STEM+L: Investigating Adolescents’ Participation Trajectories in a Collaborative Multimodal Composing Environment

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STEM+L: INVESTIGATING ADOLESCENTS' PARTICIPATION TRAJECTORIES
IN A COLLABORATIVE MULTIMODAL COMPOSING ENVIRONMENT

By
Shiyan Jiang

A DISSERTATION

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STEM+L: INVESTIGATING ADOLESCENTS' PARTICIPATION TRAJECTORIES
IN A COLLABORATIVE MULTIMODAL COMPOSING ENVIRONMENT

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This multiple case study investigated adolescents’ participation patterns and trajectories in an integrated STEM plus digital Literacy (STEM+L) project. The project aims to broaden adolescents’ participation in integrated STEM+L practices. In the project, fifth to eighth graders worked in small groups of three to four to create multimodal science fictions. In this study, I explored forms and degrees of students’ participation through two theoretical perspectives: disciplinary identity development and community of practice. The former provides a necessary lens for investigating forms of participation in three dimensions: attitudes and interests toward disciplinary roles, disciplinary knowledge and practices, recognized by oneself or others as disciplinary experts. The latter allows me to explore degrees of participation in two aspects: the breadth (e.g., time on task) and the depth (e.g., consuming or producing ideas) of participation. The following three research questions guided the study: 1) What are the notable patterns and trajectories of students’ forms of participation in STEM+L practices through disciplinary role taking? 2) What are the notable patterns and trajectories of students’ degrees of participation in STEM+L practices in terms of breadth and depth of participation? 3) What is the relationship between students’ forms of participation and degrees of participation?
To answer the research questions, four cases were selected and multiple sources of data were collected, including surveys, semi-structured interviews, student-generated multimodal artifacts, logging data in the iKOS system, video records of group working, and field notes. Specific data sources for the four focal cases varied based upon students’ choice of multimodal composing platforms, availability of video and interview data, and relevance of data to each individual case. Our analysis of these data was mainly qualitative in nature, driven by our research questions centered around students’ forms and degrees of participation in STEM+L practices.

Synthesizing findings from each case suggests that changes in the form and degree of participation, and the relationship between the two, could be due to the following factors: 1) Reflective understanding of the nature of (inter) disciplinary practices and roles; 2) Exposure and experience in composing in multiple modality; 3) The interaction between self and the community; 4) The relation between self and artifacts.

This study may inform the field the nature and possible causes of adolescents’ forms and degrees of participation. Integrated STEM+L 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. Important implications were suggested regarding what can be done to facilitate the development of disciplinary identities and the extension of participation in integrated STEM practices.
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Chapter One

Introduction

Background of the Problem

Many of the recent educational reforms have emphasized the importance of broadening adolescents’ participation in and access to high quality science, technology, engineering, and mathematics (STEM) practices (NGSS, 2017; NRC, 2017). The goal is to improve adolescents’, especially those who are typically underserved and underrepresented, STEM competence so that they are prepared to succeed in college and future careers.

As the current generation 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 express themselves and connect with others through multimodal composing, a practice in which people use different modes (e.g., texts, visuals, and sound) to make meaning and represent ideas (Kress, 2003; Kress & van Leeuwen, 2001). They are used to create and share multimodal artifacts, such as YouTube videos, personal blogs, and video games world widely (Smith, 2014).

In addition, the rapid development and expansion of online learning have reshaped participation in STEM practices. Much STEM learning occurs out of school, especially the things students read online and during interactions with others in online settings (NRC, 2014). STEM learning environments, such as IC4, a project to study online collaboration that took places across boundaries of country and STEM experience (Hamilton & Danielle, 2018). Over time, these learning environments turn into communities composed of participants who produce and share rich repositories of
domain knowledge. With the growing popularity of online learning, there is a growing emphasis on incorporating blended learning, a hybrid of classroom and online learning, into STEM education.

**Statement of the Problem**

There are four significant challenges in preparing today’s adolescents’ STEM competency: 1) implementing integrated STEM curricula, 2) broadening adolescents’ participation, especially from underrepresented minority groups, in STEM practices, 3) sustaining adolescents’ interest in STEM practices and STEM-related careers, and 4) connecting multimodal composing practices with conventional STEM practices.

How STEM careers are manifested in the workplace are quite different from how STEM subjects are taught in schools. STEM careers require the synergy of cross-disciplinary knowledge while STEM education is often practiced as education of individual disciplinary areas. Laut, Bartolini, and Porfiri (2015) found that adolescents were more interested in pursuing STEM careers after participating in an integrated STEM project because they were exposed to a broader range of subject matter in an integrated way. Their findings suggested that adolescents needed to be exposed to various disciplinary forms to connect learning with future careers. However, implementing integrated STEM curricula can place high cognitive and emotional demands on teachers, many of whom neither have experience with this manner of teaching nor possess the content knowledge necessary to across disciplines (Mobley, 2015). Thus, it’s critical to develop instructional strategies to support the implementation of integrated STEM practices.
Another challenge is to broaden adolescents’ participation in STEM education, especially for individuals from under-represented groups, such as ethnic and racial minorities, female, and English Language Learners. Much research has indicated that students who came from under-represented groups tend to lose interest in STEM around the age of 11, and the rate of interest loss increases as they progress through secondary education (Gardner, 1985; Hoffmann et al., 1985; Kerr & Robinson Kurpius, 2004). Sadler et al. (2012) further showed that female students’ interest in a STEM-related career declined sharply during high school years. To increase the numbers of adolescents choosing and remaining in STEM fields, there is a need to identify factors that positively impact their degree of participation in STEM practices.

Fostering adolescents’ interest in STEM practices and STEM-related careers is also a vital challenge. The challenge calls for a need of cultivating STEM identities (Van Horne & Bell, 2017). However, adolescents had little space to connect their personal interests and identities to STEM practices, so they don’t necessarily take on STEM identities like people in STEM workplaces. STEM education researchers and learning scientists suggest that STEM identities could be cultivated through deepening participation in various disciplinary practices and supporting navigation across forms of participation. Van Horne and Bell (2017) showed that the extent to which participation in STEM practices had the potential to create spaces where students could cultivate disciplinary identities. STEM identities could evoke intrinsic motivation in learning corresponding knowledge and interests in pursuing STEM-related careers (Archer et al., 2010). Although important strides have been made in disciplinary identity, research has only scratched the surface in understanding how adolescents develop disciplinary identity.
We need to move beyond descriptions of student participation and identity exploration, to gain an in-depth understanding of adolescents’ complex disciplinary identity developing processes.

Another challenge comes from the disconnect between students’ out-of-school multimodal composing practices and conventional STEM practices in the current educational system. Multimodal composition is engaging for adolescents and is particularly beneficial for learning to those from the underrepresented population (Smith, 2014). Hall and Coyne (2005) showed that multiple modes of representation support students' differentiated capacities in STEM learning. Although adolescents’ out-school multimodal composing interests and expertise are gradually integrated into STEM curriculums (Smith, 2016), much more needs to be done to fully connect multimodal composing practices and STEM practices to improve the degree of participation.

Besides the four practical challenges, researchers have pointed out a lack of theoretical understanding and operationalized definition of (participation in) STEM education (Hrastinski, 2008; Malinen, 2015). This is especially so in a hybrid learning environment that combines face-to-face and online environments.

**Project IF**

Project Imagine the Future (IF), initiated and co-led by Drs. Ji Shen and Blaine Smith, was developed to address the aforementioned challenges. In the project, students (sixth to eighth graders) took disciplinary roles and collaborated with each other in small groups to create multimodal science fictions. In the process, the research team invited experts from various backgrounds (e.g., marine science and game design) to give lectures
to students, led technology mini-lessons (e.g., digital tools to create animations and comics), and gave specific feedback during small-group working.

Under the context of IF, this study employs a design-based approach (Collins, 1992), which involves several iterations to generate new theories and solutions for conceptualizing learning and refining instruction in STEM education. Thus far, I have worked with three implementations of Project IF.

The key findings in prior runs include the following: 1) Students adopted, changed, and combined disciplinary roles while creating multimodal artifacts and interacting with others, which indicated a change of disciplinary identity (Jiang et al., 2016); 2) Multimodal composition extended students’ understanding of STEM knowledge and practice (Jiang et al., 2018); 3) Disciplinary role taking made students actively think about what people would do in their profession, instead of purely focusing on STEM knowledge (Jiang et al., 2018).

**Research Questions**

Situated in Project IF, the purpose of my dissertation study is to gain an in-depth and nuanced understanding of adolescents’ participation trajectories and patterns in a hybrid multimodal learning environment, project STEM+L. The guiding research questions were the following:

- **RQ1**: What are the notable patterns and trajectories of students’ forms of participation in STEM+L practices through disciplinary role taking?
- **RQ2**: What are the notable patterns and trajectories of students’ degrees of participation in STEM+L practices in terms of breadth and depth of participation?
• RQ3: What is the relationship between students’ forms of participation and degrees of participation?

Through comparative case methods (Stake, 2006), this study sheds new light on the complexity and variation of adolescents’ forms and degrees of participation in an integrated STEM project. This study will also contribute to the development of instructional strategies to support the cultivation of STEM identities in both face-to-face and online settings.

Overview of the Dissertation

In Chapter two, I discuss the theoretical framework that guided this study and the literature that shaped my inquiry. First, I describe the central construct, participation, to explain the connection between participation and learning. Also, I discuss the relevant research literature on adolescents’ participation in STEM practices - concluding with a discussion of how this study is designed to provide new insights. Then, I describe the communities of practice perspective and disciplinary identity development perspective to elucidate multiple degrees and various forms of participation.

In Chapter three, I present the design of the study as well as data collection and analysis methods. I first describe design and specific activities of project STEM+L. I will also summarize the findings of prior implementations that paved the road for the current study. Then, I present how we select focal students as well as how we collect and analyze data related to the focal students.

Chapter four presents four in-depth case studies depicting individual students’ participation trajectories and patterns in the project. Main themes for each case are
organized by the three research questions focusing on forms of participation, degrees of participation, and the relationship between forms and degrees of participation.

Finally, in chapter five, I discuss the study’s contributions for understanding adolescents’ participation in integrated STEM+L practices. In the end, I conclude with implications for classroom instruction and future research.
Chapter Two
Theoretical Framework

In this chapter, I first describe the central concept, *participation*, and discuss how the research questions emerged from a synthesis of the literature on adolescents’ participation in STEM learning environments. Then, I explain two theoretical perspectives that guided this study, communities of practice (Lave & Wenger, 1998) and disciplinary identity development (Carlone & Johnson, 2007; Van Horne & Bell, 2017), and how these perspectives were integrated to shape my inquiry in understanding participation in the STEM+L project.

**Participation and Learning**

Participation is a central concept in this study. It is generally construed as doing something together with others. It is, I believe, through participation that learning takes place. Wenger (1998) suggested that learning arose from motivated and active participation in the “practices of social communities and constructing identities in relation to these communities” (Wenger 1998, p.4). Drawing on Wenger’s theory of situated learning, Nasir and Hand (2008) further posited that participation in social and cultural practices was fundamentally related to practice-linked identities. They define practice-linked identities as “a sense of connection between the self and practice.” Consequently, an individual is more likely to participate extensively when the person feels the sense of closeness between the self and the practice. These theories emphasize the importance of understanding learning from the angle of participation in practices and identity construction at both the individual and collective level.
Although it is commonly argued that a critical challenge for STEM learning is to encourage learners’ participation, much more effort is still needed in developing a sound theoretical understanding of what participation is and how it can be studied empirically in a STEM learning environment (Hrastinski, 2008; Malinen, 2005). For instance, in Franz-Odendaal and his colleagues (2016)’ study, participation was measured in four levels: No STEM activity, low level (students’ visits to science centers/museums), moderate level (specialized group visited students’ class), and high level (students involved in a STEM program). They showed that participation in STEM activities, instead of competency in STEM subjects, significantly influenced participants’ likelihood of pursuing STEM careers. Similarly, Boyce and his colleagues (2014) highlighted that active participants reported high motivation in pursuing STEM careers. They demonstrated that the use of digital technology fostered active participation and engagement of the fifth graders. In the study, they measured participation based on how students split attention across three planes: social interaction, interaction with technology, and interaction with the natural environment.

Many scholars have conceptualized participation in STEM practices as a process of STEM identity development (Pinkard et al., 2017). For instance, Van Horne and Bell (2017) suggested that adolescents’ strong sense of STEM identity could motivate students to participate actively in STEM practices. However, STEM identity was defined in various ways, including demonstrating STEM knowledge and practice, showing positive attitudes towards STEM and interests in pursuing STEM careers, and recognizing oneself or being recognized by others as STEM person. Drawing from the
perspective of STEM identity, this study endeavors to develop a comprehensive and operationalized definition for participation in STEM education.

Reviewing research on adolescents’ participation in STEM practices revealed a lack of studies in investigating participation in hybrid contexts. Most studies examined participation in face-to-face learning environments, and only a few studies explored online participation. For example, Mark (2016) showed that STEM career professionals formed a nurturing and supportive STEM career exploration environment through interacting with adolescents periodically in face-to-face career panels or roundtables. As an example of online participation, Susaeta and his colleagues (2010) investigated a multiplayer role-playing game in which sixth graders were immersed in a virtual world for learning ecology. They explained qualitative differences in the participation between male (e.g., demonstrating greater leadership) and female (e.g., obtaining and exchanging science information) players. In fact, there is a rich body of literature on online participation in other contexts, such as general discussion forums (Hrastinski, 2008). Researchers measured online participation in various ways, including low-level conceptions of online participation, which relies on frequency counts as measures of participation (e.g., Kapu, Voiklis & Kinzer, 2008), and more complex dimensions of participation, such as whether participants feel they are taking part and are engaged in dialogues, reflected by using a combination of perceived and actual measures of participation (e.g., Preece, 2001). However, more still needs to be learned about adolescents’ online participation in STEM practices.

