Investigating Adolescents' Participation Trajectories in a Collaborative Multimodal Composing Learning Environment

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ABSTRACT: The field of STEM education calls for a nuanced understanding of participation as participation measured by attendance provides limited information about student learning. This multiple case study contributes to a nuanced understanding of youth's participation trajectories in a multimodal composition project. In the project, fifth to eighth grade students worked in small groups to create multimodal science fiction stories in which they needed to propose creative solutions to issues related to climate change. In this study, I adopted two theoretical perspectives, disciplinary identity development and community of practice, to analyze participation trajectories with multiple sources of data. This study shows that STEM practices mediated by multiple modes can not only offer students flexibility in moving across forms of participation, but also open space for them to demonstrate their expertise as knowledge producers. Furthermore, this study suggests that the following strategies could be effective for broadening participation in STEM practices: supporting the development of reflective understanding of connections between disciplines through digital literacies, providing exposure in composing with multiple modes, focusing on building a close relation between self and digital artifacts, and offering flexibility in moving across interactional spaces. These insights shed light on broadening participation in other multimodal learning settings.

Keywords: Multimodal composition, Participation trajectory, Integrated STEM, Digital literacy, Broaden participation

1. Introduction

Integrating science, technology, engineering, and mathematics (STEM) and digital literacy practices holds the promise of broadening access to STEM (Hall & Coyne, 2005). Recent educational reforms have emphasized the importance of broadening adolescents' participation in and access to high-quality STEM practices (NGSS Lead States, 2013; NRC, 2017). The goal is to improve adolescents', especially those who are underserved or underrepresented, STEM competence so that they are prepared to succeed in college and future careers. Multimodal composition, a digital literacy practice in which people use different modes (e.g., text and visual) to represent ideas (Kress, 2003; Kress & Van Leeuwen, 2001), is engaging for adolescents. Integrating multimodal composition in STEM learning is particularly beneficial for minority students (Smith, 2014).

As the current generation of students grows up with increasing experience in consuming and creating digital products, STEM education needs to embrace this experience to enrich and support student learning. Adolescents are used to expressing themselves and connecting with others through multimodal composing. They often create and share digital multimodal artifacts, such as YouTube videos, personal blogs, and video games world widely (Smith, 2014). Students who were disengaged from school could be popular composers out-of-school. Although adolescents' out-school multimodal composing interests and expertise are gradually integrated into STEM curriculum (Smith & Dalton, 2016), much more needs to be done to fully connect multimodal composing practices and STEM practices to increase and broaden participation.

Meanwhile, researchers point out a lack of theoretical understanding and operationalized definition of participation in STEM education (Hrastinski, 2008; Malinen, 2015). Measuring participation from theoretical perspectives can guide us to better understand student learning as participation measured by attendance provides limited information about student learning. Youth tended to lose interest in certain disciplines gradually, especially STEM disciplines. Based on understanding the nature of participation in a nuanced way, we can develop design principles for broadening participation. This study will address this gap by closely examining adolescents' participation trajectories in a collaborative multimodal composing learning environment, drawing on an integrated theoretical framework (as described in Section 3).

2. Literature review

The literature shows that conceptualizing participation as a process of STEM identity development holds promises to provide novel and nuanced insights into student learning (Dou & Cian, 2022; Pinkard et al., 2017).

For example, Van Horne and Bell (2017) found that in the process of becoming core members in a community, one disciplinary identity (e.g., science identity) might be stabilized while the other might be destabilized. Furthermore, they showed that the alignment between students' future possible self and science practices could contribute to the stabilization of STEM identities. As another example, Nasir and Hand (2008) posited that participation in social and cultural practices was fundamentally related to practice-linked identities. They defined practice-linked identities as "a sense of connection between the self and the practice" (p. 147). This study demonstrated that an individual was more likely to participate actively when the person could connect self and STEM practices. Collectively, these studies highlighted the importance of understanding learning from the angle of participation in practices and identity construction.

However, much more effort is still needed in building a solid theoretical understanding of participation and more importantly, turning theoretical conceptualization into empirical operationalization of participation (Cohen et al., 2021; Hrastinski, 2008; Malinen, 2015). For instance, in Franz-Odendaal and colleagues' (2016) study, participation was measured at four levels: no STEM activity, low level, moderate level, and high level. This study elucidated that participation in STEM practices influenced students' likelihood of pursuing STEM careers and suggested that more sophisticated measures of participation were needed to unfold in what ways participation affected STEM career aspirations. Similarly, Boyce and colleagues (2014) found that active participants reported high motivation in pursuing STEM careers. The authors assessed participation based on how students navigated three interactional spaces: interaction with peers, technology, and the physical environment. This study called for applying a theoretical lens to operationalize participation for understanding the dynamics of participation across spaces. Consequently, there is a need of developing a complex and detailed understanding of students' learning experiences through conceptualizing and operationalizing participation from theoretical perspectives, which is the focus of this study.

Furthermore, researchers suggest that multimodal activities are engaging for adolescents to learn STEM practices (Jiang et al., 2021; Smith et al., 2021) and often open up opportunities for students to draw upon their cultural lifeworlds and out-of-school interests in empowering ways (Hull & Katz, 2006). Strides have been made in understanding student learning in activities that integrate multimodal composition and STEM; however, findings in this area tend to focus on reporting affordances of multiple modes in disciplinary learning (Krajcik & Sutherland, 2010). Meanwhile, the literature suggested that just examining one learning space was not sufficient to gain a holistic view of student learning. It's critical to gain a multidimensional understanding of students' multimodal products, composing processes, and reflections on their choices of modes in representing STEM knowledge and practices (Smith & Shen, 2017). This approach affords analyzing student learning across multiple dimensions, but it requires careful consideration of different data sources, especially in learning environments that offer students the flexibility of choosing modes of interest. This study addresses this research gap by presenting a multidimensional understanding of student learning in a multimodal composing environment, focusing on the construct of participation.

3. Theoretical framework

To examine participation trajectories, this study draws on an integrated theoretical framework. Specifically, this study frames students' participation from a community of practice perspective (Lave & Wenger, 1991) and a disciplinary identity development perspective (Van Horne & Bell, 2017). I conceive that students' participation can take various disciplinary *forms* and reach multiple *degrees* within face-to-face and online communities of practice.

