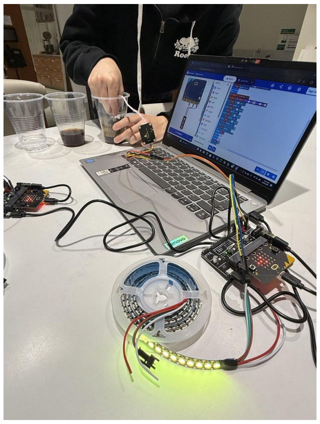
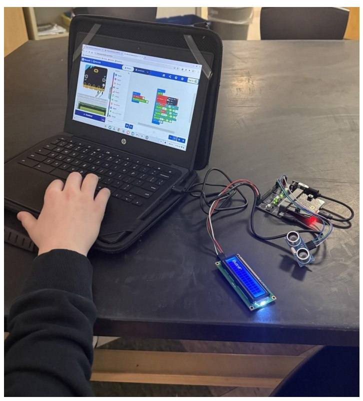
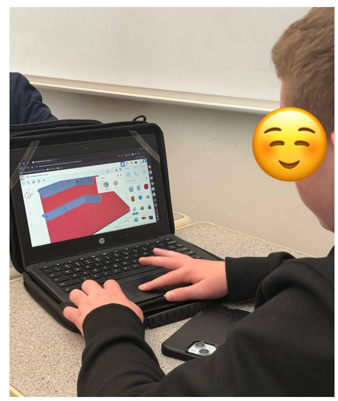
	
Microbit-Water quality detection device	Traffic hallway- measurement and CAD
	
Clogged halfway monitoring system activity	Redesign hallway traffic flow with 3D modeled floor plan

Figure 2. Engineering design activities

Participants

Youth leaders, teachers, and middle school students participated in two afterschool STEM clubs that took place for two academic years. In Year 1, the program was implemented at School A and School B, with support from two teachers, five youth leaders, and 16 students (6 from School A and 10 from School B) grades 7-8, who attended afterschool STEM club sessions and weekday in-school design workshops.

In Year 2, the program continued at the same two schools with a similar structure and participation levels, with School A and School B each having two teachers, five youth leaders, and 20 students (11 from School A and 9 from School B), and was expanded to include Saturday design and research sessions as well as Monday afterschool STEM club sessions. Informed consent and assent were obtained from all participants.

Data Collection

Data were collected through pre- and post-interviews, video recordings, observation notes of program sessions, and artifacts/activities produced. For this paper, we focus on the interviews and research observations. The interview questions were designed to explore students' sense of belonging in STEM, leadership experiences, and conceptions of engineering. The research observations were field notes that multiple researchers kept during the Saturday and school-day sessions in areas relevant to the broader project goals described early on in the paper.

Data Analysis

We employed an inductive thematic analysis [29], [30] to analyze data from pre- and post-interviews and research observations. We chose thematic analysis for its ability to detect and explain patterns connected to youth experiences of belonging in STEM, leadership practices, and engineering concepts. The analytic procedure began with open, inductive coding of interview transcripts in Dedoose qualitative analysis software, without predetermined categories. Since coding occurred in multiple waves, at least three researchers individually coded the data before meeting to compare, discuss, and merge codes through iterative consensus building. Themes were developed through multiple rounds of discussion to ensure consistency with the research questions and across all data sources.

Findings

Experiencing and Fostering Belonging in Engineering

Across pre-interviews, both STEM club students and youth leaders described belonging in engineering as interest-driven and situational, linked to engaging in hands-on activities, being creative, or spending time with friends, rather than recognition, responsibility, or contribution. Youth leaders commonly described belonging as conditional, indicating that they felt comfortable within the club but were concerned about belonging in larger engineering contexts. Post-interviews demonstrate a qualitative shift in both groups, with youth leaders showing the most significant shift. Students increasingly identified belonging as stemming from involvement, peer support, and inclusion in youth-led activities, whereas young leaders stressed the recognition and responsibility gained through facilitation and mentorship. Thus, belonging evolved from a personal sense of comfort to a relational experience based on being seen, assisting others, and contributing to a shared technical community, as discussed in the following findings.

Belonging as Comfort, Familiarity, and Interest

Pre-interviews uncovered that the youth largely associated belonging in STEM with personal passion or skill, rather than social inclusion or leadership. For example, AW defined belonging as enjoyment related to the action itself, "*I like STEM because you get to make stuff and it's fun to engineer things.*" This framing represents a personalized definition of belonging, in which their sense of belonging is tied to a preference for STEM rather than to a sense of social recognition or responsibility for others.

