frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 15 April 2025
DOI 10.3389/feduc.2025.1568153

EDITED BY
Audrey Meador,
West Texas A&M University, United States

REVIEWED BY
Shanna Peeples,
West Texas A&M University, United States
Shirley Matteson,
Texas Tech University College of Education, United States

*CORRESPONDENCE
Kristie S. Gutierrez
kgutierr@odu.edu

RECEIVED 28 January 2025
ACCEPTED 02 April 2025
PUBLISHED 15 April 2025

CITATION
Gutierrez KS, Swanson KJ and Blanchard MR (2025) Rural families' at-home STEM tinkering stimulates creativity, self-expression, and social–emotional engagement.
Front. Educ. 10:1568153.
doi: 10.3389/feduc.2025.1568153

Rural families' at-home STEM tinkering stimulates creativity, self-expression, and social–emotional engagement

Kristie S. Gutierrez[1]*, Kylie J. Swanson[2] and Margaret R. Blanchard[3]

[1]Department of Teaching and Learning, Old Dominion University, Norfolk, VA, United States, [2]Department of Teaching and Learning, University of Colorado Colorado Springs, Colorado Springs, CO, United States, [3]Department of STEM Education, North Carolina State University, Raleigh, NC, United States

Introduction: Informal STEM learning experiences include visits to museums, zoos, and aquariums, as well as experiments and other activities performed at home. Family involvement in these experiences has been linked to increased student interest and participation in STEM fields; yet, scant research has been conducted on at-home STEM.

Methods: This descriptive case study investigated the tinkering experiences of nine rural middle school students and their families who participated in a series of interactive, at-home activities. The overarching research question was: *In what ways do families engage in at-home STEM interventions? The Learning Dimensions of Making & Tinkering* framework guided data analyses of at-home audio recordings. Follow-up interviews with families about their informal STEM experiences were a secondary data source used to contextualize family dynamics.

Results: Overall, families who engaged in at-home STEM activities were most likely to demonstrate *Social & Emotional Engagement* (e.g., Collaborating and Working in Teams) and *Creativity & Self-Expression* (e.g., Expressing Joy and Delight), and were least likely to exhibit *Initiative & Intentionality*. Engagement patterns differed based on family (dynamics and backgrounds), family participant group type (number of parents and children in groups), and the STEM activity. Rich descriptions and vignettes illustrate the moment-to-moment experiences of families as they engaged in at-home STEM together. Additional evidence was gleaned through family interviews. Families valued their time together and tinkered in ways that stimulated their self-expression, creativity, and social and emotional skills.

Discussion: Recommendations for professional developers include attention to the order of activity difficulty, length of time required, inclusion of conceptual material, and allowing time for failure and risk-taking. Researcher recommendations suggest ways to streamline the data collection and analyses to ease the resources required to study other populations of interest.

KEYWORDS

rural STEM experiences, at-home STEM, tinkering, informal STEM, middle school, family engagement, creativity, social and emotional engagement

1 Introduction

Informal learning experiences are a way to engage students and their families in STEM learning and have been linked to increased interest and participation in STEM fields (Dabney et al., 2016; Lin and Schunn, 2016; Roberts et al., 2018). Informal STEM learning experiences can include visits to museums, zoos, and aquariums as well as experiments and other activities performed at home. These experiences provide context for classroom learning, access to novel ideas, and extended engagement (Roberts et al., 2018). There are benefits for children who participate in informal STEM activities at home. Lin and Schunn (2016) found that students had increased levels of interest, value, motivation, and heightened views of their competence, as has been seen with other informal learning opportunities (e.g., Bathgate et al., 2014; Blanchard et al., 2017). At-home parental involvement in their child's learning could be key to greater engagement, increased learning, and planning for post-secondary education and careers (Epstein, 1986). Thus, there is a need to provide opportunities for parents to remain involved in middle school to assist their children in content knowledge gains and planning for post-secondary education and careers (Epstein, 1986; Gutierrez and Blanchard, 2019). This qualitative exploratory case study investigates the experiences of nine rural, middle school students and their families who participated in *STEM Home Edition* over 10 months in the southeastern U.S.

2 Literature review

This literature review outlines the roles that parents and families play in STEM learning and STEM identity development, specifically related to demographic variables such as socioeconomic status, rurality, race/ethnicity, and parental education level. Research about tinkering in STEM in informal contexts (e.g., afterschool clubs, camps, museums) is also explored. Lastly, the *Learning Dimensions of Making & Tinkering Framework* (Bevan et al., 2017) is described as the conceptual framework used for this study.

2.1 Parental/family involvement

Families play an important role in students' development of STEM identities (Archer et al., 2012). Parental involvement in education is inversely proportional to student age (Hill, 2015) even though parental involvement is more closely associated with achievement in middle school and high school than in elementary school (Hill et al., 2018). Parents may become less involved during middle school due to the desire to allow their students to become more independent or due to the perception of barriers that prevent them from becoming involved with the school (Bhargava and Witherspoon, 2015; Hill et al., 2018). Increasing parental involvement in STEM learning could be a key to increasing overall STEM participation.

There are inherent challenges to parental involvement due to various demographic factors such as socioeconomics, urban/rurality, race/ethnicity, and parental educational level. Sociocultural theorists posit that in the United States, parental involvement standards are based typically on standards established by "white, middle-class, non-immigrant parents" (Holloway and Kunesh, 2015, p. 3). Crosnoe (2015) asserts that "children from socioeconomically disadvantaged and/or racial/ethnic minority backgrounds tend to benefit the most from having involved parents" (p. 63). Demographic variables are explored, below, for key factors associated with parental involvement in student learning.

2.1.1 Socioeconomic influences

Financial challenges in the home can constrain the abilities of parents to provide children with educational resources in the home such as books, age-appropriate toys, and even a proper setting for at-home learning with sufficient lighting and reduced distractions (Dearing et al., 2015). Not only do low-income families struggle to provide physical materials to support learning, but they also may struggle to provide services that would allow for better parent-school communication, such as transportation costs or inflexible work schedules. Middle and upper-class families share the common 'code book' with schools that identify implicit rules and guidelines for navigating the educational system (Hill, 2015). This allows for clearer avenues for communication between parents and schools. On the other hand, low-income parents who do not share this language often feel a lack of trust, lower status, and more substantial social barriers to building meaningful relationships with school staff (Bornstein and Bradley, 2002; Crosnoe, 2015).

2.1.2 Rurality

STEM learning and identity development in youth are influenced by the unique challenges and opportunities presented by rural environments. Rural areas often face limited access to advanced STEM resources, such as laboratories and extracurricular programs, which can hinder the development of students' STEM identities (Parker et al., 2021). However, these settings also provide unique opportunities to connect STEM education with local contexts, such as environmental stewardship, fostering relevance, and engagement in place-based education (Waters et al., 2018). Developing a strong STEM identity is crucial for rural youth, enhancing their confidence in pursuing STEM careers and helping address the broader underrepresentation of rural students in STEM fields (Bathgate et al., 2014). Tailored interventions, including mentorship programs and community-driven STEM initiatives, have shown promise in supporting identity development and increasing STEM participation among rural youth (Azano et al., 2017).

2.1.3 Race and ethnicity

Hill and colleagues (Hill, 2015; Hill and Torres, 2010) have identified challenges specific to different races and ethnic groups. Implicit knowledge is information that is generally not made completely clear or 'spelled out' (e.g., high school courses colleges and universities expect students to have taken or information on how to pay for college) through regular modes of communication but rather is embedded into the culture and school system and not commonly shared (Spencer et al., 2020). Minority parents may be less aware of or not made aware of systemic policies and unspoken (implicit) opportunities, such as courses needed for college readiness and career pathways or how to advocate for their children's educational decisions (Lareau, 2011; Lareau and Horvat, 1999; Metheny and McWhirter, 2013).

2.1.4 Parental education level

Students from families whose parents have higher levels of education or place special emphasis on scientific learning are more likely to pursue a STEM field than those from families who do not (Dabney et al., 2016). College-educated parents are better able to develop college aspirations through their involvement in their children's school behavior and achievement as compared to parents without college degrees (Hill et al., 2004). Not only do middle to upper-class families have more tacit knowledge about school function and proper pathways to college and careers, but they also have more social capital and self-efficacy. Social capital includes students' receiving "information, values, norms, standards, and expectations" through relationships with parents, peers, and others (Wells et al., 2011, p. 3). The value put on post-secondary education and expectations for college enrollment is often different between parents with varying levels of education. In addition, parents with high school terminal degrees may lack confidence or self-efficacy to assist their children with their academic work at home, leading parents to feel academically incompetent (Hornby and Lafaele, 2011).

2.1.5 Parental engagement

Increased parental involvement in their child's education has led to greater academic success (Jeynes, 2012; Yan and Lin, 2005). McKenna and Millen's (2013) model of parental engagement involves parent presence and parent voice. These researchers outline four essential components of parental engagement: (1) active and deliberate, (2) communal and personal, (3) developed over time, and (4) culturally sensitive. The focus of their model is on navigating relationships between parents and school personnel, to enhance student growth and development. Another model of parental involvement is the Hoover-Dempsey and Sandler (Walker et al., 2005) five-level model of parental involvement. This model was later revised (Whitaker, 2019) and traces family involvement from their decision to become involved (Level 1) to how they will be involved (Level 2) and the mechanisms of their involvement (Level 3). After involvement, Level 4 focuses on the mediating variables that influence parental involvement, and the final level, Level 5, focuses on child/student outcomes. Parental choice of involvement can be made both explicitly and implicitly. Parents can reflect, be aware of, and be active in their decisions to be involved or they can simply respond to external events or demands from their external environment (Hoover-Dempsey and Sandler, 1997).

2.2 Tinkering in STEM

While there are inconsistencies in the ways in which researchers define 'tinkering.' Vossoughi and Bevan (2014) highlight characteristics of tinkering from the literature that help to define the term. The authors draw on tinkering's interdisciplinary focus on STEAM (science, technology, engineering, arts, and mathematics), creative problem solving, and its "mindset that can cut across intentional building (making) and disciplinary construction activities (engineering)" (p. 8). Tinkering also has been closely tied to STEM content and practices through the inquiry-based methods of learning it is known for. Tinkerers are tasked to utilize their problem-solving and critical thinking skills to think outside the box and generate solutions to problems. Tinkering, while able to be done within traditional learning environments, is often implemented and explored through out-of-school experiences (e.g., afterschool clubs, camps, museums) (Vossoughi and Bevan, 2014).