This study frames student participation from a community of practice perspective (Lave & Wenger, 1991; Wenger, 1998). Lave and Wenger (1991) proposed that a community of practice consists of a group of people who interact with each other in the pursuit of a common goal. Over time, members of a community learn the appropriate work behaviors and norms as they increasingly participate in consuming and producing ideas. Participation in communities of practice can reach multiple *degrees*, including *breadth* and *depth* of participation (Smith & Shen, 2017). Breadth of participation was usually indicated by the amount of participation, such as time on task (Denault & Poulin, 2009; Handley et al., 2006; Preece, 2001; Zheng & Warschauer, 2015). Lave and Wenger (1991) described a range of depth of participation within communities of practice, from legitimate peripheral participation of newcomers to full participation of experts. According to Engle and Conant (2002), the moving from peripheral to full participation can be marked by levels of authorship of ideas. Engle and Conant proposed the significance of encouraging "students to be authors and producers of knowledge, with ownership over it, rather than mere consumers of it" (p. 404). Learners must aspire to become contributors and not simply consumers of knowledge produced by the community.

Furthermore, this study conceptualizes student participation as a process of disciplinary identity development. Students author various disciplinary identities prior to participating in any learning environment. As Van Horne and Bell (2017) explained, "all designed learning experiences involve a framing and cultivation of disciplinary identities" (p. 439). They also indicated that disciplinary identity development was a process of moving from legitimate peripheral participation to full participation in communities of practice through participating in domain-linked practices. In this perspective, a disciplinary identity (e.g., writing identity), is enacted when a person shows positive attitudes toward disciplines and interests in discipline-related careers (Archer et al., 2010), demonstrates normative disciplinary knowledge and practices (Carlone & Johnson, 2007), and gains recognition as a legitimate participant by self and others in communities (Lave & Wenger, 1991). Drawing on the construct of disciplinary identity, students could participate in communities of practice through taking various *forms* of participation. These forms are represented in the disciplinary roles that students play in a community in this study.

A community of practice lens examines the degree of participation while disciplinary identity development offers a way for investigating the form of participation. Combining the perspective of disciplinary identities with community of practice, we will gain insights into the degree of participation (including both breadth and depth) while students participate in STEM practices through different forms. Based on an integrated framework of participation, this study addresses the following research questions (RQ):

- RQ1: What are the trajectories of students' *forms* of participation in a collaborative multimodal composing learning environment?
- RQ2: What are the trajectories of students' *degrees (including both breadth and depth)* of participation in a collaborative multimodal composing learning environment?

4. Method

4.1. The STEM+L project

I report on a single iteration of a design-based research program (Cobb et al., 2003) that sought to broaden adolescents' participation in integrated STEM+L (STEM and digital Literacies) practices. The project was hosted at a university in a large southeastern city in the United States. In the project, students worked collaboratively in small groups to create multimodal science fictions. In their science fictions, students were required to propose a creative solution to issues related to climate change.

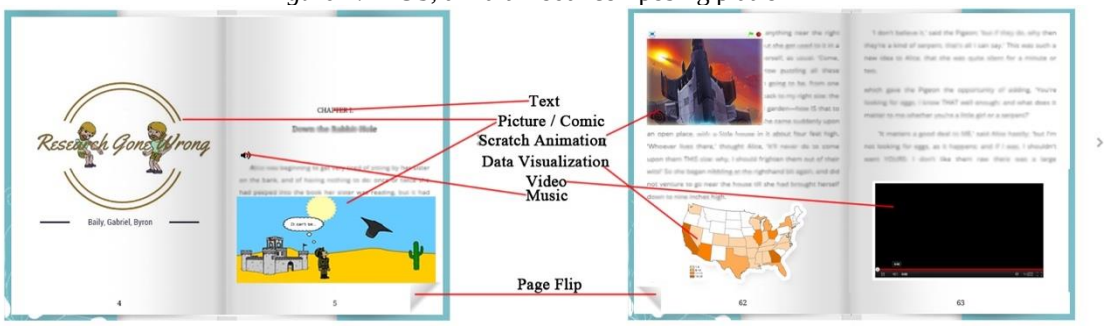
Specifically, the project included three major phases: (1) one-week summer camp; (2) fall semester extension that incorporated online learning and six physical sessions on Saturdays during the fall; (3) a final show event to authentic audiences at an international science fiction film festival. During the summer, students attended the program every day from 9:30 am to 3:30 pm for a week. Throughout the week, students learned multimodal composing tools, were introduced to story writing and climate change, and visited science labs at the University. Furthermore, they worked in small groups of three to four to complete the first version of multimodal science fictions. In the fall extension, students continued working on the multimodal science fictions in small groups. At the end of the project, they presented multimodal science fictions to authentic audiences.

Role-taking. In small groups, each student selected one of the three roles: designer, scientist, and writer. Designers were responsible for creating visual and audio representations (e.g., comic); scientists were in charge of verifying and incorporating scientific information; writers were accountable for developing and writing the fiction plot. Each group should have at least one scientist and one writer. In addition, students could propose other roles, take hybrid roles (e.g., taking the role of scientist as a major role with a minor role in design), or change roles throughout the project. Despite differentiated roles, group members collaborated with each other on their individual and collective tasks.

Multimodal composition. Students learned multimodal composing tools, including Pixton (character and comic design application), Scratch (animation and game design program), Moviemaker (video editing program), and Pixlr (image editing application). Both Pixton and Scratch provide the functions of sharing their own artifacts, remixing others' artifacts, and posting comments in the corresponding community. All groups used iKOS (Jiang et al., 2021) to compile multimodal artifacts into interactive flipbooks (Figure 1). iKOS is a web-based knowledge organization platform for individuals and/or groups to construct, share, and organize knowledge in multimodal representations. Users can embed artifacts created in the system (e.g., written narrative) and external artifacts (e.g., comics from Pixton) to generate an interactive flipbook. Despite these functions, students can interact with each other through rating, commenting, and co-editing entries within the system. The system also

creates log data of students' frequencies, durations, and sequences of computer actions (e.g., the timestamp when students click one entry). Beyond the presented technologies, students were free to bring in multimodal tools that they were familiar with, and the research team provided corresponding technology support.

Figure 1. iKOS, a multimodal composing platform



4.2. Participants

This study included a total of 42 students (19 Latinx, 14 Black, 4 White, and 5 other ethnic groups; 16 female and 26 male). These students were divided into two cohorts (cohort A, 22 students; cohort B, 20 students) due to resource limitations. Students were from public schools in the Southeastern U.S. area, with six 5th graders, fifteen 6th graders, eight 7th grades, and thirteen 8th graders. Four focal students in four different groups were selected for in-depth analysis of their participation trajectories: Olivia (all names were pseudonyms; seventh grader), Nick (sixth grader), Steve (sixth grader), and Saanvi (fifth grader). These four cases were selected for several considerations. First, they attended most or all the sessions so that a relatively complete profile for each of them could be captured. Second, these cases instantiate maximum variation (Flyvbjerg, 2006) in terms of gender, race, grade, and engagement in STEM+L practices throughout the program. The selection was also what Flyvbjerg (2006) called an informed-oriented selection: From field notes and review of their multimodal artifacts, I expected these cases to contain rich examples of scaling and assembling comparisons in participation trajectories.