Similarly, NM defined belonging as familiarity and ease with tasks, "*If you know what you're doing, it feels better to be there.*" This reply indicates belonging as task-based confidence rather than a relationship or communal feeling.

RS defined belonging as satisfaction and preference over alternative afterschool options, *"I feel like it's fun. Because, would I rather be at home… doing really nothing? Or would I be in school actually participating in fields I like, I like find like fun?*" This framing represents belonging as a personal desire rather than a relational experience. Similarly, CR characterized happiness as being with friends and engaging in activities, "*I enjoy being with my friends and doing the different activities… building robots or just TinkerCAD*." Here, belonging is present but implicit, grounded in comfort and familiarity rather than in acknowledgment or leadership.

Similar patterns were also evident in STEM club participants' pre-interviews. For example, during the pre-interview, NB, emphasized the importance of teamwork and not feeling excluded. They stated, "*we're all just… working together… as like a team on… projects… and I don't feel left out.*" This indicates that early belonging was founded on inclusion and collaboration rather than disciplinary confidence.

MB defined affiliation to the STEM group as based on comfort, familiarity, and relationships, rather than engineering identity or competency. MB stated, "*I feel comfortable here because I have some friends and my sister,*" emphasizing that being around familiar faces makes involvement easy. At the same time, MB reported feeling "*kind of overwhelmed*" as the area grew packed, suggesting that belonging was situational and responsive to the learning environment, rather than grounded in engineering experience or confidence.

AH defined belonging as contextual and unstable, with a focus on feeling comfortable in familiar locations rather than recognition or identity confirmation. They stated that, while they had a feeling of belonging in the STEM club, "*in the wider world, I feel like it'll be a lot harder*", noting that engineering spaces frequently lack representation for people like herself. This conceptualization of belonging emphasizes temporary comfort rather than steady inclusion.

Belonging as Recognition, Voice, and Shared Meaning

In post-interview discussions, youth leaders described belonging as evolving over time through leadership and peer engagement. RS described a difference in the way peers interacted with the youth leaders. "*after a few weeks… the students actually referred to us as like leaders. They started coming up asking questions like help… it was like, sweet.*" This moment represents recognition-based belonging, in which their peers acknowledged them as leaders. Similarly, ES stressed that common interests enable comfortable social interactions, "*everyone there has the same interests, so it's easier to talk to people… even if you don't know them.*" This represents belonging as community membership, rather than just task involvement.

AW said, "*It makes me feel good because we're all using our minds together, and it makes the projects better.*" This shift reflects a movement toward collective belonging, in which STEM participation is linked to collaboration rather than individual enjoyment. Similarly, RR described belonging as supporting others, "*I liked explaining it in my own way because other students understand students better.*" Here, belonging is linked to recognition as a capable peer leader, aligning with the study's emphasis on youth leadership as a means of inclusion.

In post-interviews, STEM club members increasingly defined membership as being linked to acknowledgement of their ideas and work. NB stated that having their design emphasized by an adult helped them feel like they belonged, "*Miss [H…]… used mine to show everybody… it shows that like, Oh, I have a good model. So… I belong*." This transition indicates a shift from broad inclusion to acknowledgment of engineering expertise, emphasizing the importance of youth-led activities and facilitation in making contributions visible and meaningful.

Recognizing and Responding to Harm in Engineering and Technology

Prior to involvement, students and youth leaders understood harm in engineering and technology through isolated, well-known examples (e.g., accidents, pollution, hacking), which were often presented as accidental or unrelated to design decisions. Youth leaders occasionally mentioned technology that is useful but can also be misused, but they did not articulate ethical responsibilities beyond testing or purpose, whereas students typically viewed engineering as inherently beneficial. In the post-interviews, both groups showed a marked move toward contextualized, human-centered reasoning. Students started making connections between engineering processes and contexts, such as water filtration or hallway flow design, to human health, safety, and environmental effects, while youth leaders identified indirect and systemic impacts to infrastructure, climate change, and community well-being. Together, these developments represent a transition from surface-level identification of harm to an emerging understanding of engineering as a socially embedded discipline that necessitates ethical thought, as demonstrated in the findings that follow.