For this study, we frame students’ participation from a community of practice perspective (Lave & Wenger, 1991; Wenger, 1998) and a disciplinary identity
development perspective (Van Horne & Bell, 2017). We conceive that students’ participation can take various disciplinary forms and reach multiple degrees within face-to-face and online communities of practice (Figure 1). I will elaborate on each of the perspectives in the following.

Figure 1. Framework of participation.

Community 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 for the pursuit of a common goal. Communities of practice include three essential characteristics: a domain, a community, and a practice (Wenger, 2005). A domain provides a common focus for a community and defines the key issues that members of the community need to address. A community represents a group of members who interact with each other and develop relationships that enable collective learning. A practice brings together members of the community, namely practitioners, in doing something with similar goals. Over time, members of a community learn the appropriate work behaviors and norms as they increasingly participate in consuming and producing ideas.
Communities of practice are everywhere and some meet mainly face-to-face while others mostly online. For instance, Evnitskaya and Morton (2011) provided evidence that traditional face-to-face science classrooms could be communities of practice when participants in classrooms used a shared repertoire of resources to engage mutually in the activity of doing school science. The proliferation of online collaboration tools resulted in the emergence of virtual communities of practice (Ardichvili, 2008). As an example of virtual communities of practice, Chiu, Hsu, & Wang (2006) investigated open professional online communities to understand the motivations behind people’s willingness to participate in online discussions. In addition to studies focusing on face-to-face and online communities of practice as separate entities, there have been studies investigating blended communities. For example, Trust and Horrocks (2017) interviewed 26 K-12 teachers to understand their participation in blended communities of practice which incorporated both in-person and online interactions.

Community of practice has been a successful perspective for studying student learning in K-12 settings. A key idea in a community of practices is to advance the collective knowledge of the community. Scardamalia and Bereiter (1994) demonstrated that classrooms are communities in which students engage in producing knowledge of value to a community and continually improving it. Similarly, Roth (1995) proposed that a key aspect in communities is the flow of students’ knowledge. Through investigating students’ participation in tool-related and discursive practices in an elementary science classroom, Roth demonstrated the emergence of community when different types of knowledge were constructed, shared, and recognized by students. Roth emphasized knowledge building among practitioners.
The literature suggests that learning in communities of practice is about becoming experts and expertise in communities should be understood as a *process* rather than a *state* (Gee, 2005; Scardamalia & Bereiter, 1994; Tennant, 1999). Furthermore, Bielaczyc and Collins (1999) argued that a successful community should allow the diversity of expertise among its members and the development of individual expertise and interests. Through developing diverse expertise, students knew that some other member had the expertise they could benefit from so that they could make contributions valuable to each other.

Participation in communities of practice can reach multiple degrees, including breadth and depth of participation (Shen & Smith, 2017). Breadth of participation was usually indicated by the amount of participation, such as time on task and number of contributions (Denault & Poulin, 2009; Handley et al., 2006; Preece, 2001; Zheng & Warschauer, 2015). Lave and Wenger (1991) described a range of depths of participation within communities of practice, from legitimate peripheral participation of newcomers and 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.” It indicated that learners must aspire to become contributors and not simple observers and consumers of knowledge produced by the community.

The level of authorship of ideas can be represented in both face-to-face discussions and within online learning platforms. For example, Weinberger and Fischer (2006) delineated to what extent learners refer to contributions of their learning partners
to explain the different level of authorship of ideas during face-to-face discussions. They differentiated people who articulate original ideas, built on existing ideas without significant revisions, critique existing ideas with significant revisions, and try to understand existing ideas. Situated in an online learning environment, Janssen, Erkens, and Kirschner (2011) examined the level of authorship from two perspectives: content space and relational space. The content space is about task-oriented composing (e.g., creating digital artifacts) while relational space is about dialogues (e.g., commenting on existing artifacts) with team members.

Although the literature has thoroughly examined degrees of participation in STEM learning environments, changes in the degree of participation over time had not yet been addressed properly. Measuring the degree of participation as number of words contributed per minute in a Knowledge Forum, Prinsen, Volman, and Terwel (2007) demonstrated that girls and students who were popular among classmates contributed more in discussion forums concerning the topic of “nutrition and health.” In terms of types of participation, they coded students’ contributions into six dimensions: providing answers or explaining, agreeing, disagreeing, asking questions for facts or an explanation, regulative contributions, and affective contributions. They found that boys tended to disagree with others more often than girls and girls’ contributions contained more information requesting than contributions from boys. This study highlighted gender differences in students' degree of participation in online discussions. Although the study provided insights on controlling the intervention for gender differences, it did not investigate when and why gender played a role in changing degree of participation.
Scholars have also explored strategies that can be used to stimulate high degree of participation situated in CSCL learning environments. For example, Janssen et al. (2007) argued that visualization of participation within groups could affect the degree of participation through motivational and feedback processes. Visualization of participation might motivate students to increase their participation through social comparison and serve as external feedback that allows them to decide which practices they have to engage in to move group projects forward. This study pointed out the importance of awareness of self and group contributions in promoting participation. However, it did not closely investigate how being aware of contributions impact students’ participation processes.

In summary, the perspective of communities of practice allows me to explore the following question when examining participation: What are the notable patterns and trajectories of students’ degrees of participation? More specifically, it allows me to look at my focal cases from two angles: breadth and depth of participation (Figure 2). One the one hand, it provides a framework to examine the dynamics of how each individual student moves between degrees of participation as a process. On the other hand, we closely investigate the actions and behaviors of each individual student as being situated in a collective community in which students interacted with each other while participating in a set of practices, in this case, integrated STEM+L practices.
Disciplinary Identity Development

An important construct that people use to describe the learning or participation of the individuals in a community of practice is identity. Identity is what makes up a person and can be interpreted in many ways. From a biological perspective, it usually refers to physical traits and genetic wiring; from a psychological perspective, it could include personality, beliefs, knowledge, etc.; from a sociocultural perspective, it may consist of the collection of roles that people take in different organizations and communities (McCall & Simmons, 1966; Stryker, 1987; Stryker & Burke, 2000).

From a disciplinary perspective, an identity entails norms and standards accepted in a particular field of study. In this perspective, a disciplinary identity (e.g., science identity and 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 various communities (Lave & Wenger, 1991).

Attitudes and interests. The literature illustrated that students became either less or more interested in disciplinary practices. For instance, Bouillion and Gomez (2001)
investigated fifth graders’ interests in disciplinary practices after participating in a project with a special emphasis on integrating science and language arts. The project, called “Chicago River Project”, brought together students, teachers (from various disciplines, including language arts, science, and technology), parents, and scientist experiences with the river, pollution, and the practice of caring for the land. Bouillion and Gomez found that some students could express very detailed areas of science that they were interested in continuing to explore in the future. The study suggested that empowering students in doing something good for their community had the potential of facilitating students’ interest in science. It indicated that having authentic purposes might improve interests and attitudes toward disciplinary practices.

Similarly, Nixon and Akerson (2004) implemented a project that integrated science and language arts in a fifth-grade classroom. In the project, students used reading and writing to learn science about ecosystems and science was a context for reading and writing. They found that the integration of language arts sometimes had a negative influence on the science objectives. For instance, number of revisions in writing could quickly make students lose interest and enthusiasm for the topic of science. They also found that some students preferred to write about personal experiences although highly engaged in science activities. The study called for the need for balanced and effective interdisciplinary science and language arts instruction so that one would not have a negative impact on the other.

In addition, researchers pointed out that integrating disciplinary practices had the potential to improve students interests in pursuing STEM careers in the future. Students would view science as much more than just a set of facts to be memorized when reading
fictional literature about science (Everman, 2016). In this way, students might develop interest in being a scientist and engage curiosity about understanding the world from the perspective of science.

As evident in the literature, more needs to be learned how students change attitudes and interests in these practices across time, what triggers or contributes to the changes, and whether the changes have impacts on students’ views of their future professions.

Knowledge and practice. The literature highlighted that curriculums aiming at integrating science and language arts led to greater student achievement in both (Bradbury; 2014) or only one (Nixon & Akerson, 2004) of two disciplines. Fang et al. (2008), for example, found that students who participated in an integrated learning project scored higher in science achievement than students in inquiry-only science teaching. In the project, six graders followed reading strategies (e.g., paraphrasing and summarizing) to build comprehension of science texts. Students learned to synthesize, analyze, and critique the information presented in science texts in ways that real scientists do. Also, Ritchie, Tomas, and Tones (2011) examined the impact of writing scientific narratives on sixth graders’ science learning. Students generated two stories that merged scientific information about biosecurity with narrative storylines. Through qualitatively analyzing student interviews, they found out that writing storylines helped students develop a deeper understanding of science ideas and build a strong concern in socioscientific issues.

Students also demonstrated achievement gains after participating in learning environments that integrated science and mathematics. For example, Judson and Sawada
(2000) examined the impact of integrating mathematics into a science class on high schoolers’ achievement in math. Students in the integrated science course attained high achievement on the statistics unit in math class. Based on a meta-analysis of 31 studies of student achievement, Hurley (2001) found that the integrated science and mathematics has a positive effect on student achievement in the two domains, but its effects were much higher in science.

Although the literature documented student gains in specific domains, little is known about the development of students’ knowledge and practices in the integration between different disciplinary practices.

**Recognition.** Studies depict the impact of recognition by oneself and others on students’ participation in disciplinary practices. As an example, Zimmerman (2012) showed a girl’s participation in scientific practices in a three-year longitudinal study. Zimmerman argued that the girl’s self-recognition as a science person was “a complex relational negotiation between the ways she saw herself, how others saw her, and how she wanted others to see her.” In the study, Zimmerman stressed the importance of social recognition to competence when performing disciplinary practices. Similarly, Stevens (2000) posited that a learner might have a decreasing participation in mathematics practices if important others in a community do not recognize her competence although s/he might view her/himself as competent and perform accordingly.

Self recognition was also critical to deepening participation in disciplinary practices, Pinkard et al. (2017) investigated how narrative facilitated middle school girls’ identity development in a project-based curriculum that was designed to link the domain of computer science and engineering. In the project, students could design the narrative
characters’ everyday life in which these characters regularly engaged in complex STEM activities. Their findings revealed that infusing oneself in characters helped students develop STEM identities. Through infusing oneself in characters, students might easily recognize their disciplinary identity. Allen and Eisenhart (2017) also detailed the need to create safe spaces where students saw people like themselves as STEM capable and interested. Through an ethnographic and longitudinal study, they tracked the process of how young women fought for particular versions of future selves.

Although studies have closely examined how recognition by oneself and others on participation, they only focused on recognition in specific disciplinary practices, mostly occurred in a single disciplinary learning environment. More still needs to be learned about the impact of recognition while students are exposed to integrated disciplinary practices and how students move across these practices.

The examples above revealed that disciplinary identity development and learning are integral to each other and to learners’ participation in disciplinary activities within communities of practice (Carlone et al., 2008; Forbes & Skamp, 2016; Rodriguez & Lehman, 2018; Tan & Barton, 2008). Researchers have explored various strategies to stimulate the construction of disciplinary identity. These strategies are associated with developing positive attitudes toward and deepening participation in disciplinary practices, achieving social recognition, and facilitating self recognition. For instance, student understanding and conceptualizing of interrelations across STEM disciplines could contribute to a positive attitude toward STEM (Sahin, 2013). As an example of achieving social recognition, Li and Loverude (2013) indicated that peers, parents, and teachers could create a culturally responsive, strength based, and academically affirming nucleus
to support mathematics identity development of Black girls. Similarly, Margolis and Fisher (2003) suggested that women might have difficulty recognizing themselves as computer scientists and be systematically oppressed in pursuing computer science careers due to societal expectations. It pointed out the need for strategies in addressing identity conflict between gender identity and disciplinary identity.

Professional role-taking can be a powerful tool for facilitating students in developing disciplinary identities. Scholars have made important advances in understanding the relationship between disciplinary identity development and playing corresponding roles in schools. Much research has illustrated the difference between playing roles and embracing disciplinary identity lies in the degree to which corresponding knowledge is integrated into a person’s sense-of-self. As an example, in a curriculum where students acted as biologists, Pitts and Edelson (2014) showed that some students might adopt the role of scientist by pretending to be in that role, while some students may be considered to have adopted the role when they feel like scientists.

While much effort has been devoted to examining disciplinary identity, the investigation of multiple/cross-disciplinary identity lags far behind. There are only a handful of studies exploring this topic. As an example, Tracy and Trethewey (2005) suggested that students had multiple disciplinary identities and a particular type of disciplinary identity might be more salient in some situation than in others. They stressed that learning environments that integrated multiple disciplines could make the adaptable feature of disciplinary identity salient. Latucca (2001) proposed that individuals needed to find links between and among their multiple disciplinary identities to make sense of who they were. Furthermore, Jiang et al. (2018) proposed that students confronted with
disciplinary identity conflicts. For instance, while incorporating science information in a fairy tale, a female student who viewed herself as a writer complained, “how can a princess have anything to do with science!” Her writing identity in developing the fairy tale conflicted with science identity in incorporating science information.

This study conceptualizes student participation as a process of disciplinary identity development. Students author various disciplinary identities prior to participating in any learning environments. As Van Horne and Bell (2017) explained, “all designed learning experiences involve a framing and cultivation of disciplinary identities.” They also indicated that the development of disciplinary identity was a process of moving from legitimate peripheral participation to full participation in communities of practice through participating in domain-linked practices. In the process of becoming core members in a community, one disciplinary identity might be stabilized while the other might be destabilized. We need to learn more about the complexity and variation of identity development processes.