In all settings, tinkering activities have specific goals and parameters the tinkerers are working toward; additionally, learning practices such as failure and multiple iterations are intimately part of the tinkering process (Vossoughi et al., 2013). Marcus et al. (2021) explored ways in which families and children engaged in engineering design challenges in a way to tinker and learn about engineering-related content. They contend that engineering is one of many fields that can be effectively explored through tinkering as "children playfully explore a problem space and test and iteratively adjust their creations during tinkering" (p. 2). Using both real-time audio recording during tinkering activities and a narrative reflection following the experience, Marcus et al. found that providing families with exhibit/activity-specific information for completing the activity was crucial, as was the provision of testing stations for families to fully engage in engineering practices. Simpson et al. (2020) found similar results in their work in an afterschool STEM program for K-2 and 3–6 grade students in six elementary schools. Partnering with a local museum, the youth learned about electricity and circuitry and then tinkered to construct flashlights, light-up greeting cards, and bookmarks with conductive thread. While aligned with the NGSS (2013), the informal context allowed students to demonstrate their science and engineering practices in unique ways that are not always encouraged (i.e., summative testing requirements) or allowed (i.e., provision of time and/or resources) in more formal classroom settings. Their work in informal spaces such as museums supports the current push in STEM educational research that promotes and studies youth and family learning and engagement.

The purpose of this case study is to explore how families engaged in a series of at-home STEM activities. To date, scant research (e.g., Aldrich, 2023) has followed families into their homes to learn about the various ways that families tinker. Families participated in up to four carefully designed STEM activities, audio recording their interactions throughout. These families also participated in a family interview after they had completed all four STEM activities. The findings will provide informal educators with considerations for how to structure and implement STEM activities in a home environment with no direct oversight by the activity designer or STEM educational professionals.

2.3 Conceptual framework

The Learning Dimensions framework (Bevan et al., 2017; Figure 1) was selected after researchers listened to home audio recordings, read through transcripts, and considered several frameworks that might be able to capture the nature of what was happening during family interactions. Other frameworks that were considered were the revised Hoover-Dempsey Model (Walker et al., 2005) and the Situated Expectancy-Value Theory of motivation (SEVT; Wigfield and Eccles, 2020). The Learning Dimensions framework, with its five Learning Dimensions (LD) and associated indicators, captured virtually all of the interactions that took place as the families collaborated. The first, *Initiative & Intentionality* (LD1), focuses on how tinkerers "demonstrate self-directed learning, purpose, and persistence" (Bevan et al., 2017, p. 5). These indicators include setting a goal, persisting through failure, and adjusting goals based on how things develop. 'Organization of materials' was added as an LD1 indicator to capture this at-home activity (all indicators are labeled a-f, and added indicators are marked

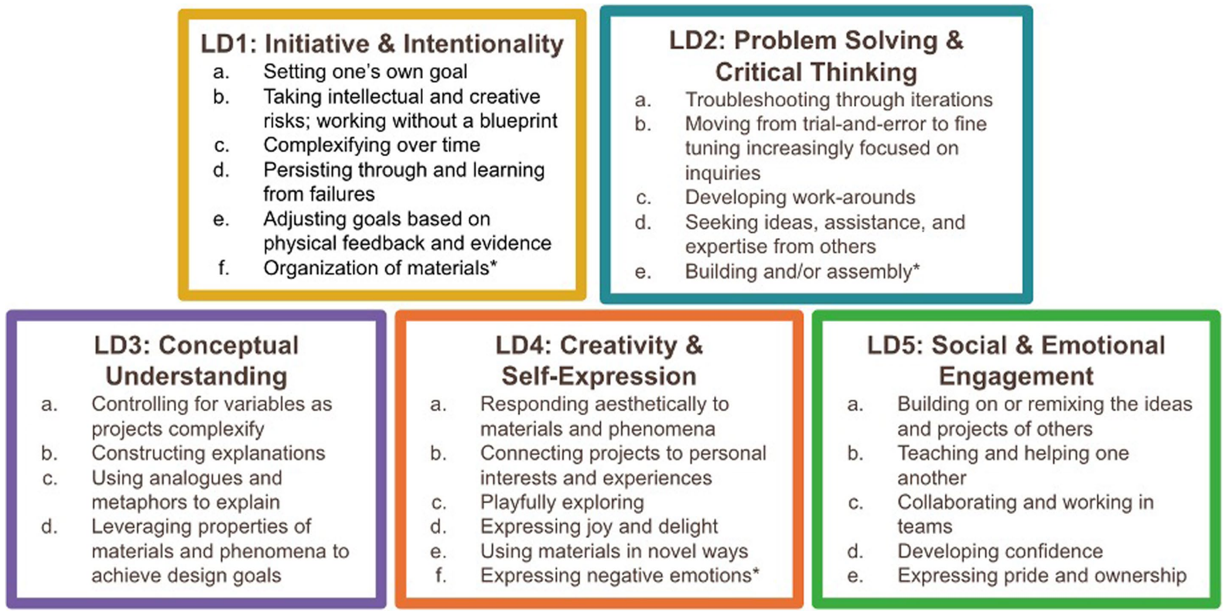

FIGURE 1
Learning dimensions of making and tinkering [adapted from Bevan et al., 2017].

with an asterisk in Figure 1). *Problem-Solving & Critical Thinking* (LD2) includes the indicators of trying out approaches, seeking ideas and assistance from others, and fine-tuning approaches. 'Building and assembly' was added as an indicator to capture the data captured in this study. *Conceptual Understanding* (LD3) focuses on how tinkerers construct explanations, use metaphors, and leverage the properties of the materials and phenomena to achieve design goals. *Creativity & Self-Expression* (LD4) captures aesthetic responses to the materials, playfully exploring, expressing joy and delight, and using materials in novel ways. 'Expressing negative emotions' was added to capture the data we coded. Finally, *Social & Emotional Engagement* (LD5) includes indicators that the tinkerers are building on the ideas of others, teaching and helping one another, developing confidence, working in teams, and expressing pride and ownership. Frequently, multiple dimensions or indicators occur concurrently in dynamic tinkering sessions.

2.4 Research design

This descriptive case study (Priya, 2021) investigated the experiences of nine families who fully participated in the *STEM Home Edition* experience in their homes. The study focused on how families interacted throughout STEM activities, drawing from a series of audio-recorded interactions, as they 'tinkered' with STEM kits and spoke with researchers during follow-up interviews with families.

2.4.1 Research questions

The overarching research question is: *In what ways did families engage in at-home STEM activities?*

1. What were the tinkering experiences: overall, of each of the families, and in what ways did they differ?
2. In what ways did families tinker, based on the makeup of the group (e.g., parents, children)?
3. In what ways did the learning dimensions and indicators differ based on the activity?

3 Materials and methods

3.1 Participants

This case study investigated the experiences of families (Total participants: $N = 30$; Families: $n = 9$; Parents/Guardians: $n = 13$, Children: $n = 17$) at 3 rural middle schools that participated in 3–4 at-home activities (and returned the associated data) during the school year. The families in this study drew from areas within the southeastern US that are predominantly considered rural fringe (less than 5 miles from an urban area of 50,000 or more) by the National Center for Educational Statistics (NCES, 2025). Nine families fully participated and their data was included in this *STEM Home Edition* (pseudonym for program) study. The nine participating families were selected because they completed over 75% of the *STEM Home Edition* activities *and* returned the associated data, out of a larger group of forty families. All families included in this case study completed the activities but may have failed to return their audio data for one activity. The authors were able to generate a robust case for each family for the variety of different activities with the completion and return of at least three of the four audio recordings. The completion of 75% or more of the activity data allowed for a comprehensive qualitative analysis of family interactions.

The after-school STEM Club students attended one of three rural, Title I middle schools in the southeastern US, and participated in the STEM Club at their school as part of an NSF-funded project (Blanchard et al., 2023). The STEM Club student membership for the participating schools was 55.0% African American, 22.5% White, 8.1% Hispanic, 6.3% two or more races, 4.5% Native American, and

3.6% American Indian/Pacific Islander. Females make up 63.1% of the clubs. The percentage of free or reduced-price lunch at all participating schools was greater than 70%. A large percentage of students at the participating schools failed the end-of-grade mathematics (70.9%) and science (36.1%) tests. Specific family demographics for those participating in the current study are shown in Table 1. In most families, the mom took the primary participating adult role. There was variation in families regarding the highest level of education of the participating adults, but most reported at least some college/technical school experience. Approximately 56% of the participating STEM Club students were White, and approximately 44% of families completed the *STEM Home Edition* activities with just one child.

3.2 STEM home edition

STEM Home Edition took place over one academic school year in the homes of students who were after-school STEM Club members and whose families opted in. Included in each of the kits were STEM activity materials, snacks, instructions for the activities, information about activity-related careers and local post-secondary opportunities, and pre-and post-activity questions (findings shared in Gutierrez and Blanchard, 2019). The *STEM Home Edition* activities (shown in Figure 2) were: Circuit Scribe Kit (i.e., electrically conductive ink and circuit components), Meccano robot (i.e., robot building kit and ability to push-button program movements), Germ Glo (i.e., visual tool to demonstrate proper handwashing techniques) and *Achoo! The most interesting book you'll ever read about germs*, and Steve Spangler's *Larry's Lab* (i.e., various water-soluble polymers—insta-snow, orbs, jelly marbles). All materials were selected by the first author to be age-appropriate, engaging, extensions of topics in the ongoing STEM clubs, and linked to content standards for middle grades.

For *STEM Home Edition,* the STEM kit was picked up by the student from a STEM Club teacher-coach and brought home. During the activity, families were asked to respond to pre and post-questions and to turn on an audio recorder to capture their verbal exchanges during the activities. When families returned the data (i.e., tape recorder, pre/post questionnaires) associated with one activity (they kept all the STEM supplies), they were provided with the next activity until they completed a possible maximum of four activities over the course of the year. Additionally, all nine families in this case study participated in post-project interviews.

3.3 Data sources and data analysis

This descriptive case study focuses on two main data sources: audio data returned from participating families and family interview data. The audio files from STEM Club families were transcribed verbatim, totaling fifty-six family audio files, sixty-two hours of audio, and 1,087 pages of transcribed home audio. Activity-specific prompting questions were provided in the STEM kits for each of the STEM activities to elicit family dialog. For example, in Activity 3 – *Achoo!* and Germ Glo - families were provided discussion questions to respond to throughout the book such as 'How would you feel if you had to live your whole life inside of one room for fear of getting deathly sick if you did not?,' and 'Why might you get a fever? Why might it be important to allow a low-grade small increase in temperature (below 102.5°F) fever to continue instead of treating it immediately?' The audio files from STEM Club family interviews were also transcribed verbatim from the nine participating families, totaling approximately 60 h of audio and 257 pages of transcribed interview audio. Questions in the interview probed participants to share which activities they liked the most and the least, justifying their reasoning for each. Also, families responded to questions about learning, both about STEM content and interpersonal skills like collaboration. Families described what they valued most through their participation in *STEM Home Edition*.

The three authors coded the home audio and family interview data in a web version of ATLAS.ti using *a priori* categories from the *Learning Dimensions of Making & Tinkering* framework. This allowed multiple coders to code at the same time. Each of the 26 indicator codes (see Figure 1) was also designated as *adult* or *youth* to discern which family member made the statement. To begin, the lead author loaded a separate version of each of the transcripts for one family, including the interview and set up the codes for each of the indicators, including a version for the adult and the child [e.g., (Adult) Persisting through and learning from failure; (Youth) Persisting through and learning from failure]. Each of the three authors independently coded all four STEM activities from one family and a family interview (>10% of data). As

TABLE 1 Demographics of participating families.