4.3. Researcher's participant observer role

My role in this study was a participant observer (Spradley, 1980) who was highly involved in designing learning activities, instructing and interacting with students, and collecting data. While interacting with students, I paid close attention to their role taking and multimodal composing processes and provided feedback when needed. As a participant observer, reflexive awareness of my own biases and positionality was crucial for establishing trustworthiness (Miles & Huberman, 1994). In order to establish trustworthiness in this qualitative study, I followed the following widely regarded standards: credibility, transferability, dependability, and confirmability (Erlandson et al., 1993).

4.4. Data collection

A variety of data were collected: pre-, mid-, and post-surveys for understanding students' experiences of the project; student-generated multimodal artifacts; iKOS logging data; comments and ratings in Pixton, Scratch, and iKOS; video records of students' physical participation together with the audio records of students' conversations; group-based semi-structured interviews (Patton, 1990) for identifying students' perceptions of teamwork, role taking, multimodal design decisions, and science learning; video reflections (i.e., students created videos to reflect on learning experiences); field notes; and physical materials (e.g., poster). Specifically, the research team used Qualtrics to administer online surveys. We conducted surveys three times: one on the first day of the summer camp, one on the fifth day of the summer camp, and one at the fifth session of the fall semester extension. In addition, in the fifth session during the fall, we conducted interviews with two groups and video and audio recorded the interviews.

Specific data sources for the four focal cases varied based upon students' choices of tools, the availability of video and interview data, and relevance of data to each case. Olivia mainly worked in iKOS; Nick contributed mostly in designing comics in Pixton and editing entries in iKOS; Steve mainly designed comics and posted

comments in Pixton; Saanvi spread her work in all composing platforms. Although Olivia worked in iKOS, we did not analyze her iKOS logging data because she typed in word documents and then pasted texts in iKOS. We also did not analyze Saanvi's logging data because she worked in her group member's account. Due to the nature of afterschool programs, we could not collect video recordings for all physical sessions of any focal students. However, we analyzed other sources of data to get a full picture of students' participation.

4.5. Data analysis

The data analysis was mainly qualitative in nature, informed by a grounded theory approach (Strauss & Corbin, 1998) to address research questions centered around students' forms and degrees of participation in STEM+L practices. Table 1 provides an overview of the data analytic process. First, surveys were qualitatively analyzed, and initial case summaries were created to show students' changes in the form of participation through role taking. Specifically, I examined students' responses to pre-, mid-, and post-surveys on attitudes toward disciplinary roles (i.e., designer, scientist, and writer) to show how forms of participation changed over time. I also connected their attitudes toward disciplinary roles with interests in disciplinary practices (e.g., design, science, and writing) and STEM careers to understand how forms of participation changed. Second, initial case summaries were created to show students' changes in the breadth of participation using frequencies of multimodal artifacts, edits in iKOS, and comments and ratings in multimodal composing platforms. Third, I conducted content analysis of multimodal artifacts and online interactions to examine the forms and depth of participation. Fourth, I used interaction analysis (Jordan & Henderson, 1995) to analyze the video recordings. Initially, I focused on "hot spots" (Jordan & Henderson, 1995) of interaction as they pertain to students' forms (e.g., designing comics to illustrate story plots as a designer) and degrees of participation (e.g., proposing new ideas). In a more systematic, second pass through the recordings, content logs and memos were developed to describe students' participation trajectories. The interaction analysis provides a fine-grained understanding of the form and degree of participation.

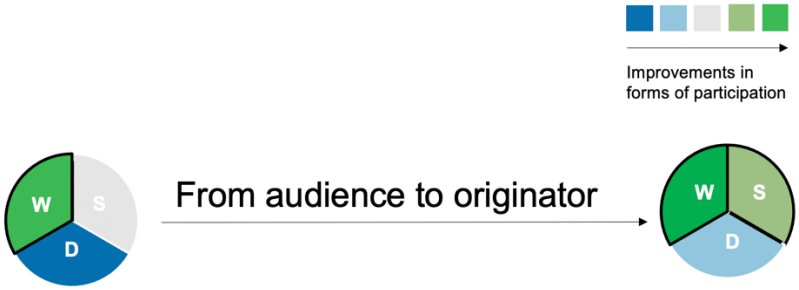
After analyzing these data sources, I discussed and revised case summaries with the larger research team in weekly meetings. In addition, I openly coded student reflections, video interviews, field notes, and physical materials that were connected to the form and degree of participation previously analyzed. In this process, I looked for connections to other data sources and new insights provided by students' perspectives and classroom observations. Afterward, I engaged in another round of revising cases with the larger research team. In this round of case revision, we followed Calabrese Barton and colleagues' (2013) methodology to craft participation trajectories based on focal events.

As an example, Figure 2 is a simplified representation of Olivia's participation. We first identified five focal events where Olivia changed her form or degree of participation through a systematic content analysis of case summaries. The focal events were creating animations, seeing a good example of enriching story with science, integrating space science into a new story, providing design ideas for textual narratives, and worrying about the design component of the story (Figure 3, a complete representation of her participation trajectory). After identifying focal events, we crafted her participation trajectory. Specifically, we first examined her changes in participation in disciplinary learning, including writing, science, and design. The color of S changed from grey to green. It means that Olivia's attitude toward science changed from neutral to positive based on survey data (Figure 2). This was a change in the form of participation. The border of pie changed from W to W and S. It means that Olivia recognized herself as a designer at the beginning and recognized herself as a writer and scientist at the end based on survey data. This was also a change in the form of participation. Olivia contributed to her group more as an audience when writing the first story, but shifted toward an originator when writing the second story based on content analysis of multimodal artifacts and interaction analysis of video recordings. The shape of the line (Figure 3) captured our qualitative interpretation of her change in originating ideas. The five focal events drove our qualitative interpretation of her changes in the depth of participation. To show the breadth of participation, we compared the number of words that Olivia wrote in two stories as she mainly engaged in this practice. Since she contributed a significant number of words in both stories, we conceptualize that her breath of participation did not change (i.e., the thickness of the line stays the same in Figure 3). Overall, driven by focal events, we crafted trajectories by first showing changes in forms of participation based on survey data and then conducting an in-depth qualitative analysis of multimodal artifacts and physical and/or online interactions to show degrees of participation.