Drawing on the construct of disciplinary identity, students could take various forms to participate in communities of practice. These forms are represented in the disciplinary roles that students play in a community in this study. Students’ role playing behaviors could be observed from their own and others’ perceptions of role taking, peer interactions in face-to-face and online settings, and artifacts.

In summary, the disciplinary identity development perspective provides a necessary lens for investigating the following question about students’ participation:

*What are the notable patterns and trajectories of students’ forms of participation through disciplinary role taking?* More specifically, we investigate the form of participation from
three dimensions: attitudes and interests, knowledge and practices, and recognition (Figure 3).

Figure 3. Form of participation.

Towards an Integrated Framework of Participation

A community of practice lens examines the degree of participation while disciplinary identity development offers a way for investigating the form of participation. These two theoretical perspectives were integrated in various ways to address the third research question: *What is the relationship between students’ forms of participation and degrees of participation?*

First, combining the perspective of disciplinary identities with community of practice, I will gain insights into the degree of participation (including both breadth and depth) while students participate in STEM practices through different forms. Particularly, whether there were commonalities and differences in choosing to participate more or less (or central or peripheral) in one disciplinary practice versus the other over time.

Second, the integrated framework offers a better means for understanding the dynamics of students’ participation. Particular attention is given to the relationship
between how students move between forms of participation and changes in the degree of participation.

This integrated framework requires the researcher to continually adjust her focus between interacting factors in order to glean a nuanced understanding of participation patterns and trajectories at differing angles and levels of detail.
Chapter Three

Methodology

This multiple case study (Yin, 2009) aims to investigate student learning, framed as participation, in a hybrid program for adolescents (age 10-13) in developing core integrated Science, Technology, Engineering, Mathematics and Digital Literacies (STEM+L) practices. In this chapter, I will describe the design of the program, prior implementations, data collection, and data analysis methods.

The STEM+L Program

The STEM+L program is a hybrid informal educational program that includes a one-week summer camp held at the University of Miami (UM) and a fall semester extension held online with six physical sessions at UM. Participating students took disciplinary roles (i.e., designer, scientist, and writer) and 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. The learning objectives of the program are 1) Facilitating students’ disciplinary identity development through role-taking; 2) Increasing students’ participation in STEM practices through multimodal composition; 3) Engaging students in collaborative knowledge building with a common science theme, climate change.

Program activities and flow. The program includes three major phases: 1) One-week summer camp held at UM; 2) Fall semester extension with six physical sessions on Saturdays at UM; 3) A final show event to authentic audiences held at the Miami Science Fiction Film Festival in the following January.
During the summer, students attended the program every day from 9:30 am to 3:30 pm for a week. They participated in the following activities (Table 1):

- At the beginning of Day one, the research team introduced the STEM+L project in which students would play disciplinary roles (Table 2) and work in small groups to create multimodal science fictions. Furthermore, students needed to address issues related to climate change in science fictions and they were encouraged to imagine what would happen to the environment in the future. Afterward, students introduced themselves. The rest of the day was spent on technology tutorials on three essential multimodal composing tools: Pixton, Scratch, and iKOS. While learning the tools, students created corresponding multimodal artifacts related to themselves in the future, such as creating comics to show their future professions and working environments. At the end of the day, students took the pre-survey.

- On Day two, the research team delivered a multimodal composing workshop that explained how modes worked together to make meaning. Then students formed small groups based on role preferences from the pre-survey. After forming groups, the research team conducted a writing workshop about elements of a good story and then students brainstormed and presented their own story elements in small groups. Students designed a house after a science unit on Earth’s energy balance during the rest of the day.

- Students continued with house design at the beginning of Day three. Then they visited a science lab and did experiments with microscopes after a lecture from a biologist. Thereafter, students analyzed the multimodal, science, and
story writing aspects of final product samples produced in our earlier implementations. The rest of the day was spent on group working.

- **Day four** started with a science activity in redesigning houses and then students worked in small groups. Afterward, students visited a science lab and did experiments with a physicist. Students spent a long period of time on group work during the rest of the day. As two break time sessions (around 15 min each) during group work, the research team briefly introduced a science workshop on sea level rise and a technology tutorial on Moviemaker. Students presented what they created so far at the end of the day.

- Students were introduced to greenhouse effect followed by building solar kits at the beginning of **Day five**. Then they finished the mid-survey. Afterward, they worked together with the goal to complete the first version of multimodal science fictions. As two break time sessions (around 15 min each) during group work, the research team explained how music could be integrated into stories and how to create interactive books in iKOS (Figure 4). At the end of the day, each group generated a practical and concrete plan for the fall semester extension with guidance from the research team.
Table 1

*Activities during the summer camp*

<table>
<thead>
<tr>
<th>Day</th>
<th>Instructor-led Activity</th>
<th>Student Activity</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Goals and objectives;</td>
<td>Self-introduction;</td>
<td>Pixton, Scratch,</td>
</tr>
<tr>
<td></td>
<td>Disciplinary roles;</td>
<td>Icebreaker activity;</td>
<td>iKOS</td>
</tr>
<tr>
<td></td>
<td>Final product samples</td>
<td>Create artifacts in Pixton, Scratch, and iKOS;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Take pre-survey;</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Multimodal composing</td>
<td>Form groups;</td>
<td>Tech support</td>
</tr>
<tr>
<td></td>
<td>workshop;</td>
<td>Brainstorm and outline stories in groups;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Writing workshop;</td>
<td>Design houses related to the science workshop;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Science workshop on</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Earth’s energy balance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Guest speaker on</td>
<td>Design houses;</td>
<td>Tech support</td>
</tr>
<tr>
<td></td>
<td>environment and human</td>
<td>Visit science labs;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>health;</td>
<td>Work in groups</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multimodal composing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>workshop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Guest speaker on</td>
<td>Redesign houses;</td>
<td>Moviemaker</td>
</tr>
<tr>
<td></td>
<td>environment and human</td>
<td>Work in groups;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>health;</td>
<td>Visit science labs;</td>
<td></td>
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<tr>
<td></td>
<td>Science workshop on</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>sea level rise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Science workshop on</td>
<td>Build solar kits;</td>
<td>iKOS</td>
</tr>
<tr>
<td></td>
<td>greenhouse effect;</td>
<td>Take mid-survey;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multimodal composing</td>
<td>Work in groups;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>workshop</td>
<td>Plan for the fall semester</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 4. iKOS Interactive Book.*

To ensure that students would make substantial progress in expanding their multimodal science fictions after the summer camp, we utilized the following strategies for the fall semester extension:
- Physical half-day sessions. The Research team hosted six physical sessions on Saturdays. During the sessions, students worked on final projects and the research team provided onsite support to address questions and concerns.

- Online feedback. The research team monitored student productivity in Pixton, Scratch, and iKOS regularly and left timely feedback.

- Interaction with the research team and peers. Students could send emails or post questions in iKOS to exchange ideas with the research team and peers. In addition, the research team communicated with students through guardians’ emails to remind students of milestones.

- Targeted video instructions. The research team posted video instructions in iKOS to provide technology tutorials and showcase other relevant information.

Students presented their multimodal science fictions to authentic audiences at the Miami International Science Fiction Film Festival on 13th January 2018. Each group described the fiction in one minute in front of the poster that the group created. After all groups finished one-minute oral presentations, audiences were invited to interact with students to learn more their fictions (Figure 5). Awards were given to groups who produced the best science integration, best story narrative, best multimodal creation, and best overall multimodal science fictions in the end.
Role-taking. Throughout the project, each student was asked to select one of the three roles: designer, scientist, and writer. These roles were created to facilitate students’ disciplinary practices in STEM+L and increase their interest and attitudes towards STEM-related careers. As shown in Table 2, designers were responsible for creating visual and audio representations (e.g., comics and animations) related to the story; Scientists were in charge of verifying and incorporating scientific information related to the story; Writers were accountable for developing and writing the fiction plot. In addition, students were flexible to 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 were asked to collaborate with each other on their individual and collective tasks.
Table 2

*Disciplinary roles and responsibilities*

<table>
<thead>
<tr>
<th>Role</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designer</td>
<td>Create multimodal artifacts related to final science fictions</td>
</tr>
<tr>
<td>Scientist</td>
<td>Incorporate scientific information into final science fictions</td>
</tr>
<tr>
<td>Writer</td>
<td>Write up the text portion of final science fictions</td>
</tr>
<tr>
<td>All</td>
<td>Collaborate with each other</td>
</tr>
</tbody>
</table>

**Multimodal composition.** In the project, students learned several multimodal composing tools, including:

- **Pixton:** A cross-platform application for designing characters and comics. Pixton also provides comic sharing and remixing functions.

- **Scratch:** A cross-platform visual programming environment for creating animations and games. Additionally, users can share their own and remix others’ artifacts in the Scratch community.

- **Moviemaker:** A windows program that allows students to create and edit videos.

- **Pixlr:** A cross-platform application for designing posters.

In addition, all groups used iKOS (innovative Knowledge Organization System) to compile multimodal artifacts (created with the above tools) into one final product. iKOS is a web-based knowledge organization platform for individuals and/or groups to construct, share, and organize knowledge in multimodal representations, including *Wiki*, *PicTag*, *Concept Map* (see Figure 6), and *Book* (See Figure 4). The *Wiki* mode is a
hypertext editing tool. *PicTag* is picture tagging, which enables students to tag any area in a self-uploaded picture with texts. In the *Concept Map* mode, students can create concept maps (Novak & Cañas, 2008) to a set of related ideas. Students can use *Book* mode to organize entries from Wiki, PicTag, and Concept Map, as well as embedding external artifacts (e.g., Pixton comics) to create an interactive flipbook (Figure 4).

Despite these functions, students can interact with each other through rating, commenting, and co-editing entries within the system. The system also automatically creates log data of students' frequencies, durations, and sequences of computer actions (e.g., the timestamp when students click one entry).

![Figure 6. iKOS: Wiki, Pictag, and Concept Map](image)

Beyond the presented technologies, students were free to bring in multimodal tools that they were familiar with and we provided corresponding technology support.

**Prior Implementations**

This study is part of a larger design study that has evolved over three pilot runs.

**Pilot study one.** The first pilot study was a nine-week after-school program implemented one day per week for 50 min per session in a local public middle school in Spring 2015. Participating students were recruited by a collaborating teacher at the school on a first-come, first-served basis. A total of 16 students (grade 6-8) enrolled in the study...
initially while 8 of them attended most sessions and contributed substantially to group projects.

In this pilot run, students picked a role among four given ones (i.e., artist, engineer, scientist, and writer). Besides writer and scientist (Table 2), they could also choose to be:

- **Artists** who led the creation of visual and audio representations for all main characters and/or scenes in the story;
- **Engineers** who were accountable for designing buildings, vehicles, and settings for the story.

The first pilot provided insights on revisions of the program. First, participants reported that they needed more time to work on group projects during final interviews. Moreover, we observed that students not just needed more time, but longer periods of time so that they would have enough time for negotiating responsibilities and working on multimodal composing practices. Thus, we decided to give students longer periods of time for group working in future implementations. Second, based on classroom observations and final interviews, students who took the role of engineer were either doing the same thing as artists or left without knowing what to do. We decided to combine the role of artist and engineer into one role, designer (Table 2). Third, our analysis of students’ final artifacts indicated that there was a lack of science concepts and a low integration between science ideas and stories in some artifacts (Jiang et al., 2016). Furthermore, we found that it was a challenge to provide instructions on science or integration between science and story because students chose different science topics that had few overlaps, such as wormhole and clone. We decided to set a common science
theme for future runs. Despite the limitations, this study was promising. In our analysis, our results showed that the high integration level between science and writing in final artifacts could be explained by flexible role-changing patterns between the writer and the scientist during group discussions (Jiang et al., 2016). Therefore, we would continue to give students the flexibility and space to change roles.

**Pilot study two.** The second pilot study was a ten-week after-school program implemented every Saturday for 2.5 hours per session at UM during Fall 2015. Eighteen students were initially interested in the program, but nine students stayed and contributed substantially to their group projects, including two girls and seven boys; two fifth graders, two sixth graders, four seventh graders, and one eighth grader.

We made three major changes in this implementation: providing longer periods of multimodal composing time, combining the role of engineer and artist into designer, and setting a common science theme. Different from pilot one, these sessions were much longer and many of the sessions were organized into three sections. The first section included guest speakers who gave presentations on a range of related topics, such as science fiction writing, frontier scientific research, and game design. In the second section, the instructors provided explicit technology mini-lessons for using various tools, as well as connected the guest speaker’s lectures with the task of the session. For instance, students learned how to use Bitstrips for creating comics and Scratch for creating animations. The last section was workshop time when students created multiple modes (e.g., visuals, text, sound) to represent their story. Instead of taking four roles, each student self-selected one of the three roles (Table 2). Regarding role taking, the new role, designer, was responsible for creating visual and audio modes. To consolidate science
learning, students needed to propose a creative solution to a common science theme in final artifacts: human and environmental health.