Family name	Race/ Ethnicity (STEM club participant)	Gender (STEM club participant)	Age (STEM club participant)	Primary participating adult(s)	Highest level of education participating adult(s)	Number of participating children
Mueller	W	F	13	Mom	GD	2
Brown	B	M	12	Mom	CG	3
Baptise	MR	F	11	Dad and Mom	HS & SC	1
Jackson	B	F	11	Mom	CG	2
Jones	B	M	11	Dad (some Mom)	SC (SC)	1
Wilson	W	M	12	Mom	GD	1
Baker	W	F	13	Mom (some Dad)	SC (GD)	4
Murphy	W	F	12	Mom	CG	2
Wagner	W	M	11	Mom	SC	1

W, white; B, black; MR, multi-racial; F, female; M, male; GD, graduate degree; CG, college graduate; HS, high school; SC, some college.

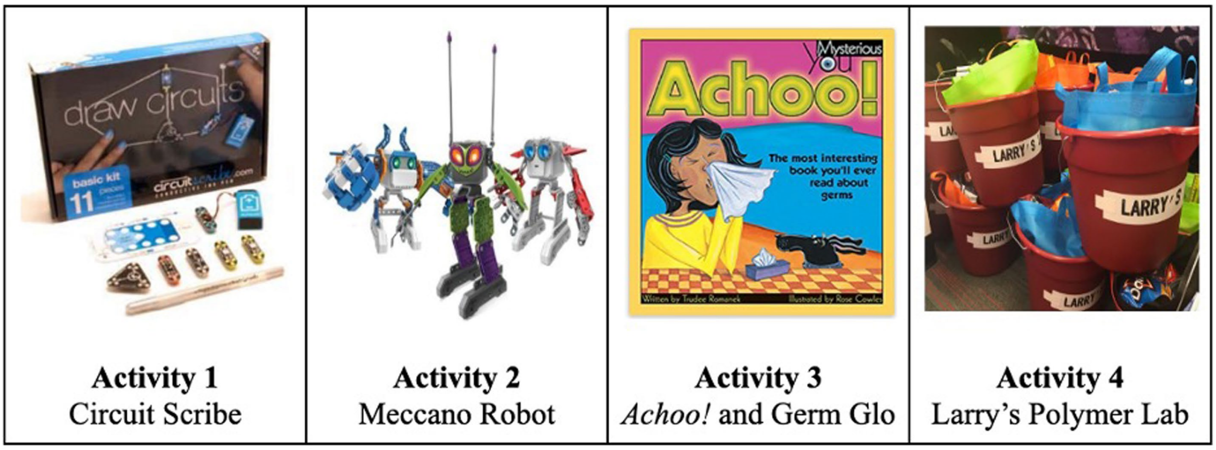

FIGURE 2
STEM home edition activities.

they worked independently but in the same room, the coders would ask questions, such as about how to handle long exchanges of working sessions [e.g., (Adult) Teaching and helping one another] interrupted by one expression [eg., (Youth) Connecting project to personal interests and experiences]. Several patterns were noted and agreed upon: it was acceptable to code long sections as one if they were consistently the same thing such as (Adult) and (Youth) Collaborating and working in teams; often there was a short interruption, such as Expressing joy or delight ("It's working, it's working!"); allow multiple codes if relevant on some/all overlapping text (e.g., Developing confidence and Expressing pride and ownership); discern between adult and youth codes; and, add in extra indicator codes for behaviors that did not seem to be captured by the original tinkering framework (Bevan et al., 2017). Common codebook keywords and concept examples that were used by the authors are provided for each Learning Dimension in Table 2.

Following this, the authors compared their codes for each of the transcripts from the same family, going slowly through each of the coded transcripts. The initial interrater reliability (>85%) reflected very similar perceptions of the codes, and the main differences were often between two codes that were in the same Learning Dimension [e.g., one person coded (Adult) Teaching and helping one another and another researcher had coded (Adult) Collaborating and working in teams - both indicators in LD5, Social and Emotional Engagement]. This process of comparing codes allowed the researchers to discuss how to tease out the differences between when to use one code versus another. The authors then evenly distributed the coding of the activities and families so that each person was responsible for all data from three individual families. Each coder had a color copy of Figure 1 by their side as they coded as well as the model from the first coded transcripts. ATLAS.ti was used to determine descriptive statistics for framework dimensions and indicators as the authors explored the data for any differences by family, family participant group type, or activity.

4 Results

The initial findings of this study showed differences in how the individual families worked through the *STEM Home Edition* activities. This spurred the second research question to further examine the differences among and between the various types of family participant groups. Lastly, the differences in tinkering between the four *STEM Home Edition* activities were explored.

4.1 Tinkering experiences overall and for each family

Parent and children's Learning Dimension indicators were quite similar across all of the dimensions and indicators. Table 2 displays the tinkering dimension and indicator breakdowns overall and by role (i.e., youth, adult). Overall, the most prominent Learning Dimensions coded during the tinkering experiences for all families was *Creativity & Self Expression*. Within Learning Dimension 4, the top coded indicators were expressing joy (LD4d, 12%), Connecting Projects to Experiences (LD4b, 9%) and Playfully Exploring (LD4b, 8%). This was followed closely by *Social & Emotional Engagement*. In this Learning Dimension 5, the top indicators were Collaborating in Teams (LD5c, 14%) and Teaching and Helping (LD5b, 10%).

Problem Solving & Critical Thinking codes, in Learning Dimension 2, were observed at a much lower frequency. Building and Assembly was the top coded indicator (LD2e, 7%), followed by Trouble-shooting (LD2a, 4%) and Seeking Ideas/expertise from others (LD2d, 4%). The Learning Dimensions that were least likely to be coded were *Initiative & Intentionality* and *Conceptual Understanding*. For *Initiative & Intentionality* (LD 1), the highest indicator coded was Organization of Materials (LD1f, 5%), Setting Goals (LD1a) and Persisting/Learning through Failure (LD1d) indicators, coded at 2%, each. *Conceptual Understanding* (LD 3) was the least likely to be coded, at less than 7% overall, with Constructing Explanations (LD3b, 4%) the most commonly coded indicator.

Overall, the most prominent dimension coded during the tinkering experiences for each individual family was *Creativity & Self Expression* (≥29% of codes for all families). This was followed closely by *Social & Emotional Engagement* (≥20% of codes for all families). *Problem-Solving & Critical Thinking* were observed at a much lower frequency, and *Initiative & Intentionality* and *Conceptual*

TABLE 2 Learning dimensions and indicators for all activities by percentage.

Learning dimension 1: Initiative and intentionality						
Common codebook keywords/concepts: listing of materials, finding/organizing materials, failure, change of plan						
Indicators	a. Setting goals	b. Taking creative risks	c. Complexifying over time	d. Persisting/ Learning through failure	e. Adjusting goals based on feedback	f. Organization of materials
Overall	2	<1	0	2	<1	5
Youth	1	<1	0	1	<1	2
Adult	1	0	0	1	<1	2

Learning dimension 2: Problem solving and critical thinking					
Common codebook keywords/concepts: idea sharing, asking for help from family member, construction, building, figuring out					
	a. Trouble- shooting	b. Moving from trial and error	c. Developing work-arounds	d. Seeking ideas/expertise from others	e. Building/ assembly
Overall	4	<1	1	4	7
Youth	2	<1	<1	3	4
Adult	2	<1	<1	<1	3

Learning dimension 3: Conceptual understanding				
Common codebook keywords/concepts: explanation of concepts, answering content questions by family member, describing/sense making in their own words				
	a. Control for variables	b. Constructing explanations	c. Using analogs and metaphors	d. Leveraging properties for design goals
Overall	<1	4	1	<1
Youth	<1	2	1	<1
Adult	0	1	<1	<1

Learning dimension 4: Creativity and self-expression						
Common codebook keywords/concepts: positive/negative affective reactions, relating activity to personal knowledge or lives, "playing" with materials, singing or joking with family, expressive interjections (e.g., *Oh!, Ahhh!, Wow!*)						
Indicators	a. Responding aesthetically	b. Connecting projects to experiences	c. Playfully exploring	d. Expressing joy	e. Novel use of materials	f. Expressing negative emotions
Overall	4	9	8	12	<1	4
Youth	2	5	5	7	<1	2
Adult	2	4	3	4	<1	2

Learning dimension 5: Social and emotional engagement					
Common codebook keywords/concepts: family member explains how to do something to another unsolicited, expresses pride in activity (e.g., *look what I did, did you see that?*), *expressing reciprocal help within family team, increase in confidence*					
Indicators	a. Building on ideas of others	b. Teaching and helping	c. Collaborating in teams	d. Developing confidence	e. Expressing pride and ownership
Overall	<1	10	14	2	3
Youth	<1	4	7	2	2
Adult	<1	6	6	<1	<1

The color of the dimensions and indicators parallel the colors in the framework in Figure 1.

Understanding were the lowest dimensions coded, with only 2% coded for one family. Figure 3 displays the tinkering dimensions broken down by family.

In order to highlight the unique experiences of different families, the researchers selected those whose dimension score averages differed. Most families were within 1–4 percentage points of the average for each dimension. A few families were 5–9 percentage points from the average and even fewer were 10 or more percentage points from the average. Of those families with the most unique dimensional breakdown, the Brown, Baker, Mueller, and Wilson families stand out. These families had the highest deviation (five percentage points or more from the average) for two or more dimensions. Please refer back to the family demographics (Table 1) for more context about each family.

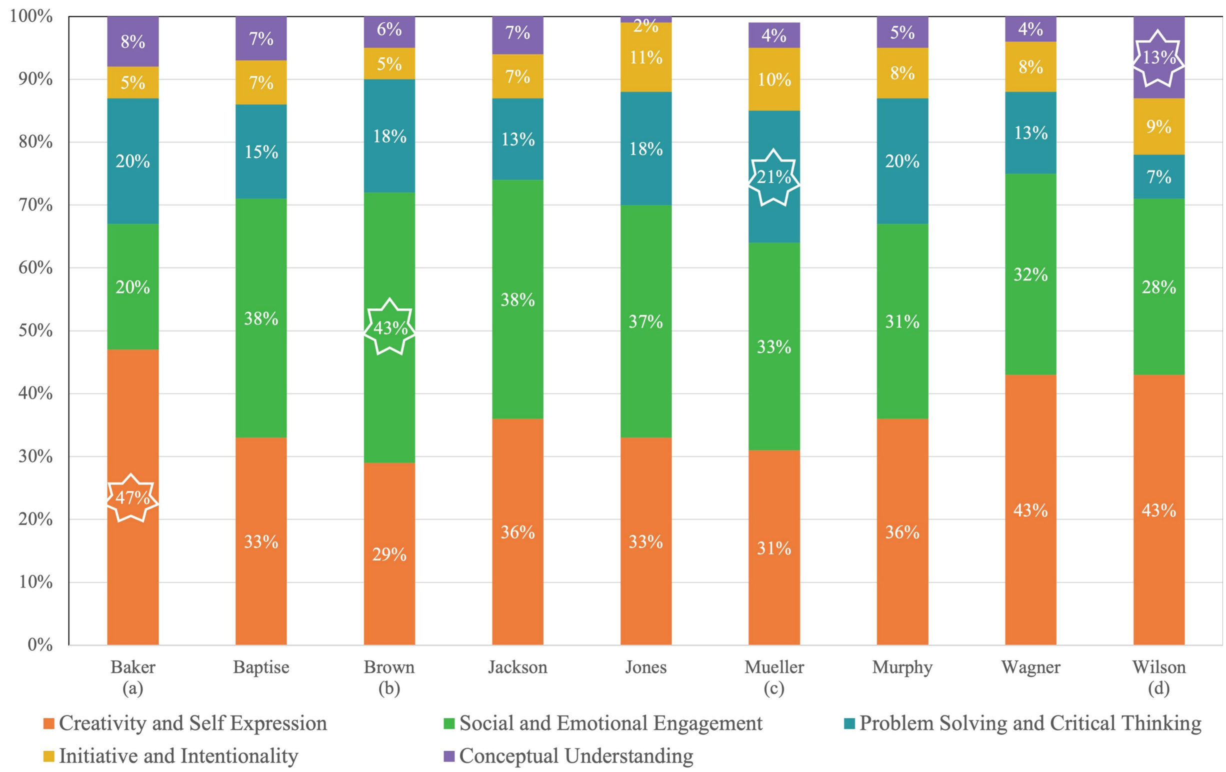

FIGURE 3
Dimensions of making and tinkering percentages by family for all activities.