Harm as Abstract or Technical

Prior to their involvement in the program, youth leaders frequently used ambiguous or surface-level language to indicate harm. For example, GQ noted, "*technology can cause harm like viruses or hacking,*" CR stated, "*engineering… helps solve problems… I can't really think of any harm.*" These answers reflect a one-dimensional view of harm that ignores social and environmental effects. Similarly, NM stated, "*If something doesn't work right, it could be bad.*" These statements imply that harm was initially perceived as a malfunction or misuse rather than as an ethical issue within societies. Similarly, FM struggled to define harm, "*I can't really think of one [failed design]*." These responses indicate a limited ethical framework, with engineering essentially seen as a problem-solving activity.

NB initially saw engineering and science as inherently beneficial, noting, "*I think science just talks about ways to help stuff, not really hurt.*" When asked how engineering may help prevent injury, NB said, "*I'm not sure*." These comments reveal a narrow ethical framework in which engineering was considered only useful, with little regard for possible harm or responsibility.

MB had early awareness of harm during the pre-interview, stating that engineering may be harmful by intent: "*some people engineer things that aren't good… like weapons.*" However, when asked how harm might be avoided, MB said, "*I'm not really sure,*" indicating that while harm was recognizable, strategies for prevention or responsibility were underdeveloped at this stage.

AH first described engineering harm as neutral, stating that technology may be utilized for both good and harmful purposes, "*nothing is essentially like, good or bad….. engineering could be used for good, like building houses, like Hurricane proof homes and stuff, but it can also be used for bad things. And the same thing is with technology, so it can cause harm, it can also do good.*". Harm was defined as misuse rather than ethical duty.

Harm as Social, Environmental Consequences and Contextual

Following the workshops, youth leaders demonstrated a deeper understanding of harm to people and the environment, and of responsibility. For instance, GQ reflected, "*humans caused global warming, so engineers have to think about what they're making.*" This statement demonstrates a shift in engineering towards human responsibility, from technical failure to social consequences. RR also emphasized prevention and care, "*you have to think about how it affects people before you build it.*" Post-interviews indicated that youth leaders began to conceptualize engineering as a human-centered activity, which aligns with the program's harm-reduction objective.

RS directly linked engineering with environmental impact, "*Cars… help us travel, but they release carbon emissions… speeding up climate change*," ES also noted, "*Factories can pollute the air… building takes away wildlife*." These comments represent a development toward systems thinking, in which engineering is recognized as having unexpected implications for people and the environment.

Importantly, students associated harm recognition with specific behaviors. ES described the paper aircraft activity as symbolic, "*If it goes longer with less fuel, it's better for the environment and people's quality of life.*" This suggests activity-mediated ethical thinking, rather than abstract moralizing.

In the post-interview, NB showed an increasing understanding of harm and responsibility in regard to engineering activities. When commenting on water-related projects, NB stated, "*if we don't have good water, then we're not going to be safe and healthy.*" The comment reveals a shift toward viewing engineering challenges as directly related to human health and safety, suggesting that hands-on, context-driven activities fostered more specific ethical thinking.

AH in post-interview clearly connected harm to human motivations and decision-making, claiming, "*we couldn't stop putting greenhouse gas into the air, because we couldn't stop wanting money*." They defined design work as guided by the understanding that it will affect someone, indicating a trend towards human-centered ethical thinking. AH described leadership as mentally demanding yet important. Despite being frustrated when "*a lot of the kids didn't really listen*," they liked helping others learn. They defined leadership as perseverance in the face of exclusion, telling prospective leaders that "*you have to make that space for yourself*". This makes student leadership critical to the long-term viability of inclusive engineering settings.

While participants demonstrated increased awareness of harm and responsibility, their reasoning was often grounded in explicit and visible examples, such as pollution or safety. Such responses represent developmentally appropriate entry points into ethical reasoning, with conceptualizations beginning with obvious impacts and progressing to increasingly complicated ethical considerations.

Youth Leadership in Developing and Maintaining Engineering Environments

Prior to the interviews, students and youth leaders mostly conceived of leadership in hierarchical, task-oriented terms, emphasizing teaching, control, and individual characteristics such as knowledge and responsibility. Students' pre-interviews provided minimal articulation of youth leaders' duties, with most referring to them implicitly as assistants or teachers rather than peers, impacting the learning environment. Youth leaders described leadership as helping or leading, rather than highlighting relational or emotional work. Post-interviews indicate a significant reframe for both groups. Students increasingly described youth leaders as approachable peers who explained ideas, provided reassurance, and promoted inclusion during engineering activities, whereas youth leaders emphasized leadership as relational, emotionally demanding, and care-oriented, requiring patience, empathy, and responsiveness to peers' needs. Thus, leadership shifted from task management to community leadership, supported by specific data showing how young leaders actively constructed inclusive and sustainable engineering learning settings.