The second pilot provided insights on how to scaffold peer interaction in multimodal composing environments. After analyzing students’ science fictions and interviews, we inductively derived the following broad themes based on the function of visual modes in each story: 1) comics driven by story narratives; 2) story narratives driven by comics; 3) stories narratives and animations were parallel. This analysis of students’ artifacts and interviews demonstrated that different multimodal composition themes hinted on dynamics of group interactions (Jiang et al., 2016). To further investigate group interactions, we coded students’ group discussions to understand how different modes (e.g., visuals, sounds, and texts) mediated composing processes. One of the findings indicated that students discussed more often about comics than other forms of modes. Synthesizing peer discourse, we concluded with two unique features that made comics a popular media: 1) comics allowed students to project an identity on a self-created avatar through which they interacted with peers; 2) comics could expand topics of discussions through visualizations of details. The first feature suggested that the process of creating one’s avatar, which played a role in self-representation, motivated students to talk about avatars during peer interaction (Leary, 2007). The second feature showed that making learning visible in multimodal artifacts (e.g., comics) was critical to foster peer interaction (Jahnke, Norqvist, & Olsson, 2013). We decided to design more activities that could help students to project themselves into multimodal composing.

This study also provided insights on data collection. We found that some students changed roles frequently and were conscious of the change. Also, sometimes students
would use the role to defend for authorship of artifacts during multimodal composition. Thus, we decided to include surveys at multiple time points to examine students’ role changing in future implementations.

**Pilot study three.** The third pilot study was implemented during Fall 2016 in a Public, experimental school of choice in Miami, FL. Participating students were from a classroom of 6th graders (n=32). The instructor helped with managing the classroom.

Students worked in small groups to create multimodal science fictions. Typically, each group had three to five students. Each student picked one of the three roles (Table 2) with the requirement that each group must have at least one writer and one scientist. Despite the differentiated roles, team members were asked to collaborate with each other on their individual and collective tasks.

During Fall 2016, students had two classes every week. The two classes happened every Tuesday and Friday afternoon from 1:00 to 3:00. Every Tuesday, classes were taught by the research team in the UM computer lab; Every Friday, classes were taught by the research team at the school. Throughout the classes, students were introduced to several technological tools, including Scratch, Bitstrips, and Venngage for creating multimodal artifacts. Science-related activities included learning science concepts in WISE (Linn et al., 2003), attending lectures presented by guest speakers from different science backgrounds, and visiting science labs at UM. We also designed activities in which students could project themselves into multimodal composing. One of them was a design task named “Me in 20 Years.” In the activity, students made comics to show their professions and working environments in 20 years.
One analytical angle of this study was inspired by the theory of science identity development (Carlone & Johnson, 2007). The first phase of the analysis involved working through all data sources (surveys, interviews, and artifacts in different technology platforms) for each student who took the role of the scientist to build scientist profiles. In the second phase of analysis, we focused on students’ responses related to science identity (e.g., whether students like the role of scientist) and identified science identity development themes through iteratively reading through and coding responses and students’ artifacts. The results showed that 1) Multimodal composition extended students’ understanding of scientific knowledge and practice; 2) Taking the role of scientist made students actively think about what scientists would do in their profession, instead of purely focusing on scientific knowledge; 3) Students took hybrid roles (a combination of scientists and other roles) to resolve science identity conflicts and transitions. To further investigate disciplinary identity (including science identity), we decided to collect data on disciplinary identity development in the next iteration, the current study.

**Current design.** Based on experiences and insights gained from the three pilot studies, we utilized the following design features in the current study:

- Multimodal composing: 1) Providing sufficient small group working time; 2) Developing activities in which students could project themselves into multimodal composing; 3) Using mentor artifacts to explain how multiple modes work together to communicate messages; 4) Guiding students to design online interactive books from multimodal artifacts, including those created
within the iKOS system and those created in external platforms (e.g., Scratch and Pixton).

- Role taking: 1) Making sure that students have the flexibility to take hybrid roles, change roles, and propose new roles based on team agreement; 2) Collecting data about students’ perceptions of their own and others’ role-taking.

- Disciplinary identity development: 1) Developing disciplinary-specific activities; 2) Collecting data related to disciplinary identity development.

- Science instruction: 1) Choosing a common science theme (i.e., climate change) connected with students’ prior experience; 2) Providing science instructions related to the science theme throughout the project; 3) Facilitating students to think about how to incorporate these science concepts into final projects.

Data Collection

Research questions. The purpose of this study was to closely examine how students participate in the hybrid STEM+L program. The research questions are:

- RQ1: What are the notable patterns and trajectories of students’ forms of participation in STEM+L practices through disciplinary role taking?

- RQ2: What are the notable patterns and trajectories of students’ degrees of participation in STEM+L practices in terms of breadth and depth of participation?

- RQ3: What is the relationship between students’ forms of participation and degrees of participation?
**Participants.** To recruit our participants, we sent flyers to local libraries, collaborating teachers, and posted it on UM’s School of Education and Human Development website. There were about 60 applicants. Priorities were given to those who are from underrepresented groups in STEM, including racial minorities, females, and English Language Learners. Due to the number of applicants, we opened two cohorts instead of one as initially planned. A total of 42 students from both cohorts stayed after the first session and they were the participants of this study (Table 3). These 42 students were divided into two cohorts (cohort A and B) due to resource limitations. Among them, 14 were black; 19 were Hispanic; four were white; the remaining five were other; 16 were female and 26 were male. Students were from schools in South Florida area, with six 5th graders, fifteen 6th graders, eight 7th grades, and thirteen 8th graders.

Table 3

<table>
<thead>
<tr>
<th>Gender</th>
<th>Grade</th>
<th>Ethnicity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>M</td>
</tr>
<tr>
<td>A</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>26</td>
</tr>
</tbody>
</table>

During the summer camp, 22 students of cohort A attended all the sessions except that one student of cohort A did not show up on the last two days; 20 students of cohort B attended all sessions except that one student of cohort B missed the last day. 21 students attended more than three physical sessions in the fall.
**Focal students.** Four focal students in four different groups were selected for in-depth analysis of their participation patterns and trajectories: Steve (6th grader), Nick (6th grader), Olivia (7th grader), and Saanvi (5th grader; see Table 4). We selected these four cases for several considerations. First, they attended most or all of the sessions so that we have a relatively complete profile for each of them. Second, these cases instantiate maximum variation (Flyvbjerg, 2006) in terms of gender, race, grade, and their engagement in STEM+L practices throughout the project. Our selection was also what Flyvbjerg (2006) called an informed-oriented selection: From field notes, our review of their multimodal artifacts, students’ survey responses, and activities (e.g., posting comments) in multimodal composing platforms, we expected these cases to contain rich examples of scaling and assembling comparisons in participation patterns and trajectories.

Table 4

*Attendance of focal students (M=Male, F=Female, AA=African American, H=Hispanic, A=Asian, W=White)*

<table>
<thead>
<tr>
<th>Name</th>
<th>Gender</th>
<th>Race</th>
<th>Grade</th>
<th>Summer camp</th>
<th>Fall session 1</th>
<th>Fall session 2</th>
<th>Fall session 3</th>
<th>Fall session 4</th>
<th>Fall session 5</th>
<th>Fall session 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steve</td>
<td>M</td>
<td>AA</td>
<td>6</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Nick</td>
<td>M</td>
<td>H</td>
<td>6</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Olivia</td>
<td>F</td>
<td>W</td>
<td>7</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Saanvi</td>
<td>F</td>
<td>A</td>
<td>5</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

**Researcher's participant observer role.** My role in this study was one of the participant observers (Gall et al., 2007) who was highly involved in designing the curriculum, 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 sometimes provided feedback if they had questions or were
experiencing difficulties. In addition, I assisted with collecting all data sources except for
video recordings and conducting semi-structured interviews. As a participant observer,
reflexive awareness of my own biases and positionality was crucial for establishing
trustworthiness (Miles & Huberman, 1994). I will describe how I addressed my biases
and issues of trustworthiness of this study in the section of data analysis.

**Data sources.** We collected the following sources of data (Column 1 in Table 5):

- **Pre-, mid-, and post-surveys.** We used online surveys (see Appendix A, B, and
  C) that have been developed based on prior implementations to collect data
  about students’ experiences of the project in various aspects, such as attitudes
  and interests in disciplinary practices and roles. The first nine questions were
  5-Likert scale format (1 = strongly disagree and 5 = strongly agree) and the
  rest questions were open-ended format. We conducted online surveys three
times: one at Day one of the summer camp, one at Day five of the summer
  camp, and one at the fifth physical session of fall semester extension.

- **Student-generated digital multimodal artifacts.** We collected artifacts that
  students generated throughout the project, including iKOS entries, comics,
  animations, videos, voice narrations, and other digital multimodal artifacts.

- **iKOS logging data.** The iKOS system logged processes of accessing entries,
  including creating, editing, and viewing entries.

- **Comments and ratings in Pixton, Scratch, and iKOS.** Pixton, Scratch, and
  iKOS could show data related to comments, including the person who posted
  comments and when comments were posted. The three platforms could show
the number of ratings. However, only iKOS could identify the person who gave ratings and show when ratings were given.

- Video records of students’ physical participation together with the audio records of students’ conversations during the summer camp and physical sessions during fall. Separate cameras and audio recorders were set off to capture four focus groups made up of 3-5 students each. Purposive sampling (Morgan & Scannell, 1998; Patton, 1990) was used to select focus groups during the summer. We selected groups that had diversity in gender, age, and race/ethnicity to have a range of representation across different backgrounds. However, in the fall, we chose another two groups because more than two members in two of the four groups left the project after summer camp.

- Video reflections. We also integrated video reflection (Smith & Dalton, 2016) at the first physical session in the fall (see Appendix D), which involves students creating videos to reflect upon their progress, such as group collaborations and role taking during the summer.

- Group-based semi-structured interviews. At the fifth physical session during fall, we conducted focus-group interviews (see Appendix F) with two selected groups to learn more about students’ perceptions of collaborative processes, role changing, design decisions, and science learning.

- Field notes. During the summer, after each day, I wrote field notes and another researcher reviewed the field notes on the same day to provide feedback. While writing field notes, I attuned to any key events or patterns
concerning students’ role taking, collaboration with others (peers or the research team), and any other pertinent events that emerged.

- Physical materials. We collected physical materials that students created, such as graphic organizers and notebooks. Before working in small groups, students were asked to complete graphic organizers (see Appendix E) to make concrete plans (e.g., create a four-panel comic to show the transformations of Crystal, Keke, and Sara) for the working session on that day. Also, we collected notes or sketches that students made on notebooks.

Table 5

Data sources and analysis

<table>
<thead>
<tr>
<th>Data Sources</th>
<th>Analysis</th>
<th>Inference</th>
<th>Research Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-, mid-, and post-surveys</td>
<td>Analysis of responses to items related to role taking, such as “please rate the following statements regarding the three roles you can take in the STEM+L Academy: - I like to be a Designer.”</td>
<td>Attitudes and interests in taking the three roles measure the form of participation</td>
<td>RQ1</td>
</tr>
<tr>
<td>Student-generated digital multimodal artifacts</td>
<td>Modal use</td>
<td>The usage of modes measures the form of participation</td>
<td>RQ1</td>
</tr>
<tr>
<td>Number of artifacts</td>
<td>The number of artifacts measures the breadth of participation</td>
<td></td>
<td>RQ2</td>
</tr>
<tr>
<td>iKOS logging data</td>
<td>Content analysis of edits in iKOS (The coding framework was explained in the data analysis section)</td>
<td>Carrying out role-specific practices measures the form of participation</td>
<td>RQ1</td>
</tr>
<tr>
<td>Number of edits</td>
<td>The number of edits measures the breadth of participation</td>
<td></td>
<td>RQ2</td>
</tr>
<tr>
<td>Content analysis of edits in iKOS (The coding framework was explained in the data analysis section)</td>
<td>To what extent do edits add on new ideas measures the depth of participation</td>
<td></td>
<td>RQ2</td>
</tr>
<tr>
<td>Data Sources</td>
<td>Methodology</td>
<td>Research Question(s)</td>
<td>Description</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Comments and ratings in Pixton, Scratch, and iKOS</td>
<td>Content analysis of comments (The coding framework was explained in the data analysis section)</td>
<td>RQ1</td>
<td>Presenting role-specific views in comments measures the form of participation</td>
</tr>
<tr>
<td></td>
<td>Number of comments and ratings</td>
<td>RQ2</td>
<td>The number of comments and ratings measures the breadth of participation</td>
</tr>
<tr>
<td></td>
<td>Content analysis of comments (The coding framework was explained in the data analysis section)</td>
<td>RQ2</td>
<td>To what extent do comments add on new ideas measures the depth of participation</td>
</tr>
<tr>
<td>Video recordings (focus group)</td>
<td>Interaction analysis of group working</td>
<td>RQ1</td>
<td>Presenting role-specific views measures during discussions or carrying out role-specific practices during composing processes the form of participation</td>
</tr>
<tr>
<td></td>
<td>Interaction analysis of group working</td>
<td>RQ2</td>
<td>To what extent one refers to the other during discussions or to what extent one contributes to team projects during composing processes measures the depth of participation</td>
</tr>
<tr>
<td>Video recordings (focus group)</td>
<td>Openly code reflections connected to participation patterns and trajectories previously analyzed</td>
<td>RQ1, RQ2</td>
<td>Reflection on role taking measures the form of participation; Reflection on contributions for team projects measures the breadth and depth of participation</td>
</tr>
<tr>
<td>Semi-structured interviews (focus group)</td>
<td>Openly code interviews connected to participation patterns and trajectories previously analyzed</td>
<td>RQ1, RQ2</td>
<td>Students’ perceptions of role taking measures the form of participation; Contributions for team projects measures the breadth and depth of participation</td>
</tr>
<tr>
<td>Field notes and physical materials</td>
<td>Openly code field notes and physical materials connected to participation patterns and trajectories previously analyzed</td>
<td>RQ1, RQ2</td>
<td>Our observations of students’ role taking measures the form of participation; Our observations of students’ contributions for team projects measures the breadth and depth of participation</td>
</tr>
</tbody>
</table>

Specific data sources for the four focal cases varied based upon students’ choices of multimodal composing media, availability of video and interview data, and relevance
of data to each case. As shown in Table 6, Steve mainly designed comics and posted comments in Pixton; Nick contributed mostly in designing comics in Pixton and co-editing entries in iKOS; Olivia mainly worked in iKOS; Saanvi spread her work in all composing platforms. Although Olivia worked in iKOS, we did not analyze her logging data generated in iKOS because she did not write in iKOS. Instead, 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 iKOS account.