The Baker family (see Figure 3A) interactions predominantly aligned with the indicators (see Figure 1), most to least often, include playfully exploring[LD4a], expressing joy and delight[LD4d], and connecting projects to personal interests and experiences[LD4b]. This is what led to their unusually high percentage (47%) in *Creativity & Self Expression (LD4).* An example of this can be seen below in this exchange from the Baker family during Activity 4: Larry's Polymer Lab coded under *Creativity & Self Expression*:

> **Child:** Mom, I want you to feel--I want you to put your hand in there and, like, swish it around[LD4a].
>
> **Daughter:** Clear goo[LD4a].
>
> **Child:** It feels so satisfying[LD4a,d].
>
> **Daughter:** Look at this[LD4a,b].
>
> **Child:** Just put your hand in there and swish it around, Mom[LD4a,b].
>
> **Daughter:** Look at this beauty. Look at the beauty that is grava goo[LD4a,b].
>
> **Mom:** You're still having fun with that, huh? All right, let's see, S--Seth--[LD4a]
>
> **Child:** Put your hand in there and swish your hand around[LD4a].

In their interview, the Baker daughter said, "I definitely enjoyed the activities – where they were positive. There was a lot of arguing, but, I mean, that's family stuff. I thought it was fun because we were, like, all together." This statement shows the daughter is recalling the experience as fun and enjoyable and was coded under Expressing Joy and Delight[LD4d].

The Brown family (see Figure 3B) documented both adults and youth teaching and helping one another[LD5b] more often than the other families, leading to their uniquely high percentage of their interactions (43%) coded as *Social & Emotional Engagement (LD5)*. Youth sought assistance from others more regularly by asking questions and giving adults the opportunity to help and teach. This can be seen in this vignette from the Brown family during Activity 1: Circuit Scribe coded under *Social & Emotional Engagement*:

> **Son:** Oh yeah, gotta turn this right. So, it's not working now. Do a thing—put your finger right there. It's lighting up[LD5b].
>
> **Mom:** Oh, like that[LD5b].
>
> **Son:** One time I did it—when I did it, it was like that, it was that bright[LD5b].
>
> **Mom:** Oh, okay. Put your hand—[LD5b]
>
> **Son:** I think it's different because of—[LD5b]

> **Mom:** Oh wow. Oh, yeah, okay. Challenge circuit. Create a circuit that allows you to control the one LED with a switch and another by touch. Use the components wheel to complete the circuit[LD5b].
>
> **Son:** We'll need this—we're going to need every single one of these—this one. This one. These[LD5b].

In the family interview, the son said of his mom, "she's helpful." The mother of five children commented, "For me, it was interesting. It was time to spend time together doing the activities … it gave us (she and her oldest son) time to work together." She also said that her son was "way better at" most of the activities than she was. This statement was coded as adults and youth teaching and helping one another[LD5b].

The Mueller family (see Figure 3C) was unique in that they were below the averages of the other families in *Creativity & Self-expression (LD4)* but were higher in *Problem Solving & Critical Thinking (LD2)*. An example of the Muellers' troubleshooting through iterations[LD2a] can be seen here from Activity 1: Circuit Scribe:

> **Sister 1:** I finished coloring the lines[LD2a]. [drawing magnetic ink]
>
> **Brother:** Don't you supposed to--[LD2a]
>
> **Sister 2:** I don't think--I'm going to try and not fill them in, just so you can save the ink. But if it doesn't work then I'll know to fill them in[LD2a]. [add more ink in a darker line]
>
> **Sister 1:** Okay[LD2a].
>
> **Sister 2:** Put one of those slides on here. Line that up with the circles. Would you like me to help[LD2a]?
>
> **Brother:** Uh huh[LD2a].

During the interview with the Mueller family, the mom and her son reflected on the Larry's Lab activity and how they first tried one procedure and when that did not work, they consulted the directions and tried again. This exchange was coded as troubleshooting through iterations (*Problem Solving & Critical Thinking LD4*):

> **Mom:** I don't know what I did - well, no, I did - the first time I did.
>
> **Son:** She put a darker color, so she couldn't see it really good, but I put a light.
>
> **Mom:** The first time I didn't put the powder in before I put the water in. I put the water in and then the powder, but then I scooped out the lump that formed and threw it away and tried it again, but still I think it's because I didn't follow the directions in the right order.
>
> **Son:** Yeah, the water was so - some water was probably still in.

The Wilson family (see Figure 3D) had the highest percentage of all the families (13%) in *Conceptual Understanding (LD3)*. This could be because the youth and the adults were constructing explanations more than other families. This family also explained their thinking using analogies and metaphors while working through the STEM activities. The mom taught high biology and also held a graduate degree and had taught some community college courses. A sample of the Wilson family constructing explanations[LD3b] from Activity 3: *Achoo!* and Germ Glo can be seen below:

> **Son:** Um, that, um, they are usually fought off by the body. Um, b--using white--white blood cells and T--T cells[LD3b].
>
> **Mom:** T cells are a form of white blood cells[LD3b].
>
> **Son:** Ah[LD3b].
>
> **Mom:** And then you've got B cells, which also have--[LD3b]
>
> **Son:** Those--[LD3b]
>
> **Mom:** Memory cells[LD3b].
>
> **Son:** And those m--mark them. Mark the enemy[LD3b].
>
> **Mom:** And then you've got--for viruses you've got antibodies. Which are--[LD3b]
>
> **Son:** Which mark the enemy. Which mark what's bad and what's good[LD3b].
>
> **Mom:** They take the virus--yeah, and--[LD3b]
>
> **Son:** Mark it[LD3b].
>
> **Mom:** Make a copy of it so it'll recognize it the next time it goes in. If you get it again, so you won't get the whole thing, it'll start fighting it faster[LD3b].

At the end of every family interview, the researchers would ask if they had any other questions for the research team. The Wilson son took the opportunity to ask the university researcher, who he thought would be a science expert:

> The main thing I want to know is how much - how fast would a five-inch - a five-inch long blade on a propel - if a propeller has a five-inch long blade, how fast - how fast would it spin if it was - had water coming at it at five miles per hour?

This shows just how science-inclined the son of the family was and sheds light on why the family had the highest percentage in the dimension of *Conceptual Understanding*.

4.2 The ways families tinkered depended on the makeup of the family participant group (e.g., parents, children)

Of the nine participating families, there were various ways in which families participated in the activities. Some families (n = 3) generally completed their STEM activities with one adult (either mother or father) and one child [adult (s) with child] as shown in Figure 4 with two adult icons and only one child icon. While others ($n = 5$), worked through activities with at least one adult and multiple children (2+) [adult(s) with children] as shown in Figure 5 with two adult icons and multiple icons for children. Even though the activities were designed and described as family activities, there were two families in which one or multiple children worked on at least one (or all) activities with none to minimal adult presence [child(ren) only] as shown in Figure 6 with no adult icons and only icons for children bolded. Codes for all families, regardless of the family participant group, were most frequently coded in the *Creativity & Self-Expression* dimension (37%-adult(s) with child; 44%-adult(s) with children; 36%-child(ren) only), followed by the *Social & Emotional Engagement* dimension (34%-adult(s) with child; 24%-adult(s) with children; 33%-child(ren) only). However, there were differences in coding between the three family participant groups, documented in the frequency and role (adult or youth) of the participants as well as the dimension indicators.

In the first type of family participant group, adult(s) with child (see Figure 4), the conversation and frequency of interactions were fairly evenly split between the adult(s) and child. Even though there was little evidence of *Conceptual Understanding* or *Initiative & Intentionality* dimensions noted in this group structure, the adults most often assumed the teaching role in the group, while the child playfully explored. Out of the three participant group structures, this structure prompted an environment where the child frequently sought advice from their participating adult(s). The father and son from the Jones family often demonstrated this teaching interaction:

> **Dad:** I'm gonna show you, [son], this an Allen key. It goes in here like so. Put your nut on the other end. You need a washer and a nut [son]. A washer, a washer. [Son], that's a nut. That's—
>
> **Son:** What's a washer?
>
> **Dad:** That's a lock nut. A washer is this right here, baby.

However, also prevalent in this group structure, the child seemed to feel comfortable constructing explanations at twice the rate of the adults, often stemming from the increased number of questions posed by the adult. This was evidenced by the Wilson family as they completed the Germ activity:

> **Mom:** Why were germs spread easily in the past?
>
> **Son:** Because doctors th--um, didn't wash their hands and instruments.
>
> **Mom:** Yeah, in between patients. Really gross. Why aren't germs spread as easily today?
>
> **Son:** Because now we frequently wash our hands and doctors wash their instruments and hands.