Table 1. Overview of data analytic process (Strauss & Corbin, 1998)

Phase of data analytics	Data source						RQ1	RQ2
	Survey	Multimodal artifacts	Logging data	Comments and ratings	Video recordings	Others (e.g., interviews)	Forms of participation	Degrees of participation
1. Creating initial case summaries for students' forms of participation in terms of role taking	•						•	
2. Creating initial case summaries for students' breadth of participation in terms of online activities		•	•	•				•
3. Content analysis of multimodal artifacts and online interactions		•	•	•			•	•
4. Interaction analysis of video recordings					•		•	•
5. Revising case summaries	•	•	•	•	•		•	•
6. Open coding of students' perspectives on their participation and classroom observations						•	•	•
7. Revising case summaries	•	•	•	•	•	•	•	•

Figure 2. A simplified representation of Olivia's participation



Note. Each pie represents forms of participation through taking roles: W = Writer; S = Scientist, and D = Designer. Highlighted edges on pies indicate students' main roles. Colors of W/S/D represent strongly agree, disagree, neutral, agree, and strongly agree in having an interest in Writing/Science/Design.

5. Results

This section presents four cases to illuminate participation trajectories in the STEM+L project. Each case starts with a summary of the student's general background information and the group's composition. Then, I report overarching themes organized around forms and degrees of participation as framed in the two research questions.

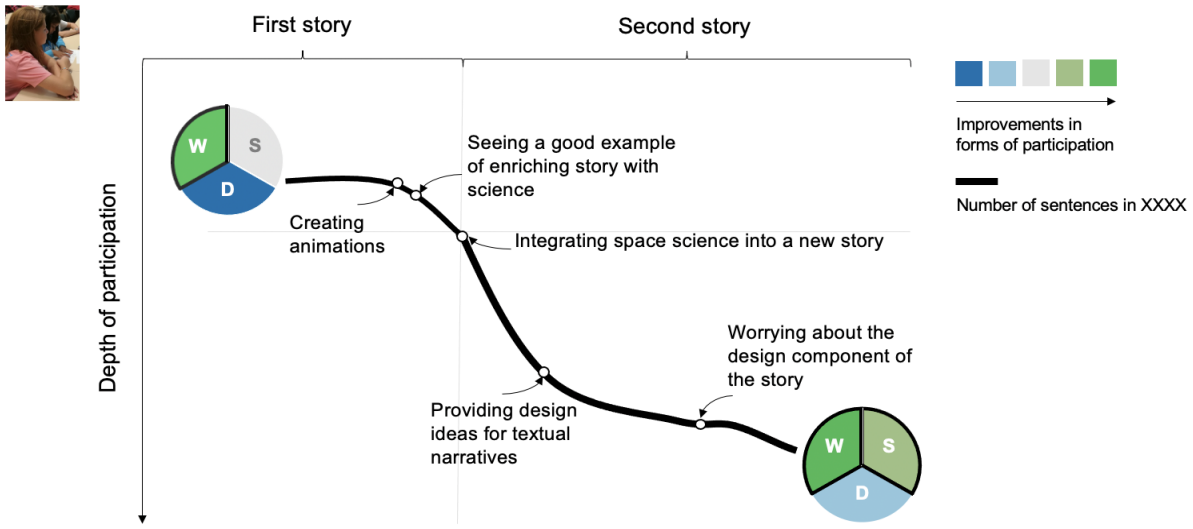
5.1. The case of Olivia: A trajectory from strong writer to emerging scientist

Olivia, a white female, was passionate about writing, selected the role of writer, and demonstrated herself as a strong writer throughout the program. In the summer, she joined a group of all seventh-grade students including Alyssa (African American female) who was the designer and Diego (Latino) and Bing (Asian male) who were both scientists. Diego led the development of the first story which was about a man who woke up after two years of a coma only to find out that the Earth was in darkness due to a long solar eclipse. Although Olivia was not excited about the story proposed by Diego, as the writer she wrote four chapters (1415 words in total). While working on the first story, she wrote textual narratives to match ideas in Diego's comics.

In the fall, because Diego and Bing didn't return to the program, Olivia and Alyssa decided to write a new story in spite of the instructors' advice to expand or revise the one the group had written in the summer. Inspired by a NASA news release about the discovery of a potential ninth planet, the two girls composed a fiction about a female middle schooler who wrote a story to describe her adventure on a new planet. Compared to the summer, Olivia was more active in developing the new story and provided Alyssa with design ideas. The pair ended up creating a story with three chapters (1787 words in total), two images, and four animations.

Figure 3 summarizes Olivia's participation in STEM+L practices. In this case, forms of participation changed mainly in the role of scientist while degrees of participation increased slightly in the breadth and greatly in the depth of participation.

Figure 3. Olivia's participation trajectories



Note. Each pie represents forms of participation through taking roles: W = Writer; S = Scientist, and D = Designer. Highlighted edges on pies indicate students' main roles. Thicker lines represent more breadth of participation.

5.1.1. Forms and degrees of participation

Olivia's case reveals a significant change in the form of participation, from taking the role of writer to taking the hybrid role of writer and scientist (Figure 3). Initially, Olivia only wanted to take the role of writer because of her passion and expertise in writing. She explained, "I love to write. I find myself transported to another world when getting my thoughts typed on a screen. My hands do the typing, and my brain the storytelling" (pre-survey). Understanding the connection between writing and science and learning examples of the integration between the two practices in animations helped Olivia expand from her comfort zone of writing into science learning. She successfully connected both and "worked well as writer and scientist" (post-survey).

As made evident in this case, the depth of participation changed significantly while the breadth of participation was pretty stable. Although having created many textural narratives in both fictions, Olivia contributed substantially in generating new ideas while composing the second fiction. The second fiction was inspired by a NASA news release about the discovery of a potential ninth planet. When Olivia came to a physical session, she discussed the news with one researcher and shared with the researcher the idea of creating a new story based on the ninth planet (Excerpt 1).

Excerpt 1 [Group working on the second fall session]
1 Olivia (*showing her screen*): Look at this. I do not know whether it's okay. Here, I wrote about the ninth planet, like how it looks and how the life there might be. I want to write a new story about the ninth planet.
2 Researcher: That's a lot. I would hesitate to change the whole story. But go ahead and jump in some ideas.
(*Olivia read her writing to the researcher*)
3 Olivia (*in an excited tone*): I am thinking that the ninth planet might like the surface of the Earth. There could be life on it, similar or might be different from us. Our story could show the possible things that are going on in the ninth planet.

The excerpt above demonstrated that the second story was driven by a science topic, the ninth planet, that Olivia was interested in. Olivia led the second fiction while two male students led the first one. While sometimes she expressed concern about missing comics in the story as the designer was only interested in creating Scratch animations, overall, her depth of participation improved over time. Being able to control the story development gave her a sense of ownership. It indicated that the cultivation of a sense of ownership would help increase the degree (especially depth) of participation.