Table 6

Data sources for focal students (x indicates major data sources for analysis in multimodal composing platforms)

<table>
<thead>
<tr>
<th>Data sources</th>
<th>Steve</th>
<th>Nick</th>
<th>Olivia</th>
<th>Saanvi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surveys</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Pixton artifacts</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Scratch artifacts</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>iKOS artifacts</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>iKOS logging data</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Comments and ratings in Pixton, Scratch, and iKOS</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video recordings</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Video reflections</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Semi-structured interviews</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Field notes and physical materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Although we collected video recordings for the four focal students, we did not have video data for all physical sessions for any of them. In the summer, we videotaped four groups using purposeful sampling (Patton, 1990; Strauss & Corbin, 1998) and Olivia
was in one of the original focus groups. In the fall, due to attrition of team members, we
switched to videotape two different groups that had all team members returning in the fall.
Nick and Saanvi were in the two new focus groups and these groups were team-
interviewed in the end. Steve’s group was neither in the initial nor the new focus groups
because the group had little interactions. Nonetheless, we had two video recordings for
the group during the fall for variation purpose.

Data Analysis

Our analyses of these data were mainly qualitative in nature, driven by our
research questions centered around students’ forms and degrees of participation in
STEM+L practices. In the following, we describe in detail some specific analyses
techniques concerning data sources described in the previous section. The description
focuses on the first and second research questions. The third research question regarding
the relationship between the form and degree of participation will be answered after
connecting the results from the first and second questions.

Analyzing surveys. We qualitatively analyzed online surveys to investigate the
form of participation through role taking. Specifically, we 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 change over time. We also
connect their attitudes toward disciplinary roles with interests in disciplinary practices
(e.g., design, science, and writing) and STEM careers to explain why forms of
participation change.

Analyzing student-generated digital multimodal artifacts. We analyzed
multimodal artifacts students generate in terms of frequencies and level of disciplinary
knowledge and practices. Descriptive statistics (e.g., frequencies) about the artifacts were conducted. From the frequencies and level of disciplinary knowledge and practices, we can infer both the breadth and form of participation respectively.

Cases used iKOS as the major textual production tool. Therefore, used a coding framework (Table 8) that we developed before to analyze the science component of textual artifacts in iKOS. Each sentence was assessed from two aspects: science integration and science explanation. The level of science integration indicates how well science concepts are integrated into the storyline while the level of science explanation shows students’ efforts in explaining science concepts to readers.

As focal students chose Pixton as the major visual composing tool for team projects, we derived a coding framework to analyze the design (Table 7) and science (Table 8) aspect of Pixton comics. Each comic panel was assessed from three aspects: design, science (when comic panels include science ideas), and writing (when comic panels include texts). Codes in the design aspect were adopted from the literature (e.g., Ichino et al., 2010; Thomas & Martin, 2008) while codes in the science aspect were derived from our own coding framework. In addition, we assessed the writing aspect of comics from two dimensions: word maturity and percentage of correct word sequences. Word maturity models the degree to which a word is known at different levels of language exposure (Biemiller et al., 2014) while a correct word sequence is defined as a sequence of “two adjacent correctly spelled words that is acceptable within the context of the phrase” (Videen, 1982). We implemented Latent Semantic Analysis (Kireyev & Landauer, 2011) and Maximum Mutual Information Estimation training (Normandin,
Lacouture, & Cardin, 1994) in Python to compute word maturity and percentage of correct word sequence respectively.

Table 7

The coding framework for design aspect in Pixton comics (Form of participation)

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Objects were not consistent with each other</td>
<td>0</td>
<td>Spaces between panels were small</td>
</tr>
<tr>
<td>1</td>
<td>Objects were consistent with each other</td>
<td>1</td>
<td>Spaces between panels were large</td>
</tr>
</tbody>
</table>

Table 8

The coding framework for science component in textual artifacts in iKOS and Pixton comics (Form of participation)

<table>
<thead>
<tr>
<th>Coding aspect</th>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science integration</td>
<td>1</td>
<td>Science concepts are integrated into the (storyline) / (comic panel) superficially</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Science concepts are somewhat integrated into the (storyline) / (comic panel)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Science concepts are well integrated into the (storyline) / (comic panel)</td>
</tr>
<tr>
<td>Science explanation</td>
<td>1</td>
<td>The (sentence) / (comic panel) includes big science ideas that needs to clarify</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>The (sentence) / (comic panel) makes a clear general statement about science ideas</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>The (sentence) / (comic panel) demonstrates how to apply the science principle</td>
</tr>
</tbody>
</table>

Analyzing iKOS logging data. iKOS logging (Figure 7) allows for the time-stamped recording of keyboard and mouse events to give detailed information about students’ composing processes. Specifically, it tracked the following events: creating new entries, opening entries with and without modifications, and deleting entries.

Figure 7. A snapshot of iKOS logging data.
To answer the research questions regarding form and degree of participation, we examined the literature (e.g., Flower & Hayes, 1981) and reviewed the logging data, and derived 2 broad coding categories of composing processes: open entries 1) with and 2) without modifications. We implemented an O(ND) difference algorithm described by Myers (1986) for computing the difference between strings by identifying the smallest number of changes needed to make the strings equivalent. Specifically, we compared the previous entry (when a student opened the entry) to the current entry (when a student left the entry) to examine whether texts were changed and (if changed) the smallest number of changes. Then we segmented the changes into sentences and used each individual sentence (when a student opened the entry) as the unit of analysis.

For the category of opening entries with modifications, we adopted Benetos’s (2015) framework in coding textual mode modifications and extended the framework to code non-textual mode modifications (Table 9). As shown in Table 9, codes represented different levels of depth of participation. For instance, rewriting a sentence for correcting grammars and revising a sentence for revising existing ideas were both coded as “contributor.” We can also identify the form of participation with the framework in Table 10.
Table 9

The coding framework for iKOS logging data (Depth of participation)

<table>
<thead>
<tr>
<th>Action</th>
<th>Category</th>
<th>Depth</th>
<th>Code</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open entries with modifications</td>
<td>Textual mode modification</td>
<td>Originator</td>
<td>Generate</td>
<td>Introduce new idea in new sentences</td>
<td>Introduce a new story plot by adding a new sentence: “He used to fight a monster that he also managed to encounter.”</td>
</tr>
<tr>
<td>Contributors/Critics</td>
<td>Rewrite</td>
<td></td>
<td></td>
<td>Correct or rephrase sentences for grammatical errors</td>
<td>In a sentence, change “there” to “There.”</td>
</tr>
<tr>
<td>Contributors/Critics</td>
<td>Revise</td>
<td></td>
<td></td>
<td>Add related idea and/or delete minor ideas to existing text to revise idea</td>
<td>In a sentence, change “a way to get oxygen from water” to “a machine that extracted oxygen from water.”</td>
</tr>
<tr>
<td>Contributors/Critics</td>
<td>Remove</td>
<td></td>
<td></td>
<td>Delete texts permanently</td>
<td>Delete the following sentence: “Things like wood, steel, stone.”</td>
</tr>
<tr>
<td>Non-textual mode modification</td>
<td>Originator</td>
<td>Generate</td>
<td></td>
<td>Add self-created modes</td>
<td>Add a picture token by himself</td>
</tr>
<tr>
<td>Contributors</td>
<td>Edit</td>
<td></td>
<td></td>
<td>Add other-created modes or adjust features (e.g., size) of modes</td>
<td>Change the size of a Scratch animation</td>
</tr>
<tr>
<td>Critic</td>
<td>Remove</td>
<td></td>
<td></td>
<td>Delete modes permanently</td>
<td>Delete an image</td>
</tr>
</tbody>
</table>

Open entries without modifications  N/A | Audience     N/A | N/A | N/A
Table 10

The coding framework for iKOS logging data (Form of participation)

<table>
<thead>
<tr>
<th>Action</th>
<th>Form</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open entries with modifications</td>
<td>Designer</td>
<td>Modify non-textual modes</td>
<td>Add a comic showing Nathan dropped a pickaxe.</td>
</tr>
<tr>
<td></td>
<td>Scientist</td>
<td>Modify any modes that showed science ideas</td>
<td>Adjust the size of a Scratch animation that showed the movement of the Earth</td>
</tr>
<tr>
<td></td>
<td>Writer</td>
<td>Modify textual modes</td>
<td>Add sentences</td>
</tr>
<tr>
<td>Open entries without modifications</td>
<td>Other</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The action of opening entries without modifications indicated that students opened entries accidentally or on purpose. We coded it as “audience” from the angle of depth of participation. However, we could not identify form of participation in this action because usually entries included all disciplinary knowledge and we did not know where students focused on after opening entries. Therefore, we coded it as “other” from the angle of form of participation. The frequency of opening entries without modifications was used as a measure of breadth of participation.

Analyzing comments and ratings in Pixton, Scratch, and iKOS. To answer the first question regarding the form of participation over time, we will apply content analysis in each comment to determine role-specific views. In reviewing the literature and comments posted by students, we derived the coding framework in Table 11. For example, both student A and student B commented on student C’s comic: “This story was really funny” from student A and “How do you create so many views (panels) in the comic” from student B. In this scenario, student A, taking the role of writer, focused
more on the plot side while student B, taking the role of scientist, focused more on the design side.

Table 11

The coding framework for comments and ratings (Form of participation)

<table>
<thead>
<tr>
<th>Action</th>
<th>Form</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post comments</td>
<td>Designer</td>
<td>Comments are related to designing practices</td>
<td>“although the post-apocalyptic background was off it was a great story”</td>
</tr>
<tr>
<td></td>
<td>Scientist</td>
<td>Comments are related to science ideas</td>
<td>“That guy must have been loud no one can hear you in space.”</td>
</tr>
<tr>
<td></td>
<td>Writer</td>
<td>Comments are related to writings</td>
<td>A comment for a comic: “The speech bubble had too many texts”</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>Comments are not related to specific disciplinary practices</td>
<td>“This is funny”</td>
</tr>
<tr>
<td>Give ratings</td>
<td>Other</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

To investigate changes in the patterns of student participation for the second question, we will use frequencies of comments and ratings to measure the breadth of participation and to what extent comments add on new information will be analyzed to determine the depth of participation (Table 12).
Table 12

The coding framework for comments and ratings (Depth of participation)

<table>
<thead>
<tr>
<th>Action</th>
<th>Depth</th>
<th>Code</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post comments</td>
<td>Audience</td>
<td>Clarify</td>
<td>Ask questions for clarification</td>
<td>“what would be in that pit?”</td>
</tr>
<tr>
<td>Audience</td>
<td>Rate</td>
<td>Praise</td>
<td>Give good or bad remarks without specifying the weakness or strength</td>
<td>“so excited”</td>
</tr>
<tr>
<td>Contributor</td>
<td>Rephrase</td>
<td>Interpret</td>
<td>Interpret the artifact</td>
<td>“rege mountain.”</td>
</tr>
<tr>
<td>Critic</td>
<td>Praise</td>
<td>Problem</td>
<td>Good remarks on what constitutes the strength</td>
<td>“awesome use of background.”</td>
</tr>
<tr>
<td></td>
<td>detection</td>
<td>diagnosis</td>
<td>Statement about what is wrong or weak</td>
<td>“That guy must have been loud no one can hear you in space.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Explanation on why the problem happened</td>
<td>“although the post-apocalyptic background was off it was a great story”</td>
</tr>
<tr>
<td>Critic</td>
<td>Solution</td>
<td>Suggestion</td>
<td>Statement about how to improve the problem</td>
<td>“Flying is for the birds but still cool.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Comments are not related to the artifact</td>
<td>“Prez swag froki.”</td>
</tr>
</tbody>
</table>

Make ratings  | Audience  | N/A | N/A | N/A  |

Analyzing video recordings. We used methods of interaction analysis (Derry et al. 2010; Jordan & Henderson, 1995) when analyzing the video recordings of focal students. Initially, we 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 as an originator). In a more systematic, second pass through the recordings, content logs and memos were developed to describe students’ participation patterns and trajectories.

For selected episodes in the record, we paid close attention to the multimodal talk-in-interaction during group working, that is, the sequence of turns of talk (Schegloff,
tool use, gesture, and body movement. Group working includes two kinds of activities: discussion and composing. Discussions were investigated from two angles: role-specific views and to what extent one refers to learning partner’s contribution. For example, student A who took the role of a writer provides explanations for student B’s questions about comic design. In this case, student A participated in the discussion by presenting a designer’s view and providing elaborated responses to learning partners’ contribution (contributor). Also, composing processes were examined from two similar angles: role-specific practices and to what extent one contributes to team projects. For instance, Student C, taking the role of a scientist, searched for scientific information online following student A’s suggestion. In this case, student C participated in the composing processes by carrying out scientific practices as building on someone else’s idea (contributor).

The interaction analysis, including content logs, memos, and hot spots of each focal students’ contribution to group discussion and composing processes over time, provides a fine-grained understanding of the forms and degrees of participation.

Analyzing video reflections. Instead of utilizing writing as a mode for reflection, students were asked to create video reflections in the first physical session during the fall extension. In video reflections, students used class observation images and videos, their multimodal products, and some other resources that they select to reflect on learning experiences during the summer camp (e.g., contributions for team projects and role-taking). In addition, students reflected on video creation experiences (e.g., “what was your goal when creating your video reflection”) through a survey. These reflections were openly-coded to understand the trajectory of students’ participation in the project and
students’ reflective understanding of their own role taking (form of participation) and contributions (degree of participation).