Leadership: Authority or Instruction

Initially, youth leaders defined leadership as explaining tasks and providing guidance. NM stated, "*leaders tell people what to do and how to do it.*" This indicates a hierarchical vision of leadership that emphasizes instruction above facilitation.

CR described a leader as someone who "*takes charge… and guides people through problems*." FM similarly emphasized traits, "*bravery, responsible, organized*." These descriptions of leadership emphasize individual attributes rather than relational activity.

Leadership as Facilitation and Care

Youth leaders in post-interviews stressed leadership as assisting peers and shaping the learning environment. RR explains, "*even when it was frustrating, we were there to help and guide*." Similarly, AW noted, "*people warmed up more when we helped instead of just telling them.*" These responses reflect a shift toward relational leadership, with student leaders actively fostering inclusive, friendly engineering environments.

RS explained, "*even if it was frustrating, we were there to help and guide.*" FM explained the emotional complexity of leadership, "*It felt good being a leader… but also stressful because you have to help everyone at once.*" FL emphasized learning through challenges, "*there were problems… but we learned to challenge those*." The responses above suggest that leadership is challenging and requires emotional regulation, mediation, and peer support.

From the perspective of STEM club members, youth leadership techniques also contributed to a sense of belonging by making students' ideas visible and appreciated, as evidenced by NB's remark that their work was emphasized during club activities.

Tension Between Control and Openness

Across post-interviews, youth described tension between enjoying autonomy and feeling overwhelmed. RS stated, "*I like that there's multiple ways… but sometimes it's hard to find the best way.*" FM reflected the tension, "*multiple things are happening at once… it's kind of hard*." This theme emphasizes productive conflict, in which openness fosters creativity while introducing cognitive and emotional burdens.

Discussion

This study examined how middle school students felt a sense of belonging, developed ethical awareness about harm, and demonstrated leadership in technology-rich, youth-led afterschool STEM activities. The findings show that belonging, ethical reasoning, and leadership are relational practices that developed via participation, acknowledgment, and accountability. In this section, we contextualize these findings within previous research on informal STEM learning, youth leadership, and justice-oriented engineering education, emphasizing how youth-led, participatory programs may uniquely promote such formative transitions.

From interest-based participation to recognition-based belonging

Consistent with previous research, youth initially characterized STEM membership as based on interest, enjoyment, or task familiarity, rather than social recognition or leadership [10], [32]. Early definitions of belonging centered on loving activities, feeling at ease with tasks, or spending time with peers, patterns frequent in informal STEM environments that promote voluntary engagement and low barriers to entry [9]. These findings are consistent with research indicating that early participation is frequently motivated by situational interest rather than identification or group membership [36].

However, post-interviews revealed a shift toward recognition-based belonging, with youth defining belonging as being recognized for their ideas, leadership, and achievements. This transformation is consistent with identity development research, which suggests that persistent belonging involves external acknowledgment and legitimate engagement rather than only interest or comfort [3], [4]. When youths were positioned as facilitators and knowledge providers, belonging was linked to being perceived as capable by peers and adults, corroborating the idea that recognition is an important process for shaping STEM identities [5].

Additionally, youth identified belonging as something that must be actively claimed at times, particularly by students who did not feel reflected in larger STEM narratives. This conclusion is consistent with research on "rightful presence," which highlights that belonging is more than inclusion; it also involves establishing legitimacy in settings that have traditionally excluded particular identities [22]. In this sense, youth leadership served not just as an instructional tool, but also as a means of reforming whose involvement is valued in engineering settings.

Raising Ethical Awareness through Contextualized Engineering Practice

Youth perceptions of harm changed during the program. Prior to participation, harm was mostly defined in technical or abstract terms, such as malfunction, misuse, or isolated accidents. This is consistent with engineering education research findings, which reveal that students frequently conceive of engineering as value-neutral and focused on problem-solving rather than societal effects [34], [31].

Following participation in the youth-led, context-driven design activities, students began to express harm as socially created and ethically significant, connecting engineering decisions to environmental degradation, public safety, and community well-being. This change is consistent with justice-centered STEM education literature, which shows that learners' ethical reasoning improves when they work on real-world, locally relevant problems rather than decontextualized technical difficulties [21]. Hands-on activities such as water-quality testing and emissions-aware design appeared to aid this shift by making consequences visible and tangible.