In this case, the change from being a writer to a writer and scientist motivated Olivia to originate more science ideas in story writing. This suggests that the recognition of taking the role of scientist, impacted by changes in group dynamics (missing two scientists), contributed to improvements in both the breadth and depth of participation in science. Meanwhile, extended depth of participation in science, mediated by a sense of ownership, enabled her to originate most ideas in story writing and developed a positive attitude towards the role of scientist. In summary, Olivia's case illustrates that understanding the connection between disciplinary practices could result in changes in the form of participation while a sense of ownership is very important for deepening the depth of participation.

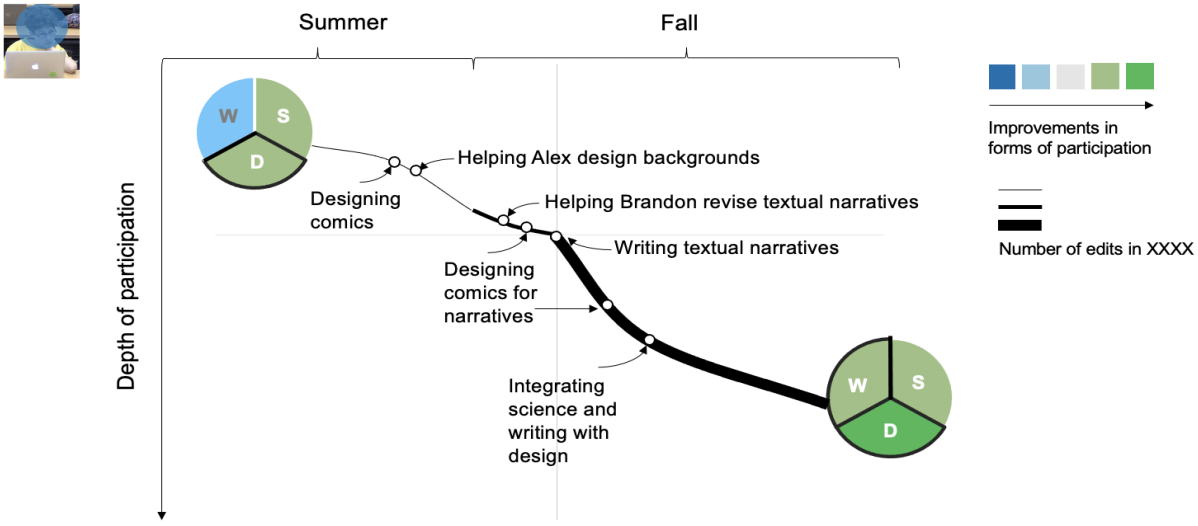
5.2. The case of Nick: A trajectory from diligent designer to motivated writer

Nick (sixth grade; Latino) took the role of designer, working with Alex (sixth grade; White male), the scientist, and Brandon (sixth grade; White male), the writer. The team composed a multimodal science fiction titled "What Would Happen if the World Stopped Spinning". In the fiction, three survivors, each representing a group member, discovered a new civilization after an asteroid struck the Earth and stopped the Earth from spinning. The team's multimodal composing processes involved the design of comics, photos, and images (Nick's major contribution), the development of textual narratives (Brandon and Nick's major contribution), and the creation of animations (Alex's major contribution).

To fulfill the role of designer, Nick mainly worked on creating comics during the summer camp and early fall, but engaged in designing visuals and writing textual narratives towards the end of the project. Overall, he contributed in creating a book cover and a photo, designing comics in Pixton, and writing story narratives in iKOS. Meanwhile, Nick was a collaborator and was the only one in the team who preferred working with others.

As shown in Figure 4, Nick extended his role of designer to the role of designer and writer. In this case, forms of participation changed in all three aspects (i.e., attitudes and interests, knowledge and practices, and recognition) while degrees of participation increased greatly in both the breadth and depth of participation.

Figure 4. Nick's participation trajectories

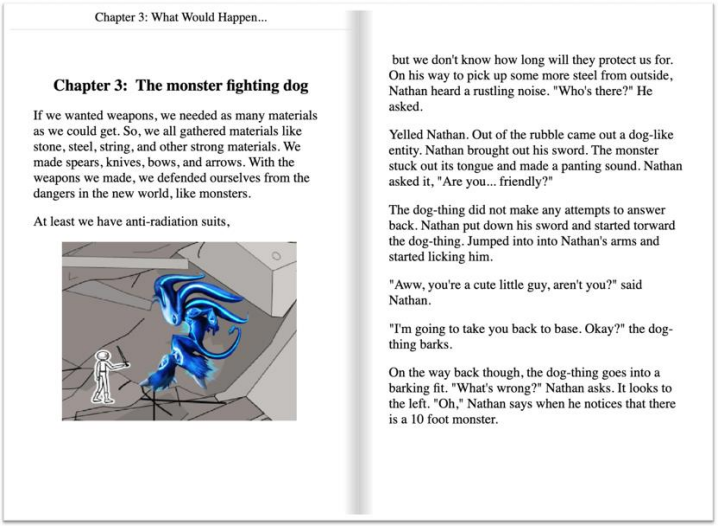


5.2.1. Forms and degrees of participation

Taking the role of designer as his primary form of participation, Nick's interest in being a designer stayed positive. He focused on designing comics for his team's work. Although the number of comics didn't change significantly over time, the quality did. This was reflected in his improved portrayal of nuanced actions of characters in his comics and better integration between comics and narratives, as well as incorporation of science concepts occasionally.

More interestingly, his attitude toward the role of writer turned from negative to positive (Figure 4). First, his preference in working with and helping others enabled him to enter writing practice. He started from reading textual narratives, then revised Brandon's texts, and finally wrote the story himself. This was consistent with his view of role taking as a way to try out different practices, including the writing practice that he had little confidence in, which in turn reinforced his self-recognition of being a writer. Second, the integration between design (i.e., creating comics) and writing (i.e., producing textual narratives) enabled Nick to see relevance and develop confidence in writing. As he was confident in design but not in writing in the beginning, extending that comfort zone to connect different disciplinary practices helped him build confidence in new areas. Third, the change from being a contributor to an originator in writing gave him more authority and agency in being a writer. While editing texts as a writer, besides revising existing texts as a more peripheral participant, over time, Nick added original story narratives as a more central participant. Lastly, infusing himself in his own character in the story (Figure 5) and being able to make himself visible in the team artifact might also contribute to a more positive attitude towards taking the role of writer.

Figure 5. Nick wrote a chapter about the character, Nathan, representing himself in the story


Chapter 3: What Would Happen...

Chapter 3: The monster fighting dog

If we wanted weapons, we needed as many materials as we could get. So, we all gathered materials like stone, steel, string, and other strong materials. We made spears, knives, bows, and arrows. With the weapons we made, we defended ourselves from the dangers in the new world, like monsters.