**Analyzing semi-structured interviews, field notes, and physical materials.** I openly-coded student interviews, field notes, and physical materials that are connected to the form and degree of participation previously analyzed, also looking for connections to other data sources and new insights provided by students’ perspective and our classroom observations.

**Trustworthiness**

In order to establish trustworthiness in this qualitative study, we followed the following widely-regarded standards: credibility, transferability, dependability, and confirmability (Erlandson, Harris, Skipper, & Allen, 1993; Lincoln & Guba, 1985; Shenton, 2004). In this section, I will describe detailed strategies for supporting the trustworthiness of findings.

**Credibility.** To accurately examine students’ forms and degrees of participation, I constantly compared and contrasted (Strauss & Corbin, 1998) the results of analysis of all available data sources, including the analysis of surveys, student-generated digital multimodal artifacts, online interactions in multimodal platforms, iKOS logging data, video recordings, student-generated video reflections, semi-structured interviews, field notes, and student-generated physical materials to triangulate our findings. I also relied on other researchers’ observations of students’ participation. Frequent debriefing sessions with my advisor, Dr. Ji Shen, throughout all stages of this study helped me to see my biases, positionality, and discuss emerging themes.
Extensive engagement with the participants is another approach for building credibility (Erlandson et al, 1993). My persistent participations and observations provided the necessary depth to understand the unique social world of the program and allowed me to build trust with participants.

**Transferability.** To ensure that the findings of this study can be transferred to other contexts and settings (Lincoln & Guba, 1985), I provided thick descriptions of cases, categories, and themes. I also provided a means of comparison between the cases so that readers can get insights on how to transfer findings.

**Dependability.** To establish dependability, which refers to “if the work were repeated, in the same context, with the same methods and with the same participants, similar results would be obtained” (Shenton, 2004, p.71), I reported a detailed description of the research methodology.

**Confirmability.** Confirmability is the degree to which the findings of a study are not influenced by a researcher’s biases, positionality, motivation or interest (Lincoln & Guba, 1985). I was aware that my biases and the positionality could affect the interpretation of the data. In qualitative studies, Denzin and Lincoln explained that “there are no objective observations, only observations socially situated in the world of - and between - the observer and the observed” (p.31). I position myself as an Asian female born and raised in mainland China, speaking English as a second language, and experienced different cultures, educational, political, and other contexts. Also, my personal interest in visual design and research interest in identity development might have an impact on the data analysis. To resolve my possible biases and positionality into interpretations of the data and findings, I had frequent debriefing sessions with my
advisor. Also, I approached to available participants and other members in the research team to confirm the subjective construction of my interpretations.

Limitations

The present study had some limitations due to its scope and the nature of afterschool programs. It is important to remember that these findings are deeply situated within this project and are not intended to be overly generalized. Although we could not collect video recordings for all physical sessions of any focal students to show full participation patterns and trajectories, we analyzed other sources of data to get a full picture of students’ participation.

We intended to apply maximum variation in selecting cases covering all the three roles. However, we ended up with choosing cases taking the role of designer and writer because they showed changes in forms and/or degrees of participation.

Also, it’s important to note that there was no doubt that interactions and events occurring in students’ daily life could affect their participation patterns and trajectories. Although these influences are outside of the scope of this study, I have attempted to uncover them through interacting with students during group work and conducting interviews.
Chapter Four

Case Studies

This chapter presents four detailed cases to illuminate students’ participation patterns and trajectories in the STEM+L project. Each case starts with a summary of the student’s general background information and the group’s composition. The results are reported in overarching themes organized around forms and degrees of participation as framed in the first and second research questions. The discussion includes a section on the relationship between the form and degree of participation as raised in the third research question.

Table 13 showed four multimodal science fictions composed by groups that the focal students were in.

- Steve’s group (Steve, Designer; Kaylee, Scientist; Pi, Writer) created the story “Captain atomicon” in which Jason became a superhero and learned to control powers with the help of a scientist, Dr. K. The story included 2705 words, four comics, and one image.

- Nick’s group (Nick, Designer; Alex, Scientist; Brandon, Writer) created a story entitled “What would happen if the world stopped spinning.” In the story, three characters, representing themselves, survived after the Earth stopped spinning. There were 1159 words, two comics, one photo, one image, and two animations in the story.

- Olivia’s group (Olivia, Writer; Alyssa, Designer; Diego, Scientist; Bing, Scientist) composed the story “Haluki star” in which Lucy wrote a story to
describe her adventure in planet *Haluki*. The story had 1787 words, four animations, and two images.

- Saanvi’s group (Saanvi, Designer; Mariana, Designer; Emilia, Scientist; Valeria, Writer) composed a story called “*Tsunami terror*”, in which three protagonists (representing Saanvi, Mariana, and Valeria) saved people from a tsunami triggered by the antagonist (representing Emilia). Their story included 698 words, four comics, one image, two voice narrations, and three pieces of music.

### Table 13

**Focus students and their multimodal science fictions (D=Designer; S=Scientist; W=Writer)**

<table>
<thead>
<tr>
<th>Name (Role, Grade)</th>
<th>Group member (Role, Grade)</th>
<th>Title</th>
<th>Main character</th>
<th>Storyline</th>
<th>Science topic</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steve (D, 6)</td>
<td>Kaylee (S, 7)</td>
<td>Captain atomicon</td>
<td>Jason, Dr. K</td>
<td>Jason became a superhero after he got exposed to a nuclear bomb. Dr. K, a scientist, helped Jason in controlling powers and fought monsters.</td>
<td>Nuclear eruption; Mutation; Neurology;</td>
<td>Text; Comic; Image</td>
</tr>
<tr>
<td>Nick (D, 6)</td>
<td>Alex (S, 6)</td>
<td>What would happen if the world stopped spinning</td>
<td>Nathan, Luke, Zhang</td>
<td>Nathan, Luke, and Zhang survived after the earth stopped spinning and they found a new civilization.</td>
<td>Earth science; Mutation; Evolution</td>
<td>Text; Comic; Image; Photo; Animation</td>
</tr>
<tr>
<td>Olivia (W, 7)</td>
<td>Alyssa (D, 7)</td>
<td>Haluki star</td>
<td>Lucy, Halukinu Masanluka</td>
<td>Lucy wrote a story in which she took an adventure in Haluki star.</td>
<td>Space</td>
<td>Text; Image; Animation</td>
</tr>
<tr>
<td>Saanvi (D, 5)</td>
<td>Emilia (S, 6)</td>
<td>Tsunami terror</td>
<td>Keke, Sara, Kai, Crystal</td>
<td>Keke, Sara, and Crystal saved the world after Kai triggered a tsunami.</td>
<td>Tsunami</td>
<td>Text; Image; Comic; Voice narration; Music</td>
</tr>
</tbody>
</table>
The Case of Steve: Creative Designer and Active Commenter

Steve was a sixth-grade male who was self-identified as an African American. He took the role of designer in the team composed of one designer (himself), one scientist (Kaylee, seventh-grade female African American), and one writer (Pi, eighth-grade male Indian American). The team created a multimodal science fiction titled “Captain Atomicon” (Table 13). The team’s multimodal composing processes for “Captain Atomicon” 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 contributions).

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. He chose Pixton as the main composing platform to design comics and his comics often included online images. In contrast to his working-alone style during small group meetings, he was very active in making comments to others’ comics in Pixton.

Because of his role of designer and his choice of Pixton as the major composing tool, we mainly analyzed his comics and online comments in Pixton. Steve’s participation patterns and trajectories, including illustrative examples, will be described in the following sections.

Form of Participation: Role Taking

Steve’s form of participation in terms of role taking was manifested in various aspects including consistent attitudes toward the three roles and demonstration of improvement in designing comics within and across panels, developing writing skill in
comics, and representing science ideas with multiple modes in comics. Each of these aspects will be described in detail in the following.

**Attitudes and interests.** Overall, Steve had consistent attitudes toward the three roles (i.e., designer, scientist, and writer) in the project. Specifically, his attitudes toward the roles of designer and scientist stayed positive, whereas his attitude toward the role of writer stayed negative throughout the program (Figure 8). This pattern is consistent with his self-reported interests in media design, science, science fiction, and STEM profession, and lack of interest in writing.

![Figure 8.](image) Steve’s responses in pre, mid, and post-survey (He did not respond to the pre-survey with respect to his preferences in the three roles).

Steve’s attitudes toward taking the role of designer were positive in both the mid and post-survey. In the mid-survey, he “agreed” that he liked to be a designer and expressed the passion and creativities in “designing photos” and “creating comics.” To fulfill the role of designer, he used “cool” online photos gathered using search engines to create comics. Being able to remix online photos in comics could be one explanation for
his positive attitude towards the role of designer. He had the same attitude toward the role of designer in the post-survey.

His attitude toward taking the role of scientist changed from “strongly agree” to “agree.” Although there was a changing level in attitudes, his explanations were the same in the mid- and post-surveys, “I love science.” His positive attitude in the role of scientist was associated with the self-reported strong interest in science throughout the project.

Steve maintained a negative attitude toward the role of writer in the team. In both mid- and post-surveys, he “disagreed” to be a writer because he had preferences in other roles. While explaining the reason for interests in the three roles, he reported, “I rated them in that way because I love science and hate writing” (mid-survey) and “I like to be a designer because I am an abstract kind of guy and I love science” (post-survey). The responses suggested that he preferred science and design practices over writing.

His negative attitudes toward the role of writer could be due to the fact that he could not find a way to participate in writing practices in the team. This was reflected in his negative attitudes toward role taking. In the pre-survey, he “disagreed” that one should have a role because it constrained helping each other, “if everyone helps one another, the project will be done 2x as fast.” In the mid-survey, he was “undecided” about having a role, “it can go both ways.” In the post-survey, he “disagreed” on having a role because he “liked to spread the work.” From Steve’s perspective, role taking constrained collaboration and participation in disciplinary practices beyond design.

Steve’s negative attitude of having a role was also related to his preference of working with others over working alone. As he explained in the pre-survey, “when I work with a group, the final product will be even better, thanks to the extra hands and
points of view.” He “strongly agreed” that he preferred teamwork in the rest two surveys. In the comic design, he pointed out the importance of having a team, “he is nothing without the team.” (Figure 9)

Figure 9. Steve integrated the idea of collaboration in the comic.

Despite his preference in working with others, in reality, he had very limited opportunities to physically interact with his group members. Based on the field notes and video observations, both Pi and Kaylee interacted more with students in other groups. During the summer, Pi exchanged ideas with an eighth-grade male in another group while Kaylee always sat in her cousin’s group. In the fall, they usually wore headsets and worked in silence (Figure 10). Steve tried to reach Pi in iKOS, but merely received responses. He commented on their Book entry which only included texts produced by Pi (Figure 11). Some comments were even made while the team sat together. Pi, the writer, rarely responded to Steve’s comments in iKOS (Figure 12). In general, Steve had few opportunities to interact with his team members. The very limited interaction between Steve and the writer (Pi) might explain his negative attitude toward being a writer in the project.
Figure 10. Steve (right) and Pi (left) worked in silence during small-group work time on 12/02/2017.

Chapter 1
Chapter One: Captain Atomixxon

As I open the door to go outside, I can smell all the toxic chemicals in the air. It smells like death and carbon dioxide. Ugh! I would hate to live in this place like my best friend Kayxia (Kayxia is a nuclear physicist, that is a type of scientist).

Oh, yeah I didn’t tell you, I don’t live here in New Mexico. Hi, my name is Jason Miller. I live in New York by myself. I would have lived with my family in Ohio but my dad bailed on me and my mom when I was 3, and mom died in a car accident when I was 7. Grandma took me in when my mom died and raised me until I was 19, then I went to Colorado University in New York and that’s been my home ever since. Now, I am 24 years old and just graduated from college. I’m also single and ready to mingle. I came here to visit my grandma.

Grandma told me to go to Publix and get some bread, milk, eggs, and some jerky. Even though that barely costs 20 dollars, grandma gave me a $50 dollar bill and told me to spend the leftover money on whatever I wanted. Grandma is loaded; she made millions modeling for some makeup company that nobody remembers.

I had walked halfway to Publix when this huge white light just erupted, then a second later a huge bang and a wave of air hit me. I was a blind, deaf, and off balance for about 10 minutes, then everything just went black.

I wake up and can’t move, and I’m staring at this white ceiling. It took me about a minute to realize that I was in a hospital, then I start to panic.

I finally got a moment of assurance when I saw grandma sleeping in a chair right next to my bed. Then a nurse came in and had a surprised look on her a face when she saw me sitting up on my bed. I asked her what happened,

“Mr. Jason you have been in a coma for nearly two weeks,” said the nurse.

Figure 11. Screenshot of iKOS Book entry. The iKOS Book only had Pi’s textual narratives.

Figure 12. Comments between Steve and Pi on the Book entry in iKOS.
Knowledge and practices. As a designer in the team, Steve chose Pixton as the main composing platform in which he created one comic during the summer camp, five comics during the early fall extension, and one comic during the late fall extension. The following sections illustrate some changes in disciplinary knowledge and practices exhibited in his Pixton comics.

Improvement in comic design. The comic is a medium that heavily emphasizes its message delivery on visual sequences. An important feature of comic design is thematic congruence, which incorporates two aspects: agreement of elements within one panel and the gutter between panels.