While positive overall, the adults in this group structure expressed more negative emotions (e.g., frustrations with time or off-task behaviors) than the child. For example, in the Wilson family the mom had to keep focusing her son during the germ activity saying, "Oh come on, I'm sure that might be one of the things. We gotta-but we gotta stay focused so we can get done. Okay? You got that, I'll get the lights. Got it?" Even considering the occasional negative emotions expressed, both the adult(s) (9 instances) and child (12 instances) in this group structure showed persistence through failure while completing the STEM activities. Figure 4 illustrates the most common indicators noted for this family participant group, including who initiated the indicator. For example, the two most common indicators for adult(s) were both in the *Social & Emotional Engagement* dimension as indicated by green arrows (see *Learning Dimensions of Making & Tinkering Framework*, Figure 1)--teaching and helping one another (14.1%) and

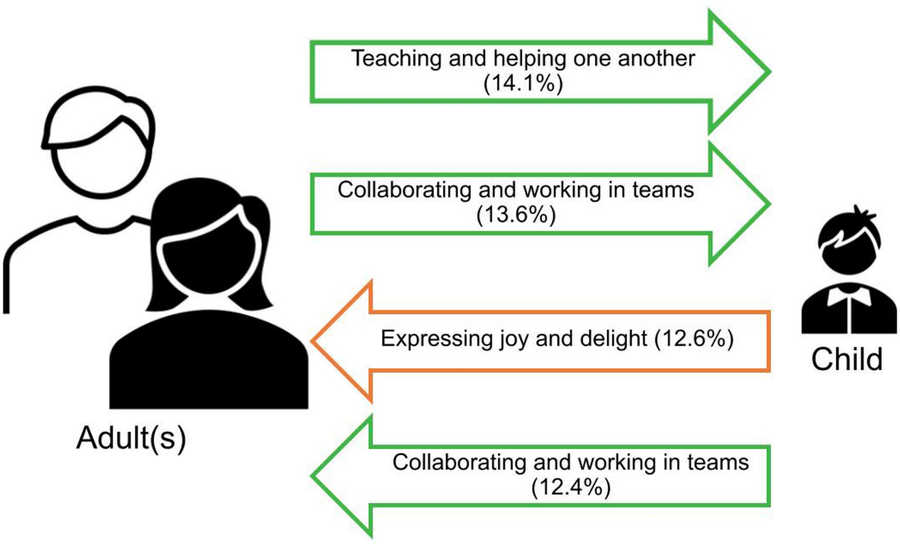

FIGURE 4
Family participant group: one or two adults and one child.

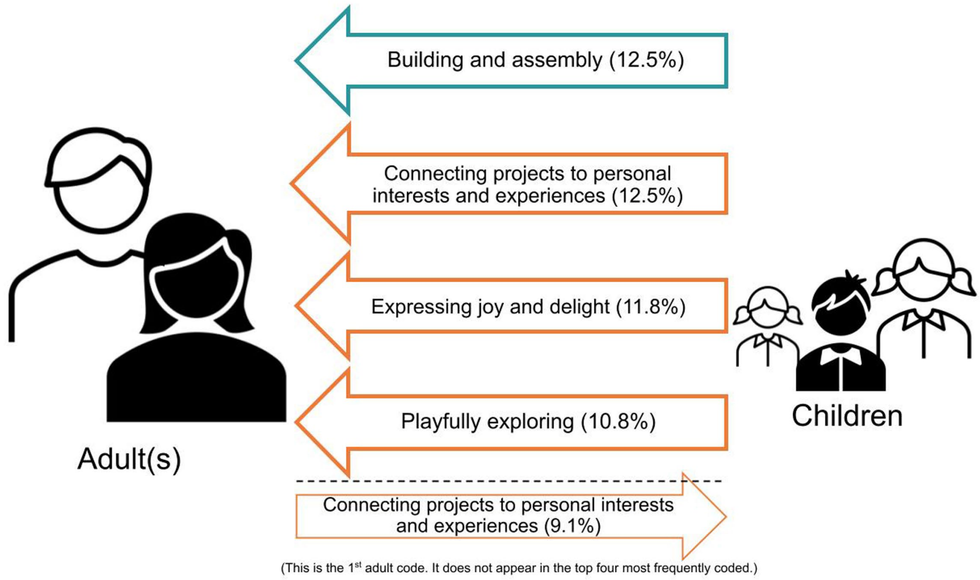

FIGURE 5
One or two adults and multiple children.

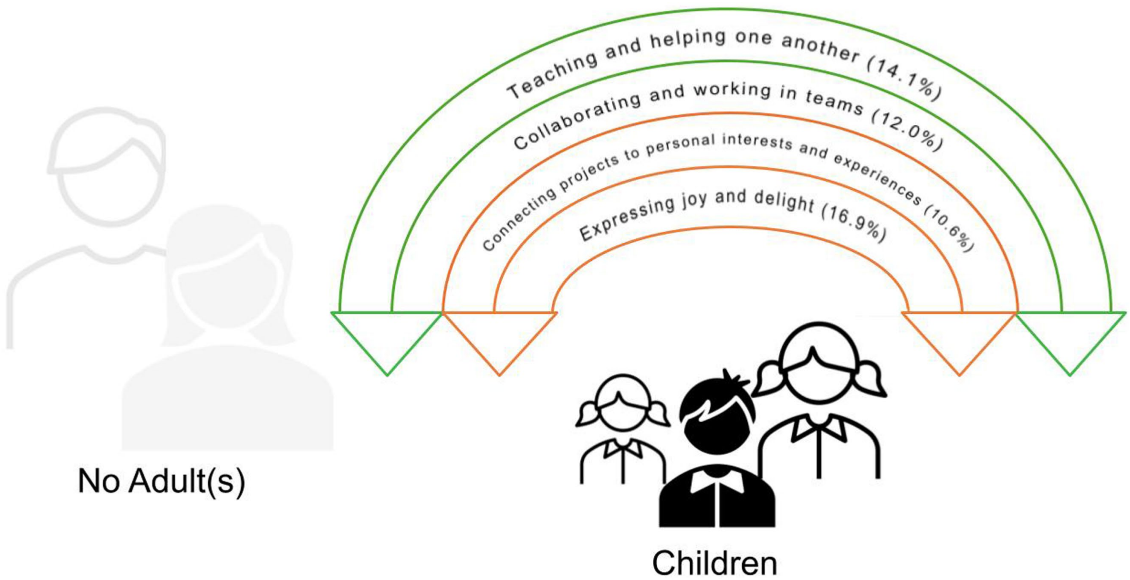

FIGURE 6
No adults and one child or multiple children.

collaborating and working in teams (13.6%). Whereas the most common child indicators were in *Creativity & Self-Expression* (orange arrow), expressing joy and delight (12.6%), and *Social & Emotional Engagement* (green arrow), collaborating and working in teams (12.4%). The Jones family exuded joy and delight throughout the overwhelming majority of their activity interactions, as when engineering their robot:

> **Son:** This is going to turn out really good.
>
> **Dad:** It's--I think it's going to be awesome, buddy. We'll see.
>
> **Son:** Uh huh.
>
> **Dad:** If not, we'll have fun doing it.
>
> **Son:** Yep, that's the best part about it.

During the interview with the Jones family, the dad talked about learning through collaboration with his son and how that was a meaningful experience for him: "Let us back off this and go back to what we were doing and, you know, that's the thing. So we did learn some family skills along with it."

In the second type of family participant group, adult(s) with children (see Figure 5), the children were more often collaborating with one another throughout the activity, leaving less room or need for parental input. For instance, in the robot activity, the children in the Baker family equally led the efforts for building and assembly:

> **Child 5:** All right, guess it's your turn [Child 3].
>
> **Child 3:** Uh.
>
> **Child 4:** All right, what's next?
>
> **Child 5:** Something to do with arms.
>
> **Child 3:** All right, I'll sit over here.
>
> **Child 4:** Is this--is it the third one?
>
> **Child 5:** Third one.
>
> **Child 4:** All right, you need these pieces. So you need a--
>
> **Child 3:** Mom.
>
> **Child 4:** Bracket.
>
> **Child 3:** Mom.
>
> **Mom:** Yes, [Daughter].
>
> **Child 3:** I'm gonna get them myself.
>
> **Child 1:** Number 3.
>
> **Child 5:** Your tools.
>
> **Child 3:** Thank you.
>
> **Child 1:** You guys are horrible at teamwork.
>
> **Child 3:** Uh–.

The children often used the adult(s) as an expert, asking them questions if they were not able to solve a problem themselves. When there were multiple children participating in the activities, the dynamic of the interactions was different than in the adult(s) and child family participant group. The collaboration between the children was more prevalent and the children seemed to display affective responses more often in this family participant group – the children expressed more joy and delight (34 instances) as well as more negative emotions (21 instances) compared to the adult(s) (14 instances of joy and delight, 1 instance of negative emotion). In the interview with the Baker family, the Baker mom reasserted, "When they were excited and positive about it, then I love that kind of thing." This provided evidence that she witnessed her children's joy and delight while working with them throughout the *Home Edition* experience.

During the polymer activity, the children in the Brown family expressed joy and delight (as well as some negative emotions) through their exploration of materials:

> **Child 4:** It's gooey and slimy.
>
> **Child 1:** Gooey and slimy.
>
> **Child 3:** Ew, ew, ew, ew, ew.
>
> **Child 4:** And it feels great, and it's cold.
>
> **Child 1:** Okay.
>
> **Child 4:** I wanted to touch a big part. I'm gonna do it on this one. I touched the big part!
>
> **Child 3:** I want to touch it. I want to touch the big part. Ah. Look Mommy!

For this type grouping (one or more adults and multiple children), when emotions for the children were high, the group's persistence through failure was also very low for both children and adults (2 instances noted for all activities). Aside from the social interactions of the children and adult(s), there was little evidence of participants in these family participant groups (one or two adults and one child) constructing explanations during their activities; however, they often related their projects to personal interests, as exhibited by the children from the Baker family as they completed the germ activity:

> **Mom:** Perhaps there's signs. So, how would you feel if you had to spend your whole life inside--would it be worth it to get the blood--the marrow transplant and maybe die and possibly be--live outside of a bubble, or would you just stay in a bubble your whole life.
>
> **Daughter 2:** I'd like to do something about it.
>
> **Mom:** You'd never be able to feel grass.
>
> **Daughter 1:** I would never be able to really eat food, because food is covered in germs. They, they would have to get special food.
>
> **Mom:** Yeah.
>
> **Daughter 1:** That would be disgusting. I would never be able to eat peeps.
>
> **Mom:** So you'd never be able to pet a dog.
>
> **Daughter 1:** I like my peeps.
>
> **Mom:** Or a bunny.
>
> **Son:** I'd be like, could you bring in some video games? I actually don't know what a video game would be.

10.3389/feduc.2025.1568153

> **Mom:** Okay. Well, I'm sure you could have, like, a sanitized video system. But, like, you'd never be able to feel the wind blowing in your face. Or the rain. You, like, wouldn't know what that would be like.

Figure 5 illustrates the overwhelming presence of the children as families completed the STEM activities. The top four indicators were all from the role of the children, with three aligned with the Creativity & Self-Expression dimension (orange arrows) and one, building and assembly (12.5%), stemming from the Problem Solving & Critical Thinking dimension (blue arrow). The most prevalent indicator that came from the adult(s) role also falls under Creativity & Self-Expression as they connected the projects to personal interests and experiences (9.1%).

Lastly, in the third family participant group type, children only (see Figure 6), the child interacted with other children or talked out loud to the recorder, if alone. There were often minor interjections from an adult, but their interactions with the child(ren) were unsubstantial to the outcome of the STEM activity. Similarly to the second family participant group type, with multiple children present, this context, with only children also seemed to generate high affective states. The children seemed to have a good time working with only themselves or other children; however, there were more bickering and negative emotions noted as well.