It is important to emphasize that, while we observed evidence for ethical reasoning among youth, it was frequently grounded in obvious and explicit examples of harm. Rather than dismissing this as an oversimplification, we view it as a developmentally appropriate step in learning about ethics. Early engagement with engineering ethics frequently starts with detecting visible forms of harm before moving on to more sophisticated issues like trade-offs, competing stakeholder interests, or unintended consequences.

Importantly, youth did not solely identify harm, but increasingly saw engineers as responsible individuals capable of minimizing harmful consequences. This aligns with work in engineering education that prioritizes care, prevention, and responsibility over failure avoidance [6], [37]. These findings imply that informal, youth-led engineering spaces may be particularly well-suited to developing ethical awareness because they allow students to combine technological design with lived experiences and moral reasoning.

Future iterations of this work may include more complicated ethical dilemmas to assist in the development of advanced ethical reasoning.

Youth Leadership: Relational, Emotional, and Ethical Practice

Conceptions of youth leadership also developed over the course of the program. Leadership was first defined in hierarchical terms, directing others, providing orders, or managing tasks, reflecting prevailing paradigms of power that were frequently reinforced in school-based contexts [14]. However, as time passed,

youths began to characterize leadership as facilitation, care, and emotional work, emphasizing patience, support, and responsiveness to their peers' needs.
This change reflects previous research indicating that youth leadership in informal learning situations is frequently developed via practice rather than teaching and is highly relational [16], [15]. Youth leaders mentioned dealing with dissatisfaction, overcoming peer opposition, and balancing openness with structured experiences, consistent with research on peer mentorship and collaborative learning in STEM [33]. The conflict that youth express between autonomy and overload emphasizes the constructive complexity of youth-led settings. Open-ended design encouraged creativity and ownership while also presenting cognitive and emotional challenges, reflecting studies on productive struggle in makerspaces and design-based learning [13], [35]. Rather than viewing these conflicts as shortcomings, the findings show that handling uncertainty is an essential leadership skill, especially in ethical, community-oriented engineering environments.

Implications for informal STEM education and youth-centered engineering
Taken together, these findings highlight the potential of youth-led, participatory approaches in informal STEM education. The program promoted the development of belonging as recognition, engineering as a human-centered activity, and leadership as care-oriented and relational by enabling students to be leaders, designers, and ethical decision-makers. These findings build on previous research on informal STEM learning by demonstrating how YPAR-informed approaches can promote identity formation, ethical reasoning, and community building simultaneously. The findings also indicate that technology-rich environments by themselves are inadequate for equitable and critical learning; the social structure of involvement, particularly who leads and whose ideas are valued, influences teenage experiences [25], [26]. Designing informal engineering programs that explicitly prioritize youth leadership and ethical reflection may be crucial for building inclusive, responsible engineering trajectories.

While this study focuses on shifts in belonging, ethical awareness, and leadership within the program, these improvements may have long-term implications for STEM participation. Previous research has suggested that experiences of belonging and recognition are associated to persistence in STEM pathways; however, this study does not explicitly examine outcomes such as career aspirations or future course-taking decisions.

Conclusion
Our work illustrates how youth-led, technology-rich afterschool STEM activities can support middle school students in developing a sense of belonging, ethical awareness, and engineering leadership skills. Youth gradually shifted their perception of belonging from individual interest or comfort to acknowledgment, voice, and shared duty within a community. Through persistent leadership positions and peer facilitation, participants developed to perceive engineering as a human-centered activity with social and environmental implications, rather than just a technical undertaking.
The findings also demonstrate that involving students in participatory, context-driven engineering activities can improve their ability to perceive harm and express responsibility to others and the environment. Youth leadership evolved into a relational, care-oriented approach, requiring emotional management, teamwork, and responsiveness to peers. Together, our findings demonstrate the importance of YPAR-informed, informal STEM environments in establishing youths as skilled contributors, ethical thinkers, and community builders, with implications for developing more inclusive and responsible engineering paths. These findings indicate entry points into identity and ethical development, and they may lead to more complex understandings of engineering responsibility over time.
This study was conducted in two youth-led afterschool STEM programs within a single school district. Furthermore, the qualitative design was based on interviews and observations, which capture participants' perceptions but may not include all instances of belonging, ethical reasoning, or leadership.

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