Within one panel: Leveraging online sources to support thematic congruence. Steve liked to incorporate online images to enrich his comic design. As shown in Table 14, his comics had quite a few online images (e.g., on average around 2 online images in each panel of comic “The atomic arsenal”). As he emphasized in the video reflection during the first fall session, the inclusion of online images could enrich his experience in design practices.
Table 14

*Design aspect of Steve’s comics (N/A represents a comic without title). The average level of thematic congruence within panels refers to (on average) whether elements were consistent with each other in each panel. The average gutter refers to (on average) whether spaces between panels were small.*

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Number of panels</th>
<th>Number of online images (Average number of images per panel)</th>
<th>Number of characters</th>
<th>Average level of thematic congruence within panels</th>
<th>Average gutter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>Me in 20 years</td>
<td>9</td>
<td>11 (1.2)</td>
<td>6</td>
<td>0.67</td>
<td>0.5</td>
</tr>
<tr>
<td>Early Fall</td>
<td>Awesome insanity</td>
<td>15</td>
<td>11 (0.7)</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Captain of atomic</td>
<td>15</td>
<td>24 (1.6)</td>
<td>2</td>
<td>0.85</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>6</td>
<td>13 (2.2)</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AZ</td>
<td>1</td>
<td>4 (4.0)</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Awesome randomness</td>
<td>23</td>
<td>29 (1.3)</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Fall</td>
<td>The atomic arsenal</td>
<td>30</td>
<td>57 (1.9)</td>
<td>1</td>
<td>0.90</td>
<td>0.07</td>
</tr>
</tbody>
</table>

There was a noticeable improvement in Steve’s use of online images to support thematic congruence (Table 14). The average level of thematic congruence within panels increased from 0.67 to 0.9. Figure 13 showed different levels of multimodal design for thematic congruence. While designing comic “Me in 20 years” in the summer, Steve used an online picture of a fried chicken in outer space. The online picture was inconsistent with the comic panel both in graphic design and in explaining his future profession. In contrast, while designing comic “Captain of atomic” in the fall, he used an online picture...
of a sword while Dr. K explained equipment to Jason in the story. It showed apparent congruence between the sword and the comic panel.

Figure 13. An example (left) of less congruent design in comic “Me in 20 years” and an example (right) of more congruent design in comic “Captain of atomic.”

Gutter between panels. The average gutter decreased from 0.5 to 0.07 (Table 14). In comic “Me in 20 years”, he switched backgrounds between panels that had weak connections and included six characters (Table 14), which resulted in an obscure storyline and story theme. As shown in the left example of Figure 14, the connection between the two panels was weak because he left too many questions for the audience to think about between the two panels, such as which character represented Steve, and whether the living room and the bedroom were in the same building. Later, he demonstrated clarity and continuity of storytelling in comics through carefully designing and arranging elements across panels (Figure 14). An audience can easily understand that an old man was explaining different equipment to Jason in the right example of Figure 14.
Figure 14. An example (left) of large gutter from two sequenced comic panels of comic “Me in 20 years” and an example (right) of small gutter from two sequenced comic panels of comic “Captain of atomic.”

**Improvement in writing in comics.** Despite short text lines, the speech balloons and captions provided the opportunities for Steve to practice writing. Table 15 showed noticeable improvements of Steve’s writing skill in words per sentences (1.57 to 10.03), vocabulary maturity (6.11 to 9.40), and percentage of correct word sequences (22% to 81%). For example, as shown in figure 15, texts in balloons or captions were simple words (e.g., “yeeeeaaaaahhhhh” from comic “Me in 20 years”) or short sentences (e.g., “best day ever” from comic “Me in 20 years”) in the beginning. Gradually, he started to use more sophisticated vocabularies, and longer sentences (e.g., ‘And if his weapons ever get stolen or lost he can use his radiation to make laser weapons” from comic “The atomic arsenal”). Speech balloons and captions served as space for Steve to practice and demonstrate his writing skill.
Table 15

Writing aspect of Steve’s comics (N/A represents a comic without title). Word maturity models the degree to which a word is known at different levels of language exposure while a correct word sequence is a sequence of two correctly spelled words that are acceptable within the context of the phrase.

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>(Word, Sentence) count</th>
<th>Average words per sentence</th>
<th>Average vocabulary maturity</th>
<th>Average percentage of correct word sequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>Me in 20 years</td>
<td>(11, 7)</td>
<td>1.57</td>
<td>6.11</td>
<td>22%</td>
</tr>
<tr>
<td>Early Fall</td>
<td>Awesome insanity</td>
<td>(63, 18)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Captain of atomic</td>
<td>(75, 15)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AZ</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Fall</td>
<td>Awesome randomness</td>
<td>(39, 12)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Fall</td>
<td>The atomic arsenal</td>
<td>(311, 31)</td>
<td>10.03</td>
<td>9.40</td>
<td>81%</td>
</tr>
</tbody>
</table>

Figure 15. An example (left) of having simple words from comic “Me in 20 years and an example (right) of having longer sentences from comic “The atomic arsenal.”

Improvement in representing science ideas with multiple modes in comics.

Steve learned to combine multiple modes to represent science ideas. Table 16 showed the overall increasing trend in the number of modes to explain science ideas. For instance, he only had a science word, “teleport”, in the speech balloon in a comic that he created in
the early fall (Figure 16). In contrast, he used both science words, “transform”, in the captions and pictures of viruses to explain how the shark became a monster (Figure 16).

Table 16

Science aspect of Steve’s comics (N/A represents a comic without title). The level of science integration indicates how well science concepts are integrated into the storyline while the level of science explanation shows students’ efforts in explaining science concepts to readers.

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Number of modes in science</th>
<th>Science integration</th>
<th>Science explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>Me in 20 years</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Early Fall</td>
<td>Awesome insanity</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Captain of atomic</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>AZ</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Awesome randomness</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Late Fall</td>
<td>The atomic arsenal</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 16. An example (left) of explaining science ideas in single mode from comic “Awesome insanity” and an example (right) of explaining science ideas with two modes from comic “The atomic arsenal.”

Table 16 also demonstrated that the science integration level was high in all comics while the level of science explanation was low. It indicated that science ideas were highly integrated into the comic. As shown in Figure 16 (left), the concept of
“teleport” was seamlessly integrated into the dialogue between two characters. Although the level of science explanation was low overall, he consistently incorporated science ideas in comic design.

**Degree of Participation**

In Steve’s case, although the breadth of participation concerning his contribution to their team project was constant, the breadth of participation concerning his contribution to the whole class increased. His depth of participation was evidenced in originating more ideas in comic design, and expressing himself and interacting with others as an active commenter in Pixton.

**Originator in Pixton.** Even though there was no apparent improvement in the number of comics from summer to fall, Steve became an originator while composing comics. With Pixton, he created seven comics (Table 17) in the project: Four were related to the team project; Two were designed for fun while he was in the summer camp and at home during the fall extension; The one “Me in 20 years” was an in-class assignment for all students during the summer camp. The four comics created for the team project were complementary to but sometimes in conflict with Pi’s writing (Table 17). For example, Pi wrote: “as for those superpowers we need to design you a suit,’ said Kaysia.” Different from Pi’s writing, Steve proposed new ideas and designed the comic “Captain of atomic” in which an old man gave a presentation of a superpower suit to Jason.
Table 17

Seven comics created by Steve (Bold texts represent main characters in textual narratives; N/A represents a comic without title)

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Team project</th>
<th>Main storyline</th>
<th>Connection with Pi’s writing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>Me in 20 years</td>
<td>No</td>
<td>Different adventures on the earth, undersea, and outer space.</td>
<td></td>
</tr>
<tr>
<td>Early Fall</td>
<td>Awesome insanity</td>
<td>No</td>
<td>In character A’s dream, Character A (with toon force) and B (with teleportation) saved character C with the help of character D and E.</td>
<td>Both Pi’s writing and the comic had a superpower suit and tools. However, the comic had Character F explained them to Jason in details while the writing part was that Dr. K gave them to Jason without explanations.</td>
</tr>
<tr>
<td></td>
<td>Captain of atomic</td>
<td>Yes</td>
<td>Character F gave a presentation to introduce a superpower suit and tools to Jason.</td>
<td>The comic added two characters and the idea of running away from waves.</td>
</tr>
<tr>
<td>N/A</td>
<td></td>
<td>Yes</td>
<td>Jason, character G and H were running away from a big wave.</td>
<td>The comic added two characters and the idea of standing in a wave.</td>
</tr>
<tr>
<td>AZ</td>
<td>Awesome randomness</td>
<td>Yes</td>
<td>Dr. K, Character I and J were standing in the middle of a big wave.</td>
<td>The comic added two characters and the idea of standing in a wave.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>A baby went to the Mars and met a chicken. Then they came back to the Earth.</td>
<td>Both Pi’s writing and the comic had a superpower suit and an introduction of different functions. However, the comic added the idea that the suit could work in different environments.</td>
</tr>
<tr>
<td>Late Fall</td>
<td>The atomic arsenal</td>
<td>Yes</td>
<td>Dr. K introduces a superpower suit that has different functions and can function in different environments.</td>
<td></td>
</tr>
</tbody>
</table>

Active commenter in Pixton. As evidenced in his comments in Pixton, there were improvements in both the breadth and depth of participation. In the role of designer, Steve actively commented on others’ comics in Pixton. In the project, we did not prompt or require students to make comments so that only a few (student 1, 4, and 16) made
comments. Steve (Student 1 in Figure 17) was one who posted the most comments in Pixton.

Besides being an audience, Steve contributed and evaluated existing ideas through interpreting as well as elaborating on the strength and weakness of others’ comics. Figure 18 shows that Steve started to comment on comics in September and posted more comments regularly in October and November. While posting comments as an audience, he not only rated others’ comics (e.g., “there was no need for improvement.”), but also intended to invite others to read his comics (e.g., “I thought my comic about dream was awesome.”). In addition, he evaluated comics as a critic (Figure 19), “flying is for birds but still cool.” The comment pointed out that it was scientifically impossible for a man to fly like a bird without additional equipment. Steve’s active engagement in commenting
comics indicated that he tried to interact with others as well as expressing himself in Pixton.

Figure 18. Steve’s comments in Pixton.

Figure 19. Steve commented on one comic created by others in Pixton.
Discussion

Figure 20. Steve’s participation patterns and trajectories. 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.

Figure 20 summarizes Steve’s participation in this program. The x-axis indicates the rough timeline while the y-axis indicates the depth of participation. Steve mainly took the role of designer throughout the project. In his case, forms of participation changed in the dimension of disciplinary knowledge and practices while degrees of participation increased slightly in both breadth and depth.

With respect to forms of participation, Steve took on the role as the 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 overtime (in Figure 20, the color of the D slice of the pie changed from orange to red). The improvement was evidenced in his more advanced
comic design (e.g., better thematic congruence and more efficient use of online
resources), incorporating better writing in comics (e.g., speech bubbles with better
writing), and integrating science ideas with multiple modes (e.g., learned to use 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.

With respect to the breadth of participation, 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. Although being silent and
limited in physical interactions, Steve became more active in interacting with others in
the community by posting online comments. His breadth of participation was extended
through the online space.

With respect to the depth of participation, Steve changed from more peripheral
participation 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 final fiction plot and a contributor to visualize the story narrative, 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 addition, the case illustrates that improvements in forms of participation (disciplinary knowledge and practices in this case) could increase degrees of participation (Figure 21). The improvement in designing comics with multiple modes (e.g., combining online pictures and texts) motivated Steve to add his own ideas in comics. While composing with multiple modes, Steve branched out and drew on his own personal knowledge and preferences in creating multimodal comics. With the affordances of modalities, he might be aware of his design identity and became active in expressing ideas within design. This case reveals that the proficiency in composing with multiple modes promises to be a powerful vehicle for expressing ideas.

The case also shows that Steve’s desire of increasing degrees of participation led to an expansion of space in forms of participation. Steve attempted to propose new ideas, however, one of the team members, Pi, rarely responded to him. This interactional characteristic within the small group drove Steve to shift his participation as a designer from the small group to online interactions in the whole class. He became an active commenter in Pixton and posted comments to the whole class.
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.

**The Case of Nick: Diligent Designer and Motivated Writer**

Nick was a sixth-grade Latino. He took the role of designer in his group, 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” (Table 13). 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 contributions), 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 toward the end of the project. 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. He was willing to assist group members in performing joint tasks, including creating background drawings for Alex’s science animations and revising Brandon’s writing.

Because of his role of designer and his choice of Pixton and iKOS as the major composing tools, we mainly analyzed his comics and iKOS logging data. Nick’s
trajectories in forms and degrees of participation, along with illustrative examples, will be described in the following sections.

**Form of Participation: Role taking**

Nick’s form of participation in terms of role taking was manifested in (a) more positive attitudes toward the role of designer and (especially) writer, and stable attitudes toward the role of scientist, (b) improvements in comic design, integration between comic and writing, and integration of science ideas in visuals and texts, and (c) recognized himself and by team members as both a designer and writer. Each of these aspects will be described and discussed in the following.

**Attitudes and interests.** Initially, Nick chose the role of designer in the pre-survey because he was confident of conducting design practices. As he reported, “I would like to be a designer because I can design how things look” (pre-survey). In contrast, although he “strongly liked” science, he was “undecided” about being a scientist in the team. He explained, “I was not sure if I will be good at the scientist role” (pre-survey). He “disagreed” to be a writer because he didn’t like writing as he “can't think of anything to write about” (pre-survey). These responses suggested that Nick was clear about his strengths and selected a role that he had much confidence in performing associated practices.

Taking on the role of the designer, Nick became more interested in the role of designer over time (Figure 22). First, he had confidence in carrying out design practices and could design visuals. Second, being able to perform design practices not only built his confidence in being a designer, but also facilitated him to link design with writing. In
this way, he built confidence in writing, which is the practice that he felt less comfortable with. This might contribute to the increased interest in taking the role of designer.