The brother and sister from the Jackson family expressed joy and delight, with a bit of frustration (negative emotion) while working together on the liquid circuit activity:

> **Sister:** That's dope. So, oh am I falling off--So, when you take--so the light doesn't light up when you just have the battery and the circuit with the two pin module and the LED. So, what you have to do is you have to--and you have to stick it through the two pin. Get serious, [brother]. Oh my gosh, that's so cool.
>
> **Brother:** Oh, it lit up, all right, that's dope.

The Baker family daughter expressed frustration when trying to understand the liquid circuitry activity instructions:

> I don't even know what this is talking about, it's like some sort of series panel, a uniform vertical manner, what the heck is that? I didn't learn anything. How did you feel? I feel like my time was wasted. Thanks.

There was some evidence of the children asking each other questions and constructing explanations; often these explanations were built by connecting the STEM activity and content to concepts and content they already knew, making it relatable. The children in the Murphy family helped one another out in the robot activity:

> **Child 2:** I mean, I'm so confused. Because this--does this mean, like, the bottom or the top.
>
> **Child 1:** Look at the sides, there's, like, plus and minus on them.
>
> **Child 2:** I know, but like, does this mean, like, will the plus be on top or in the bottom area?
>
> **Child 1:** That means the plus will be on top. So, uh, if the plus is on top, where you said the plus sign? That's the plus sign. So the plus sign, there the plus sign. Because if you look, that always has to go there. So you just keep looking over there.
>
> **Child 2:** And then the minus goes there, and the plus goes there.
>
> **Child 1:** Thank you.

Without an adult present, children did not show much persistence through failure; when they were not able to figure something out, the children often gave up since they did not have an adult to encourage their persistence. This was highlighted in the exasperation of one of the Murphy children as they talked through their failure to construct and code functioning robot movements:

> Uh, why won't it play? Ugh. Okay, I'm done. Oh, I guess I'm not done. Here we go. Uh, don't fall, please, please, please, please, please. No, this way. This way. Okay. Oh, no. Oh, oh, okay. No, uh, okay. Just, okay, fall down like a drunk woman in heels.

During the family interviews, the parents of children whose families were consistently categorized in the "child-only" group for this study (little to no participation with their child(ren) during the STEM activities) provided brief and vague reflections, likely due to their limited involvement in the activities. The children, however, recalled their experiences in greater detail.

Figure 6 illustrates the most common indicators noted for this group structure. For the children-only group, two common indicators were in the Social and Emotional Engagement dimension (green arrows)--Teaching and Helping one Another (14.1%) and Collaborating and Working in Teams (12.0%), while the other two most common indicators were in Creativity and Self-Expression (orange arrows), Connecting Projects to Personal Interests and Experiences (10.6%), and Expressing Joy and Delight (16.9%).

4.3 The ways the dimensions and indicators differed, based on the activity

The family interactions during the first activity, Circuit Scribe, were primarily coded in the *Creativity & Self Expression* (35%) and *Social & Emotional Engagement* (34%) Learning Dimensions, as shown in Table 3. The most frequently coded indicators were Youth Collaborating and Working in Teams, Youth Expressing Joy and Delight, Adult Expressing Joy and Delight, and Adult Collaborating and Working in Teams. During the family interview the Jones' son recalled a time he proudly showed his circuit to others, expressing his enjoyment "…they said no way. I said, 'watch.' I says, 'it's not a piece of board, it's a piece of metal, but I'm telling you, it conduct electricity with this ink. It's special ink.' And I drew it out and put it over there, and it lit up." Although the verbal exchanges between Adult and Youth were fairly equal, the Youth seemed to be Playfully Exploring, Developing Confidence, and Expressing Pride and Ownership more frequently than the Adults. Very few statements were coded in the Conceptual Understanding dimension.

Interactions for the second activity, Meccano Robot, were similar to the first activity, with most codes in *Creativity & Self Expression*

TABLE 3 Percentage (and frequency) of dimensions by activity.

Dimension	Activity 1 Circuit Scribe	Activity 2 Robot	Activity 3 Ah-choo!	Activity 4 Larry's Lab
Creativity and self-expression	35% (158)	36% (163)	**47% (89)**	**46% (148)**
Social and emotional engagement	34% (155)	31% (137)	34% (65)	25% (81)
Problem solving and critical thinking	**20% (90)**	**20% (89)**	4% (7)	9% (28)
Initiative and intentionality	7% (32)	10% (46)	4% (7)	8% (25)
Conceptual understanding	4% (18)	3% (14)	**12% (22)**	**13% (42)**

The color of the dimensions parallel the colors in the framework in Figure 1. Dimensions are arranged from top (LD 4: Creativity and self-expression) to bottom (LD3: Conceptual understanding) beginning with the dimension most commonly coded for all activities. Bold numbers indicate noticeably higher percentages for that particular dimension than in the other activities for that same dimension.

(36%) and *Social & Emotional Engagement* (31%) Learning Dimensions. The most frequently coded indicators were Youth Collaborating and Working in Teams, Youth Expressing Joy and Delight, Youth Building and Assembly, and Adult Collaborating and Working in Teams. Youth Building and Assembly was coded almost twice as frequently as Adult Building and Assembly. Youth also sought Ideas and Assistance from others and connected the Project to their Personal Experiences more than adults during this activity. Adults verbalized less Joy and Delight than in activity one (Circuit Scribe). Youth seemed to Develop Confidence and also expressed a lack of confidence (negatively coded for this indicator) throughout the activity, mirroring the trial-and-error nature of the activity. The Brown son showed this as he reflected on the robot activity in the family interview, saying: "Like it can become an adventure because it was kind of hard making the robot. I had to figure out how to put the screws. I got so frustrated. I was like, how do you do this?" As with activity one, very few codes were in the *Conceptual Understanding* Learning Dimension.

The third activity, Ah-choo, had the most codes in the *Creativity & Self Expression* (47%) and *Social & Emotional Engagement* (34%) Learning Dimensions, consistent with the first two activities. Uniquely, the third most frequently coded Learning Dimension was *Conceptual Understanding*, which had been the least frequently coded in the previous two activities. Connecting Projects to Personal Interests and Experiences, Adult Teaching and Helping One Another, and Youth Constructing Explanations were the most frequently coded indicators. During the family interview, the Wagner mom reflected on her son's experience and how interested he was, "He was absolutely fascinated with the germs. He still uses the LED light, and walks around the house, and in the bathroom, we, mom, look at this." Youth seemed to be more verbal while working through the activities and expressed more Joy and Delight than the adults. Some less frequently coded indicators in this activity were Developing Confidence and Expressing Pride and Ownership.

Lastly, during activity four, Larry's Lab, most of the codes also reflected *Creativity & Self Expression* (47%) and *Social & Emotional Engagement* (34%) code groups. Similar to activity three, activity four had a higher occurrence of these dimensions than activities one and two. Youth Expressing Joy and Delight, Youth Playfully Exploring, Youth Collaborating and Working in Teams, and Adult Collaborating and Working in Teams were the most frequent indicator codes observed. Generally, the youth spoke more than the adults in activity three and it seemed as though the adults were giving the youth more agency to explore. There was a higher rate of responding aesthetically to materials and phenomena in this activity than all the others. During the family interview, the Mueller mom expressed her engagement with the activity, "I had never heard the word polymer before, even though we had had the Orbeez [water beads], I did not, again, read the directions that came with the Orbeez. I did not realize they were called polymers."

4.4 Limitations

The study was supplemental to a larger NSF-funded STEM Clubs study. Although all STEM Club families from three middle schools were invited to participate in the *STEM Home Edition*, only 44 of those families chose to do so. Additionally, this study reports on the nine rural families who persisted through at least 3 of the 4 activities, returned the requested audio data, and participated in family interviews. Had more families participated, persisted, and completed the activities, the results may have differed. Thus, due to the nature of the case study approach, the results may not be generalizable for all populations, particularly those populations with different lived experiences. Also, the activities were completed in participants' homes, with no real-time guidance from project personnel, only written instruction. This may have been a limitation, but it also allowed families privacy and the freedom to make the STEM activity experiences their own, within their personal spaces, potentially providing a unique insight into what we know about these families' STEM tinkering. Keeping in mind these limitations, the findings will now be discussed.

5 Discussion

The purpose of this study was to gain insight into how families engaged in STEM explorations in their homes. Scant research has been published using this type of data source within participants' homes; the only published studies found took place during COVID, with external supervision (e.g., Aldrich, 2023; Martin and Thomas Murphy, 2022). Thus, the goal of this study was to gather data to understand what happens at home when families are asked to tinker in STEM when there are not any formal/informal STEM educators present (e.g., no museum staff, no STEM club leaders). The framework that guided our understanding of these interactions was the *Learning Dimensions of Making & Tinkering*. In this study, all families of students who were participating in an after-school STEM Club in any of the three participating schools were invited to participate in this after-school STEM learning experience. Nine families persisted through 3–4 activities provided. Participating families were somewhat diverse in their composition. Participating STEM students were mostly evenly split between male and female, and Black and White. While moms generally filled the adult role during the activities, there were a few instances of dads taking the lead or co-lead roles. Almost half of the families completed the *STEM Home Edition* activities with only one STEM Club youth present.

5.1 Learning dimensions and indicators overall and by family

Through audio data captured during in-home STEM activities, families were found to spend most of their time engaging in ways aligned with the dimensions of *Social & Emotional Engagement* and *Creativity & Self-Expression*. Within the *Social & Emotional Engagement* dimension, Collaborating, Working in Teams, and Teaching and Helping One Another were the most prominent indicators. For *Creativity & Self-Expression*, the indicators of Expressing Joy and Delight, Connecting Projects to Personal Interests and Experiences, and Playfully Exploring were most commonly noted. In contrast, the dimensions of *Problem Solving & Critical Thinking*, *Initiative & Intentionality*, and *Conceptual Understanding* were observed the least. Despite demographic differences such as gender, age, race/ethnicity, and educational levels, families engaged in remarkably similar ways, focusing on having fun and working together toward shared goals. Explicit learning appeared to be a secondary outcome, with engagement in social and emotional learning and creativity taking center stage in their interactions.

The majority of homes in this study were classified as 'working-class.' Nearly all participating students qualified for free lunch, either due to individual family income levels or because their schools provided free lunch to all students, reflecting the high rate of poverty in the school community. Previous research by Lareau (1987) and Stanton-Salazar (2011) suggests that 'working-class' parents often view home and school as separate domains, with schools bearing the responsibility for educational decisions, unlike upper-middle-class parents who tend to adopt a more interconnected approach by actively overseeing their child's educational progress and decisions (Lareau, 1987, 2000, 2011; Lareau and Horvat, 1999). However, findings from this study challenge these established perspectives. Based on participation rates and family responses before and after the activities, parents in these 'working-class' homes demonstrated a strong sense of responsibility for guiding their children's education and supporting their pathways toward suitable careers, indicating a more active engagement than previously reported in the literature. This is particularly salient in rural communities where connecting to familial and community assets has been identified as a powerful tool in enhancing STEM learning, identity development, and career awareness (Avery and Kassam, 2011; Bridgeforth et al., 2021; Saw and Agger, 2021).