At least we have anti-radiation suits,

but we don't know how long will they protect us for. On his way to pick up some more steel from outside, Nathan heard a rustling noise. "Who's there?" He asked.

Yelled Nathan. Out of the rubble came out a dog-like entity. Nathan brought out his sword. The monster stuck out its tongue and made a panting sound. Nathan asked it, "Are you... friendly?"

The dog-thing did not make any attempts to answer back. Nathan put down his sword and started torward the dog-thing. Jumped into into Nathan's arms and started licking him.

"Aww, you're a cute little guy, aren't you?" said Nathan.

"I'm going to take you back to base. Okay?" the dog-thing barks.

On the way back though, the dog-thing goes into a barking fit. "What's wrong?" Nathan asks. It looks to the left. "Oh," Nathan says when he notices that there is a 10 foot monster.

The case shows that the expansion of forms of participation (i.e., from taking the role of designer to taking the role of designer and writer) could open the door for deepening the depth of participation and increasing the breadth of participation. While revising Brandon's texts as a writer, Nick changed from an audience to a contributor in writing. After that, he moved to a more central participation situation, being an originator while developing his own textual narratives. Brandon's (the writer in the team) interview responses further evidenced that Nick originated various story ideas, "first, we always talked about what will happen next, and then just started adding some implements, like he added the dog (blue animal in Figure 5) and then I added other ideas." The expansion to an originator also leads to a marked increase in the breadth of participation in writing. Nick developed many more textual narratives in the fall than in the summer.

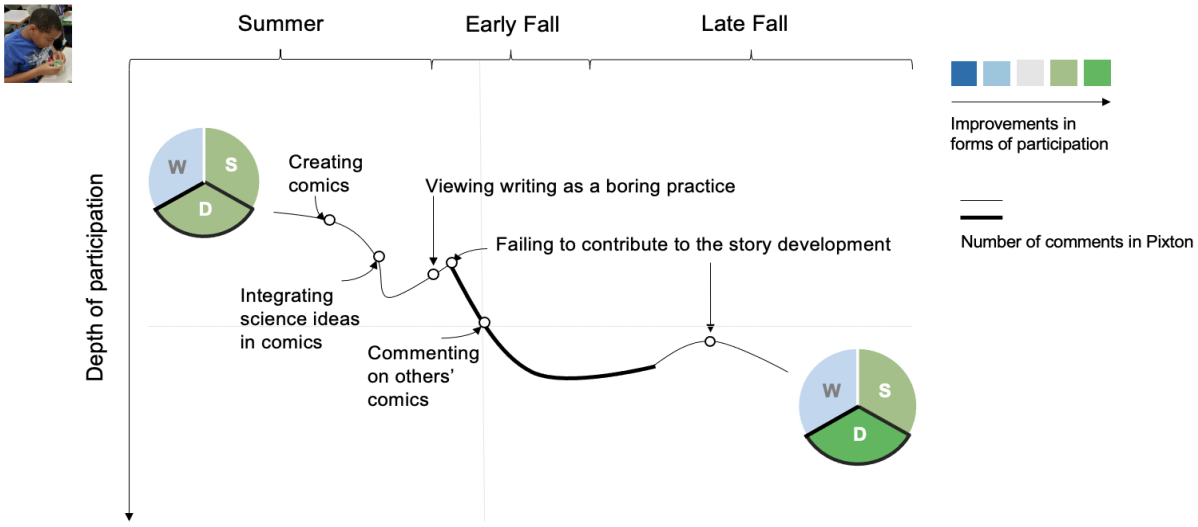
In summary, Nick's case demonstrates how role taking could be used as a tool to extend his comfort zone of design, helped him develop a strong interest in writing, and motivated him to take the role of writer. His diligence in design and helping team members ensured active participation in integrated disciplinary practices that connected different areas of disciplinary knowledge. The case also suggests that infusing himself in the story might motivate Nick to propose his own story ideas.

5.3. The case of Steve: A trajectory from creative designer to active commenter

Steve (sixth grade; African American male) took the role of designer in the team composed of one designer (himself), one scientist (Kaylee, seventh grade; African American female), and one writer (Pi, eighth grade; Indian American male). The team created a multimodal science fiction titled "Captain Atomicon." The team's multimodal composing processes involved the design of comics (Steve's major contribution), the development of textual narratives (Pi's major contribution), and the creation of a book cover (Pi's and Kaylee's major contribution).

Steve mostly worked alone during physical sessions but had active participation in online interactions. Most of the time when working on their team project, he worked by himself searching for online sources (e.g., images, videos, and music) and designing comics. In contrast to his working-alone style during small group meetings, he was very active in posting comments on others' comics in Pixton. Figure 6 summarizes Steve's participation in this program. In his case, forms of participation changed in the dimension of disciplinary practices while degrees of participation increased slightly in both breadth and depth.

Figure 6. Steve's participation trajectories



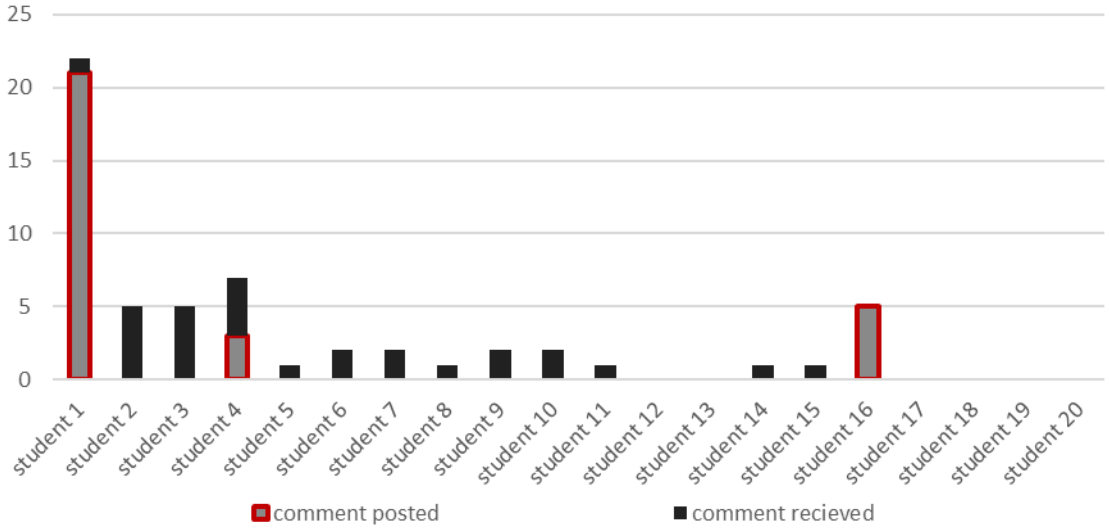
5.3.1. Forms and degrees of participation

With respect to forms of participation, Steve took on the role of designer, contributed to the team project as what the role entailed, and liked this role throughout, despite the fact that he objected to having specific roles. He demonstrated in his comics a better practicing designer over time (Figure 6). The improvement was evidenced in his more advanced comic design (e.g., better thematic congruence between comic panels), incorporating better writing in comics (e.g., speech bubbles with better writing), and integrating science ideas with multiple modes

(e.g., using a combination of texts and pictures to illustrate science ideas). These different aspects of improvement were all grounded in his contribution as the designer of the team.

His breadth of participation was extended through the online space. Even though Steve's contribution to their team project was roughly evenly distributed throughout the sessions, over time, he posted more comments regularly to the whole class in Pixton. In the project, we did not prompt or require students to make comments so only a few (students 1, 4, and 16) made comments. Steve (Student 1 in Figure 7) posted the most comments.

Figure 7. Pixton activity from cohort B. Student 1 represents Steve



As we can see, although being silent and limited in physical interactions, Steve became more active in interacting with others in the community by posting online comments.

In terms of the depth of participation, Steve changed from more peripheral to more central participation through both contributions for the team project and the whole class. In the small group, he started with being an audience to try to understand Pi's fiction plot and a contributor to visualize the story. But gradually, he proposed new ideas in his comics. Specifically, he generated story plots that were sometimes complementary to but sometimes in conflict with Pi's textual narratives. While posting comments to the whole class, he contributed ideas instead of purely evaluating ideas from the aspect of design and science, but served more as an audience in writing. It indicates that he became a more central participant in design and science, but stayed as a more peripheral participant in writing.

In summary, changes in the form of participation are reflected in the improvement in knowledge and practices associated with design while the degree of participation varied depending on the type of practices and the interactional spaces (i.e., face-to-face group interactions and online interactions in Pixton).

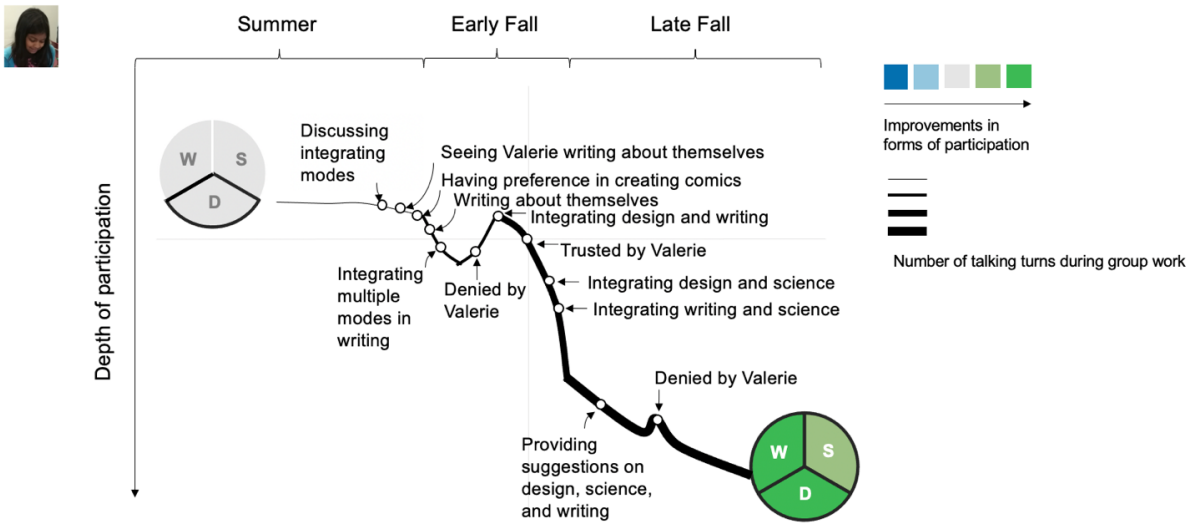
5.4. The case of Saanvi: A trajectory from conforming designer to proactive writer

Saanvi (Designer; fifth grade; Asian female) worked in a group with three sixth graders, including Valeria (Writer; Latina), Emilia (Scientist; Female; Other), and Mariana (Designer; Latina). The group created a multimodal science fiction titled "Tsunami Terror" in which Crystal, Sara, and Keke saved people from a tsunami that was triggered by Kai. The four main characters represented the four group members. While composing the fiction, Saanvi initially worked as a designer, but ended up taking all roles, especially designer and writer.

In the summer, Saanvi had remained on the periphery of the group but fulfilled her role of designer in spite of her silence and apparent isolation on the outer stage. She became strongly interested in taking the role of writer and reported the passion to take the role of writer on the last day of summer camp. In the second fall session, Saanvi had the chance to write the story while Valeria was absent. However, Valeria declined her changes to the story after coming back in the third session. Therefore, Saanvi went back to designing. While Valeria stuck with moving the storyline forward, Saanvi proposed to write narratives based on the comic that she created. Afterward, Valeria accepted Saanvi's writing. After building trust with Valeria, Saanvi had the opportunity to take the role of writer and put much effort into both writing and designing in the late fall. In addition, other group

members trusted and valued Saanvi's suggestions while constructing artifacts towards the end of the project. Figure 8 summarizes Saanvi's participation in the STEM+L project. In this case, Saanvi had improvements in all the forms of participation and increases in both the breadth and depth of participation.

Figure 8. Saanvi's participation trajectories



5.4.1. Forms and degrees of participation

In terms of forms of participation, Saanvi's role changed from taking the role of designer to taking all three roles (Figure 8). Her change in forms of participation was mainly triggered by three factors: modal preferences, writing about themselves in the story, and integrating writing and science. Having preferences in designing specific modalities (e.g., comic), Saanvi became interested in taking the role of designer. In addition, she developed a strong interest in taking the role of writer after the summer camp. She wanted to write about herself, team members, and group interactions. This indicated that projecting themselves into the story through characters had the potential of fostering interest in writing. Although having a more negative attitude towards taking the role of scientist, she became interested in specific science topics in the story (e.g., tsunami). Her motivation for exploring specific science topics was to write the story in a more scientific way.

Her breadth of participation increased through composing with multiple modes across disciplines. Initially, Saanvi only created comics and, in her opinion, having multiple modes meant doing the same thing repeatedly. She gradually learned that modes could support each other in different ways. For example, she created voice narrations of science explanations to balance the fantasy aspect of textual narratives and science components. She described, "Fantasy is easier to do but with the science you have to have a little bit of equableness" (final interview). This case shows that multimodal composing across multiple disciplinary practices could extend the breadth of participation through composing with multiple modes and creating cross-disciplinary artifacts.