5.2 Family participant group type

Youth aspirations to persist in STEM areas are formed predominantly between the ages of 10–14 (Archer et al., 2012). STEM Home Edition invited middle school youth (ages 11–14) to complete supplementary STEM activities with their families in a loosely structured informal learning environment. When at least one parent was present, children were more likely to persist through challenges and failures, with parents helping to keep youth on task when distractions arose. However, this parental involvement sometimes led to negative emotional responses, as parents took on a taskmaster role to ensure children stayed focused and completed the activity efficiently. When only one child participated, the parent often adopted a teacher or facilitator role. In contrast, when multiple children were present with at least one parent, most communication occurred between the children rather than with the parent. Children working alone appeared to have more fun but experienced less success with the activity. Regardless of group composition, group dimensions were generally similar, except for a higher occurrence of *Creativity & Expression* when multiple children participated with at least one parent. Notably, the dimension indicators shifted a great deal depending on the makeup of the group. It was hypothesized that by completing these STEM activities as a family, the intersection of their "family habitus and capital" (Archer et al., 2012, p. 882) would help increase the STEM aspirations of the participating *STEM Home Edition* children. In the current study, not all adults in the participating families professed their unwavering commitment to STEM but they all did assert their full commitment to their child(ren)'s interests and aspirations. Thus, the positive social context that the parents provided throughout the *STEM Home Edition* activities allowed their children to conceptualize their "aspirations and science careers […] play [ing] an important, albeit complex, role," particularly in families who have been subjected to inequities through social class, race, rurality, or other cultural identifier (Archer et al., 2012, p. 902).

5.3 Differences in activity type

Although some activities, such as *Achoo!*/Germ Glo and Larry's Lab, allowed for more *Conceptual Understanding*, this dimension was still the third most frequently coded overall. Interestingly, these activities also featured more expressions from youth than from their partnered adults. *Social & Emotional Engagement*, as well as *Creativity & Self-Expression*, showed little variation across activities. However, the Circuit Scribe and Meccano Robot activities exhibited a higher frequency of *Problem Solving & Critical Thinking*, while Achoo! and Larry's Lab demonstrated a much higher frequency of *Conceptual Understanding* and slightly more *Creativity & Self-Expression*. Factors contributing to this difference may include the discussion-provoking questions in the *Achoo!* book and the connections fostered throughout Larry's Lab activity. Additionally, some of the activities (e.g., Circuit Scribe, Mecanno Robot) provoked frustration as families failed in their initial tinkering attempts. Our work paralleled other work using STEM kits prepared for elementary students and their families in the home setting. Wenner and Galaviz (2020) determined that *Science Packs* should be built to help reduce intimidation for those families who "feel uncomfortable with science" and that the kits should generally be filled with "everyday, inexpensive materials" (p. 36). *STEM Home Edition* kits were prepared for older children (middle school) who were also participating in an afterschool STEM Club. Even though the participating youth had a natural acumen for engaging in STEM activities, some of the more complex kits were identified as more challenging than others for some families.

The *STEM Home Edition* project offered families opportunities and resources to explore and discuss potential career pathways with their families (Wenner and Galaviz, 2020), which is particularly important for families with low socioeconomic status, parents without post-secondary education, and minorities (Hill, 2015). The project supplied all necessary materials for the four *STEM Home Edition* activities, enabling families to fully engage in the experience within their own homes. This approach eliminated barriers related to transportation and material access, challenges frequently noted in the literature (Dearing et al., 2015). However, this study did not address other demands on families' time, though each family had the flexibility to decide when and how to complete each of the activities over the course of approximately a month.

5.4 Implications and recommendations

The findings from this study have implications for equity and access to STEM education for rural populations. First, approximately 20% of US school-aged children attend rural public schools (Showalter et al., 2017). Students within rural schools are generally underserved with respect to formal, advanced coursework (Ihrig et al., 2018), and informal learning resources and opportunities such as access to museums (Avery and Kassam, 2011). Also, rural school divisions have historically suffered from issues related to teacher retention, particularly in science and mathematics (Goodpaster et al., 2012). Additionally, gaps in STEM education in rural geographic regions throughout the globe have been identified as educational pedagogies in rural classrooms are often insufficient to meet the mandated curriculum standards (Jalak and Nasri, 2019).

In order to combat this reality, the provision of informal, at-home STEM learning opportunities for rural students and their families is suggested to build on the assets of strong, close-knit rural communities (Bridgeforth et al., 2021). Avery and Kassam (2011) assert that rural students draw on STEM funds of knowledge from their communities, homes, and environments outside of school, including family settings. *STEM Home Edition* bridges the gap between formal and informal learning spaces, drawing on community and familial resources to drive STEM education efforts with rural US middle school students and their families. We propose several specific recommendations for those creating similar informal STEM programming, perhaps in more structured out-of-school settings (e.g., STEM clubs, museums) or similar, non-structured environments (e.g., family homes), and for those who would like to research aspects of STEM education in a similar context.

5.4.1 Recommendations for professional developers

Our experiences engaging in this work have led to several general recommendations for professional developers. First, informal curriculum designers ought to provide structured and clear guidance for each activity, using plain language to ensure families can easily follow and complete them independently. Looking ahead, if providing a series of STEM home activities, designers should scaffold the experiences to start with simpler tasks at the beginning of the year, gradually increasing in complexity to encourage persistence. Stemming from our families' feedback, out-of-school projects should take no more than an hour to complete or should be easily divided into smaller parts that families can tackle over multiple days.

This study showed how the *STEM Home Edition* families engaged in differing degrees of the dimensions and indicators from *the Learning Dimensions of Making & Tinkering.* Thus, when designing informal activities for families, developers ought to consider their main goals and objectives for family outcomes. For example, designers will want to consider not only how to help families deepen their conceptual understanding of a subject but also how to foster families' social and emotional engagement, as well as support creative self-expression. By addressing these dimensions, families can have a more well-rounded and enriching experience. STEM at-home activity designers should also focus on enhancing the components of dimensions that may be less frequently observed. For instance, the dimension of *Constructing Explanations* could be improved by adding more talking points for both adults and youth in the provided materials, along with guiding questions and fully explained answers. Additionally, designers could incorporate a conceptual video, either self-made or from an existing source, like YouTube, that explains the STEM concepts involved in each activity. Lastly, to further support the dimension of *Initiative & Intentionality*, activity designers could structure time for families to set goals before the activity begins, allowing room for playful exploration and engineering that may lead to failure. Families could benefit from taking risks and learning from initial failures as they work toward their predetermined goals.

5.4.2 Recommendations for researchers

There is value in exploring how families interact with one another in informal settings where there is no direct oversight by practitioners or researchers. This type of research can provide valuable insights into family dynamics and engagement. However, coding voluminous quantities of interactive data was extremely time-consuming. Choosing a portion of the data based on each type of activity from a subgroup would likely provide sufficient data, paired with post-activity reflections or interviews.

Another novel component of this study was the use of the *Learning Dimensions of Making & Tinkering* to qualitatively code audio data. During data analyses the authors found it necessary to add several additional indicators to the original dimensions in order to capture all of the interactions for the at-home family tinkering in this study (see indicators asterisks in Figure 1). Overall, the framework was useful in coding audio data while families completed the activities, but the framework was less adept for use as a reflective tool to analyze the family interviews at the end of the *STEM Home Edition* experience. However, the framework helped triangulate the dimensions and indicators identified in the home audio data with the interview data to support and enhance the validity of the study findings. This is particularly important in case studies of social phenomena as researchers "attempt to study a case in all its dimensions" and use triangulation to cross-check the findings (Priya, 2021, p. 99).

5.5 Conclusion

In conclusion, the audio data provided evidence that the families enjoyed their time together and tinkered in ways that stimulated their creativity, social and emotional skills, and self-expression. The at-home STEM activities provided a distinct and engaging experience compared to traditional school settings. They were less rigid, sometimes less focused, but more enjoyable, interactive, and centered on skills, processes, and surprising outcomes. Families valued the time spent together, often marked by laughter and collaborative effort. The study revealed several key factors that contributed to the success of these activities. The initial difficulty level of the activities played a crucial role in retention, with less challenging tasks allowing for more time to discuss concepts and engage in deeper discussions, as seen with activities like *Achoo!* and Larry's Lab. The composition of the group also mattered, with parents helping children stay on track, while more balanced interactions occurred when there were one or two parents and one child. Activities that included reference materials, such as the *Achoo!* book fostered greater conceptual understanding. Capturing these activities on audio recordings allowed families the privacy to 'be themselves,' and provides novel insight into family tinkering in rural homes. Interviewing families was a productive way to member check the independent findings from the coded at-home tinkering data. Ultimately, the shared experience of engaging in a STEM activity together seemed to be what families most valued, particularly when it tapped into their general knowledge, sparking rich discussions and deepening their understanding of the concepts involved.

Data availability statement

The datasets presented in this article are not readily available because the IRB consent form signed by consenting minors states that data will be restricted in its raw form for researchers working on the project only. Requests to access the datasets should be directed to kgutierr@odu.edu.

Ethics statement

The studies involving humans were approved by the IRB Review Board at NC State University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

KG: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. KS: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing. MB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This material was based upon work supported by the National Science Foundation under grant no. 1433747. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Acknowledgments

The authors would like to acknowledge the entire STEM Career Clubs project team for their contributions to the STEM Club project and the supplementary *STEM Home Edition* project used for this study. The authors would especially like to thank the STEM Club middle school teacher-coaches and their students and families who engaged with the at-home STEM materials, allowing us a glimpse into their experiences.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

References

Aldrich, B. M. (2023). Parental autonomy support and children's STEM engagement during an at-home tinkering activity. [master's thesis]. Chicago, IL: Loyola University.

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., and Wong, B. (2012). Science aspirations, capital, and family habitus: how families shape children's engagement and identification with science. *Am. Educ. Res. J.* 49, 881–908. doi: 10.3102/0002831211433290

Avery, L. M., and Kassam, K.-A. (2011). Phronesis: Children's local rural knowledge of science and engineering. *J. Res. Rural. Educ.* 26, 1–18.

Azano, A. P., Callahan, C. M., Brodersen, A. V., and Caughey, M. (2017). Challenges and possibilities for gifted education in rural schools. *Gift. Child Quart.* 61, 197–209. doi: 10.1177/0016986217701830

Bathgate, M. E., Schunn, C. D., and Correnti, R. (2014). Children's motivation toward science across contexts, manner of interaction, and topic. *Sci. Educ.* 98, 189–215. doi: 10.1002/sce.21095

Bevan, B., Ryoo, J.J., Vanderwerff, A., Wilkinson, K., and Petrich, M. (2017). Making deeper learners: a tinkering learning dimensions framework v2.0. The Tinkering Studio, Exploratorium. Available at: https://drive.google.com/file/d/0B0qZeOKwdxpXelZKS3F5Q0pRV00/view?resourcekey=0-KODb2ppOn8mHHP6xAv-Q4w

Bhargava, S., and Witherspoon, D. P. (2015). Parental involvement across middle and high school: exploring contributions of individual and neighborhood characteristics. *J. Youth Adol.* 44, 1702–1719. doi: 10.1007/s10964-015-0334-9

Blanchard, M. R., Gutierrez, K. S., Hoyle, K. S., Painter, J. L., and Ragan, N. S. (2017). "Rural, underrepresented students' motivation, achievement, and perceptions in afterschool STEM clubs" in Electronic proceedings of the ESERA 2017 conference. Research, practice and collaboration in science education part 2. eds. O. Finlayson, E. McLoughlin, S. Erduran and P. Childs (Dublin, Ireland: Dublin City University), 264–272.

Blanchard, M. R., Gutierrez, K. S., Swanson, K. J., and Collier, K. M. (2023). Why do students attend STEM clubs, what do they get out of it, and where are they heading? *Educ. Sci.* 13:480. doi: 10.3390/educsci13050480

Bornstein, M. H., and Bradley, R. H. (2002). Socioeconomic status, parenting, and child development. *1st* Edn. New York, NY, US: Routledge.

Bridgeforth, J., Kennedy, K., Alonso, J., and Enoch-Stevens, T. (2021). Conceptions of choice, equity, & rurality in educational research. *Rural. Educ.* 42, 1–15. doi: 10.35608/ruraled.v42i2.1242

Crosnoe, R. (2015). "Continuities and consistencies across home and school systems" in Processes and pathways of family-school partnerships across development. eds. S. Sheridan and E. Moorman Kim (Cham: Springer), 87–103.

Dabney, K. P., Tai, R. H., and Scott, M. R. (2016). Informal science: family education, experiences, and initial interest in science. *Inter. J. Sci. Educ. Pt B.* 6, 263–282. doi: 10.1080/21548455.2015.1058990

Dearing, E., Sibley, E., and Nguyen, H. N. (2015). "Achievement mediators of family engagement in children's education: a family-school-community systems model" in Processes and pathways of family-school partnerships across development. eds. S. Sheridan and E. Kim (Cham: Springer), 17–39.

Epstein, J. L. (1986). Parents' reactions to teacher practices of parent involvement. *Elem. Sch. J.* 86, 277–294. doi: 10.1086/461449

Goodpaster, K. P. S., Adedokun, O. A., and Weaver, G. C. (2012). Teachers' perceptions of rural STEM teaching: implications for rural teacher retention. *Rural. Educ.* 33, 9–22. doi: 10.35608/ruraled.v33i3.408

Gutierrez, K. S., and Blanchard, M. R. (2019). "Leading families to STEM with extra school learning" in Electronic proceedings of the ESERA 2019 conference. The beauty and pleasure of understanding: Engaging with contemporary challenges through science education, part 2/2. eds. O. Levrini and G. Tasquier (Bologna: Alma Mater Studiorum–University of Bologna), 228–235.

Hill, N. E. (2015). "Family-school relationships during adolescence: clarifying goals, broadening conceptualizations, and deepening impact" in Processes and pathways of family-school partnerships across development. eds. S. Sheridan and E. Kim (Cham: Springer), 41–59.

Hill, N. E., Castellino, D. R., Lansford, J. E., Nowlin, P., Dodge, K. A., Bates, J. E., et al. (2004). Parent academic involvement as related to school behavior, achievement, and aspirations: demographic variations across adolescence. *Child Dev.* 75, 1491–1509. doi: 10.1111/j.1467-8624.2004.00753.x

Hill, N. E., and Torres, K. (2010). Negotiating the American dream: the paradox of aspirations and achievement among Latino students and engagement between their families and schools. *J. Soc. Issues* 66, 95–112. doi: 10.1111/j.1540-4560.2009.01635.x

Hill, N. E., Witherspoon, D. P., and Bartz, D. (2018). Parental involvement in education during middle school: perspectives of ethnically diverse parents, teachers, and students. *J. Educ. Res.* 111, 12–27. doi: 10.1080/00220671.2016.1190910

Holloway, S. D., and Kunesh, C. E. (2015). "Cultural processes and the connections among home, school, and community" in Processes and pathways of family-school partnerships across development. eds. S. Sheridan and E. Moorman Kim (Cham: Springer), 1–20.

Hoover-Dempsey, K. V., and Sandler, H. M. (1997). Why do parents become involved in their children's education? *Rev. Educ. Res.* 67, 3–42. doi: 10.3102/00346543067001003

Hornby, G., and Lafaele, R. (2011). Barriers to parental involvement in education: an explanatory model. *Educ. Rev.* 63, 37–52. doi: 10.1080/00131911.2010.488049

Ihrig, L. M., Lane, E., Mahatmya, D., and Assouline, S. G. (2018). STEM excellence and leadership program: increasing the level of STEM challenge and engagement for high-achieving students in economically disadvantaged rural communities. *J. Educ. Gift.* 41, 24–42. doi: 10.1177/0162353217745158

Jalak, J., and Nasri, N. (2019). Systematic review: The impact of pedagogy on equity in science education in rural schools. *Creat. Educ.* 10, 3243–3254. doi: 10.4236/ce.2019.1012248

Jeynes, W. (2012). A meta-analysis of the efficacy of different types of parental involvement programs for urban students. *Urban Educ.* 47, 706–742. doi: 10.1177/0042085912445643

Lareau, A. (1987). Social class differences in family-school relationships: the importance of cultural capital. *Soc. Educ.* 60, 73–85. doi: 10.2307/2112583

Lareau, A. (2000). Home advantage: Social class and parental intervention in elementary education. Massachusetts: Rowman & Littlefield Publishers.

Lareau, A. (2011). Unequal childhoods: Class, race, and family life. California: University of California Press.

Lareau, A., and Horvat, E. M. (1999). Moments of social inclusion and exclusion: race, class, and cultural capital in family-school relationships. *Soc. Educ.* 72, 37–53.

Lin, P., and Schunn, C. D. (2016). The dimensions and impact of informal science learning experiences on middle schoolers' attitudes and abilities in science. *Inter. J. Sci. Educ.* 38, 2551–2572. doi: 10.1080/09500693.2016.1251631

Marcus, M., Acosta, D. I., Tõugu, P., Uttal, D. H., and Haden, C. A. (2021). Tinkering with testing: understanding how museum program design advances engineering learning opportunities for children. *Front. Psych.* 12:689425. doi: 10.3389/fpsyg.2021.689425

Martin, L., and Thomas Murphy, C. (2022). Tinkering in the time of COVID: lessons from educators' efforts to facilitate playful tinkering through online learning. *Int. J. Play* 11, 127–144. doi: 10.1080/21594937.2022.2069350

McKenna, M. K., and Millen, J. (2013). Look! Listen! Learn! Parent narratives and grounded theory models of parent voice, presence, and engagement in K-12 education. *Sch. Comm. J.* 23, 9–48.

Metheny, J., and McWhirter, E. H. (2013). Contributions of social status and family support to college students' career decision self-efficacy and outcome expectations. *J. Career Assess.* 21, 378–394. doi: 10.1177/1069072712475164

NCES. Department of Education. (2025). Institute of Education Sciences, National Center for Education Statistics. Available online at: http://nces.ed.gov (Accessed January 31, 2025).

NGSS (2013). Next generation science standards: For states, by states. Washington, DC: The National Academies Press.

Parker, C. E., Stylinski, C. D., Bonney, C. R., and DeLisi, J. (2021). Building STEM identity in rural communities: the role of community and place-based learning. *Rural. Educ.* 42, 18–27. doi: 10.35608/ruraled.v42i2.1221

Priya, A. (2021). Case study methodology of qualitative research: key attributes and navigating the conundrums in its application. *Socio. Bull.* 70, 94–110. doi: 10.1177/0038022920970318

Roberts, T., Jackson, C., Mohr-Schroeder, M. J., Bush, S. B., Maiorca, C., Cavalcanti, M., et al. (2018). Students' perceptions of STEM learning after participating in a summer informal learning experience. *Inter. J. STEM Educ.* 5:35. doi: 10.1186/s40594-018-0133-4

Saw, G. K., and Agger, C. A. (2021). STEM pathways of rural and small-town students: Opportunities to learn, aspirations, preparation, and college enrollmen. *Educ. Res.* 50:595–606. doi: 10.3102/0013189X211027528

Showalter, D., Klein, R., Johnson, J., and Hartman, S. L. (2017). Why rural matters 2015–16: Understanding the changing landscape. Washington, DC: The Rural School and Community Trust.

Simpson, A., Burris, A., and Maltese, A. (2020). Youth's engagement as scientists and engineers in an afterschool making and tinkering program. *Res. Sci. Educ.* 50, 1–22. doi: 10.1007/s11165-017-9678-3

Spencer, M.B., Offidani-Bertrand, C., Harris, K., and Velez, G. (2020). "Examining links between culture, identity, and learning," in Handbook of the cultural foundations of learning, eds. N. S. Nasir, C. D. Lee, R. Pea and RoystonM. M. de New York: Routledge, 44–61.

Stanton-Salazar, R. D. (2011). A social capital framework for the study of institutional agents and their role in the empowerment of low-status students and youth. *Youth Soc.* 43, 1066–1109. doi: 10.1177/0044118X10382877

Vossoughi, S., and Bevan, B. (2014). Making and tinkering: a review of the literature. Nat. *Res. Council Comm. Out Sch. Time STEM.* 67, 1–55.

Vossoughi, S., Escudé, M., Kong, F., and Hooper, P. (2013). Tinkering, learning & equity in the after-school setting. In annual FabLearn conference. Palo Alto, CA: Stanford University.

Walker, J. M., Wilkins, A. S., Dallaire, J. R., Sandler, H. M., and Hoover-Dempsey, K. V. (2005). Parental involvement: model revision through scale development. *Elem. Sch. J.* 106, 85–104. doi: 10.1086/499193

Waters, S., Schroeder, B., and D'Augustino, T. (2018). Place-based education: connecting to STEM learning experiences. *Conn. Sci. Learn.* 1:7. doi: 10.1080/24758779.2018.12420512

Wells, R. S., Seifert, T. A., Padgett, R. D., Park, S., and Umbach, P. D. (2011). Why do more women than men want to earn a four-year degree? Exploring the effects of gender, social origin, and social capital on educational expectations. *J. Higher Educ.* 82, 1–32. doi: 10.1080/00221546.2011.11779083

Wenner, J. A., and Galaviz, S. (2020). Science packs: take-home STEM-themed backpacks provide opportunities for engaging family fun! *Sci. Child.* 57, 35–39.

Whitaker, M. C. (2019). "The Hoover-Dempsey and Sandler model of the parent involvement process" in The Wiley handbook of family, school, and community relationships in education. eds. S. B. Sheldon and T. A. Turner-Vorbeck (Hoboken, NJ, US: John Wiley & Sons, Inc), 421–444.

Wigfield, A., and Eccles, J. S. (2020). "35 years of research on students' subjective task values and motivation: a look Back and a look forward" in Advances in motivation science. ed. A. J. Elliot (Amsterdam, The Netherlands: Elsevier), 161–198.

Yan, W., and Lin, Q. (2005). Parent involvement and mathematics achievement: contrast across racial and ethnic groups. *J. Educ. Res*. 99, 116–127. doi: 10.3200/JOER.99.2.116