As made evident in this case, her depth of participation changed from more peripheral to more central participation after the trust between Saanvi and Valerie was established. Saanvi started with designing comics to visualize Mariana's ideas as a contributor. She also recorded voice narrations to explain the key science aspect of the story as a contributor. Over time, she could use modes that she created before as a way to originate ideas in another mode, story writing. For example, she expanded dialogues in comics into textual narratives when Valerie ran out of ideas. But her changes in writing were not accepted in the artifact until Valerie trusted and valued her writing. This case illustrates that being a contributor in one mode could lead to becoming an originator in another mode. Her more central participation was also evidenced in more active participation in group discussions. Being trusted as the one who contributed in developing story ideas, Saanvi provided ideas on all aspects of group artifacts in the late fall. Her participation was spread across various disciplinary practices when group members sought feedback from her.

In summary, Saanvi started as a quiet, passive participant but eventually ended up being a confident designer and writer who worked across multiple disciplinary domains, and an active team member others trusted and sought help. The case suggests that a student might contribute more (both in breadth and depth) in communities of practice when exposed to multiple disciplines and had flexibility in moving across disciplines to express oneself.

In addition, the extension of degrees of participation, mediated by composing with multiple modes, led to self-recognition as disciplinary persons. In this case, Saanvi clearly regarded herself as a designer, scientist, and writer who composed across disciplines (i.e., design, science, and writing) with multiple modes (e.g., comics, texts, and voice narrations). It indicates that multimodal composing might facilitate Saanvi in linking practices with disciplinary identities.

6. Discussion and implications

This study integrated the theoretical perspectives of disciplinary identity development and community of practice to examine students' participation from two dimensions: the form and the degree of participation. When comparing and contrasting these cases, commonalities and variations in changes in forms and degrees of participation were revealed. These commonalities and variations have implications for advancing our understanding of adolescents' participation trajectories in collaborative multimodal composition.

The four cases were similar in that students chose roles that fell within their practice comfort zones (Anderson & Gegg-Harrison, 2013). As a change in the form of participation, the four cases started with participating in disciplinary practices that they felt comfortable with (i.e., practice comfort zone) and used it as a bridge to move toward new disciplinary practices and take new roles. The cases reveal that students needed to see connections between disciplinary practices to move beyond practice comfort zone (Zimmerman & Land, 2014). Meanwhile, the extension of practice comfort zones set a critical foundation for the development of integrated disciplinary knowledge and practices as a change in the form of participation. Clearly, we can see that the four cases developed knowledge and skills in integrating different disciplinary knowledge and practices. This finding supports the current understanding of multiple modes driving disciplinary learning (e.g., Krajcik & Sutherland, 2010) and provides a new understanding of how students engaged in cross-disciplinary learning through composing with multiple modes.

While the four cases exhibited different breadth of participation across the program, all of them changed from more peripheral to more central participation - from consumers to producers. Scholars emphasized that learners should be encouraged to become producers of knowledge (Engle & Conant, 2002). This study adds to the research demonstrating the nuanced process of students changing from consuming ideas to producing ideas. All four cases ended up originating ideas, but the stimuli that triggered their changes and the timing when changes happened were different. Exploring the stimuli in other contexts is a promising future research direction to generate insights towards preparing students to be active learning agents in multimodal learning environments.

This paper also contributed in examining participation by connecting the form of participation, from the perspective of disciplinary identity and the degree of participation, from the perspective of community of practice. Firstly, composing with multiple modes helped grow (especially integrated) disciplinary knowledge. Improvements in disciplinary knowledge and practices provide fertile ground for the cultivation of disciplinary identities. This finding confirmed previous research indicating that multimodal composition could shape STEM identity (Pytash et al., 2017). Secondly, the interaction between self and the community has an impact on the construction of disciplinary identities. The recognition of disciplinary persons strengthens students' participation in sharing knowledge within and beyond small groups, and (even) beyond the community that students were in. Lastly, a close relation between self and artifacts, in the format of projection, motivates the extension of both breadth and (especially) depth of participation. It implies the crucial role of establishing the relation in moving students from knowledge consumers to producers. Further research is needed to probe the nuanced processes of building a close relation between self and multimodal artifacts and identify tools, materials, and activities to help students to connect themselves with artifacts.

In accordance with the literature (e.g., Hull & Katz, 2006; Smith et al., 2021), this study shows that students established a sense of ownership through composing with multiple modes. The sense of ownership can be strengthened with frequent within or across group sharing of multimodal artifacts. Furthermore, students demonstrated expertise in using composing tools. In a collaborative multimodal learning environment, the sense of ownership might create conflict. For example, in this study, Valerie initially denied Saanvi's contribution in writing. Conflict is a natural ingredient in any teamwork and avoiding conflict is not the solution (Jiang et al., 2021). Our study contributes to the literature by showing how students encountered and resolved conflicts (e.g., competing for using the same tool) while developing individual expertise. What needs to be explored further is instructional strategies that can turn these conflicts into opportunities to improve group performance. This includes transforming a competitive relationship into a collaborative one in which students could co-develop

artifacts using the same mode and integrate different modes effectively. How to leverage the sense of ownership in multimodal composition to support teamwork would be a worthwhile research direction for the future.

The findings raise new questions about the conceptualization and operationalization of participation in STEM education. Students in this study had their own preferences in modes and disciplinary practices at the beginning of the project. Thus, their entry points in learning STEM practices were different. In addition, their preferred modes and practices could change dramatically over time. This phenomenon is in accordance with several studies in the literature (e.g., Nasir & Hand, 2008; Pinkard et al., 2017). It indicates that in operationalizing participation, we should consider students' previous experiences and interests, recognize that it's critical to capture dynamic changes, and acknowledge the great diversity of participation trajectories. Also, qualitative interpretation is a critical part of operationalization. One goal of operationalization is using the result of operationalization to design technologies for supporting teaching and learning activities (Boyce et al., 2014). One promising future direction is the study of showing the quantitative aspect of participation effectively for teachers to make qualitative interpretations.

The limitations of this study point to a number of important areas for future research. These findings are deeply situated in the STEM+L project where students created multimodal science fictions in small groups. Much more needs to be understood about participation trajectories with differing students, contexts, tools, and genres. Furthermore, the scope of this study was confined to how students participated in the project and did not capture aspects of their experiences that occurred outside of the project. Further research is needed that traces adolescents' participation across contexts and spaces.

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Selection and participation of children

All consent processes and forms for this study were approved by the Solutions Institutional Review Board (IRB) (https://www.solutionsirb.com/) prior to the study's implementation. The parental consent forms were distributed and collected back before the study implementation. Students brought home the parental consent forms for signature. Parents provided consent to allow researchers to use student-generated data and conduct interviews.

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