One of the most interesting findings about Nick’s attitudes and interests was that his attitudes toward writing as well as taking the role of writer changed from negative to positive. He admitted that he “hated writing” in the pre-survey, but expressed that he liked writing in the rest two surveys. In the mid-survey, he responded, “I like to be a writer because I am confident that I can create the writing and I like to write stories” (mid-survey). While responding to the question of “what’s your favorite part of the project” in the final interview, he reported, “the writing was cool. I liked how we got to write our own book.” His responses indicated that he not only became confident in performing writing practices but also developed a strong interest in writing.

Nick’s changing attitudes toward writing and being a writer were consistent with his changing attitude toward taking roles in general. Initially, he “agreed” that he preferred taking roles but did not value it, “I do not care whether I get a specific role or

![Figure 22. Nick’s pre-, mid-, and post-survey responses.](image)
not because I know I will enjoy whatever I get” (pre-survey). In the mid-survey, he still “agreed” with preference in role taking after trying out different roles, “I like to take on designer and writer because I am not sure if I want to be a scientist.” The responses suggested that role taking provided opportunities for Nick to carry out diverse disciplinary practices. In the end, he “strongly agreed” that he would like to take roles, “I do prefer taking on a specific role. While I'm good at taking on the roles that I have now, I'm not very good at the other role” (final survey). From his perspective, role taking could strengthen specific skills and knowledge.

The attitude change in role taking was mediated by the perception of how role taking should work. He used role taking as a way to participate in different disciplinary practices, “I kind of tried out writer. I tried out pretty much all three roles. I just wasn't the best at scientist and I kind of like writing on the computer. I never really tried it before” (final interview). He further emphasized the power of role taking in enabling him to try out things, including those he felt less confident with, “if I had every single role, I would be all over the place I would think. I don't really know what I should do, I don't know what I'm best at. I do.” Through role taking, he could reach beyond the comfort zone of design and not only tried out writing, but also developed a strong interest and competence in writing.

His attitude towards taking the role of scientist stayed neutral even though he had a strong interest in science throughout the project. His responses to the question of interest in science and preference in being a scientist in the team were the same in the three surveys. On the one hand, he “strongly agreed” that he liked science and wanted to explore any science topics. On the other hand, he was “undecided” about being a scientist
in the team because he was not sure whether he could do it well. The fact was that the scientist of his team, Alex, demonstrated very strong science expertise and proposed the driving science topic (i.e., the Earth stopped spinning) for their group’s fiction. Alex was also very outspoken as the team’s scientist as he was expressive in explaining science ideas during group discussions, whole class discussions, and (especially) presentations. Moreover, as mentioned before, Alex preferred working by himself. The presence of a strong scientist who preferred working along might prevent Nick’s more active participation as a scientist in the team.

**Knowledge and practice.** As a designer in the team, Nick chose Pixton as the main composing platform in which he created five comics during the summer camp and four comics during the fall extension. He also contributed in developing textual narratives in iKOS during the fall. The following sections illustrate some changes in disciplinary knowledge and practices exhibited in artifacts that he created in Pixton and iKOS.

**Within Design: Improvement in character design.** Nick showed a growing competency in design. This was evidenced in his character design. Comparing with artifacts created in the summer, characters in Nick’s comics composed in the fall had more appropriate and dynamic gestures. Figure 23 showed a comparison of gesture design between two comics, one created in the summer and one created in the fall. The character’s gesture (e.g., facing towards the audience and wavering hands) on the left (created during summer) was not appropriate to the story context in which Nathan dropped the pickaxe on the ground while fighting a monster. In contrast, the characters’ gestures on the right (created in the fall) fit the context very well in which Nathan, Luke, and Zhang fight a monster and each of them had its own gesture with different weapons.
The improvement in character design suggested that Nick might become aware of and be able to design for visual consistency.

*Figure 23.* An example (left) of less appropriate character design in “Untitled” (created in the summer) and an example (right) of more appropriate character design in “Background” (created in the fall).

**Connecting comic design with writing: Designing comics to visualize specific writings.** From the summer to the fall, Nick learned to design comics for the purpose of visualizing specific textual narratives. During the summer, like most designers, Nick created multiple-panel comics to show continuous story plots. In the fall, most of his comics were one-panel comics that demonstrated specific writing sections (Table 18). For example, while reading chapter 3 (Figure 24), he brought up the idea of a mutant dog in the story, “in the middle of the story I came up with the idea that we would have a dog. Because since everything kind of mutated when the asteroid hit, it's kind of like a weird dog” (final interview). He wrote the corresponding narratives and created a one-panel comic (Figure 24) to show how Nathan met the mutant dog. When asked what he did specifically to fulfill his role of designer, Nick explained that he selected scenes to visualize in the final interview. In Nick’s case, comics were used efficiently to visualize specific textual narratives.
Table 18

Design aspect of Nick’s comics

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Number of panels</th>
<th>Number of characters</th>
<th>Number of balloons</th>
<th>Number of captions</th>
<th>Number of online images</th>
<th>Average gutter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>Me in 20 Years</td>
<td>7</td>
<td>2</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>My life</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Background for animation</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Backgrounds</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scenes</td>
<td>6</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>Scene 2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scene 3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Background 1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Background 2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Figure 24. Screenshot of Chapter 3. In the red box, Nick described the plot of meeting a mutant dog. The blue creature represents the mutant dog.
In addition, while setting composing goals, Nick emphasized his responsibilities and goals in “designing” and “visualizing” (goal setting worksheet) writing. From his perspective, the connection between design and writing was realized in the way of designing comics for visualizing textual narratives.

**Integrating design, writing, and science: Incorporating science ideas through multimodality.** Toward creating their final fiction, Nick was able to express science ideas through multiple modalities. For instance, in the story, Nick’s character met a mutant dog looking like a blue monster (Figure 24). Like many science fictions, mutant animals tended to be looking different from normal ones. Different from the misconception of “mutation is bad or undesirable” in many science fictions, in Nick’s narratives (mostly in chapter 3 that he wrote), the mutant dog “is good” and “friendly” and helped the three survivors to fight monsters and find a new civilization.

He also clearly demonstrated that mutation could occur with not only animals but also plants. While visiting the botanic garden in the fall, Nick took a picture of a “weird” flower (Figure 25) and inserted it in the fiction. While asked what kind of science ideas he added in the story, he described, “I also took a picture when we went to Fairchild garden. I took a picture with a camera. I also implemented it into the story” (final interview).
When Nathan came back to the base with the dog-thing, Luke and Zhang were instantly surprised. “What is that thing?” Luke asks. “I
not sure, but it’s really nice. It’s like a dog,”
Nathan answers. “Get that thing out of here. It could be really dangerous for all we know,”
Zhang says. “Are you kidding? This dog is awesome,” Nathan says.

“Two things,” Zhang continues, “It’s not a dog. Second, it won’t be so awesome when it
decides to stab you in the back.” “We should give it a name. How about Slimy?”
attack, I have nothing to do with it,” Zhang says.

Nathan decided to take the dog out for a
walk. “You don’t need a leash do you?” asked
Nathan. “You’re a good boy. You don’t need a
leash. Alright, let’s go.”

The second Nathan opens the door, Slimy
takes off running. “Slimy, get back here!”
Nathan chases after the dog. The dog runs
into the bushes. Nathan goes through also. They come to an open field, and the dog stops.
Nathan had finally caught the dog.

“What is wrong with you?” Nathan asks. “I
thought you were a good dog.” Nathan looks
around, and finds that him and the dog were
completely lost. Then he notices these odd
looking flowers. “Wow, never seen those
before,” he says.

**Figure 25.** While composing chapter 3, Nick added a “weird” flower that he took during a science field trip in the fall. Texts in the red box were about the flower.

After visiting the botanic garden, Nick shared with the class what he found, “I was attracted by this flower (Figure 25) and it looks so weird. It could be a part of our story. In our story, dogs are mutated. This kind of weird flower could also be mutated from other plants” (video recordings). In later sessions, he added the flower in the story and wrote associated narratives (Figure 25). As shown in this example, inspired by the “weird” shape of a flower, Nick integrated the idea of plant mutation in the story writing together with a picture he took.

**Collaborative composing.** Nick learned to compose collaboratively in the group. He was the only one in the team who preferred teamwork, “I do care whether I am working in a group or not because I like working with others” (pre-survey). In contrast,
both Alex and Brandon “disagreed” that they preferred working with others throughout the project. The team set goals and assigned responsibilities together during the summer. During the fall extension, most of the time, Alex and Brandon worked silently, while Nick checked what others were doing by leaning body toward them (Figure 26) and he also provided support when needed. Nicked helped Alex, the scientist, design visuals for science animations and assisted with editing textual narratives from Brandon, the writer.

Figure 26. Nick checked Alex’s screen by leaning body.

Recognition. Nick was aware of his role changing over time. As he explained in the interview, besides taking the role of designer, he also tried out other roles.

I started off with (trying out) the scientist role, but then I changed roles in the second or third session. I became a writer. In the beginning, I didn't do most of the writing, I mostly just edited. He (the writer) mostly wrote and came up with the ideas for the writing. As for being a designer, I created some scenes and things. (final interview)

He also stressed that he wrote his own ideas in the story in addition to assisting in editing existing ideas while taking the role of writer. His awareness of role changing was associated with the fact that he regarded role taking as a way of participating in different disciplinary practices.
Team members recognized that Nick took the role of writer in the project. The following excerpt demonstrated that Nick was recognized by Brandon, the writer, as being a writer in the team.

Excerpt 1
[Final interview]
Researcher: So, initially you tried out writer?
Nick: I tried being a scientist, but then I found out that was actually a lot better at being a writer.
Brandon: And then we shared the role.
Nick: Of writing.
Researcher: Can you say a bit more, when you shared this role? What does that mean?
Brandon: We both work in the role of writing.

Brandon’s recognition of Nick’s writer role might foster mutual trust between these two so that they were comfortable with developing the story narratives together. The mutual trust was reflected in the interview. Both Brandon and Nick proposed to add a function in the iKOS system that would allow users to write together without restrictions, “there can be a higher rank that would allow someone to write without someone having to approve them. But there could also be a rank that your writing also has to be approved” (final interview). In the current system, co-authors needed to be approved by the main author after making changes.

Degree of participation

In Nick’s case, the breadth of participation increased mainly in developing textual narratives while the depth of participation was reflected in supporting team members as a contributor, reading entries as an audience, and gradually proposing new ideas as an originator.

Supporting team members as a contributor throughout the project. As a collaborative contributor, Nick designed one background drawing for Alex’s science
animations in Scratch and one Pixton comic to visualize story narratives from Brandon. Alex, the scientist in the team, described, “I sometimes used to create characters that he (Nick) sent online and then I also used some of his backgrounds and then I started making some of the images” (final interview). In addition, Nick embedded one of Alex’s animations in iKOS. Although he did not create the animation, he constantly justified the location and size of animations in iKOS. Nick also visualized Brandon’s writings with comics. For instance, after reading Brandon’s textual narratives (i.e., “once they were done building the shelter, they decided they should make some weapons.”), he created a comic (Figure 27) in Pixton and embedded it in iKOS. He supported group members as a contributor when needed.

Figure 27. Nick created a comic panel to visualize Brandon’s texts.

**Reading entries as an audience in the fall.** In addition to participating in design practices in Scratch and Pixton, Nick also viewed entries in iKOS as an audience. Specifically, he viewed their own and other teams’ entries 95 times as an audience. As shown in Figure 28, the entry-viewing frequency was highest on December 17, 2017. On that day, in addition to viewing their team’s entries, he frequently opened different students’ entries to read what others created in iKOS. In contrast, Alex, the scientist, did
not view any of their own team and other teams’ entries in iKOS while Brandon, the
writer, worked more on editing instead of viewing their own entries and only opened
other teams’ entries once in November. It suggested that Nick cared about peer generated
artifacts both within and beyond his team.

![Figure 28](image)

*Figure 28.* Nick’s iKOS entry viewing activities over time. The area of bubbles
represents the number of viewing times. Yellow represents the team’s own entries and
green represents others’ entries.

**Proposing new ideas as an originator in the fall.** As an originator, Nick edited
visual artifacts, including one photo and two comics in iKOS in the fall. As described
before, he took a photo of a flower and implemented it in the story as an originator. Also,
Nick ended up with visualizing his own narratives with comics as an originator. As an
example, Nick added a comic showing his own character fighting a monster in chapter
two. Chapter 2 was about Alex’s character built the shelter for the three survivors to live
in. To make his character visible in the chapter, he added a new story plot in which his
own character had more actions. As shown in Figure 29, he added the following sentence:
“while Luke was building the shelter, Nathan managed to find a pickaxe that he used to
fight a monster...whether we like it or not.” After that, he created a comic in Pixton to
visualize the writing and embedded it in chapter 2.
Figure 29. Screenshot of Chapter 2 in which Nick visualized his own textual narratives with one-panel comic.

Besides adding visuals, Nick edited texts as a critic, contributor, and originator. In total, he added new ideas in 46 sentences (examples in Table 19), and revised ideas in 15 sentences and deleted 9 sentences.

Table 19

Examples of edits in iKOS

<table>
<thead>
<tr>
<th>Depth</th>
<th>Action</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Originator</td>
<td>Generate</td>
<td>Introduce new ideas in new sentences</td>
<td>Introduce a new story plot by adding a new sentence: “He used to fight a monster that he also managed to encounter.”</td>
</tr>
<tr>
<td>Contributor/Critic</td>
<td>Rewrite</td>
<td>Correct or rephrase sentences for grammatical errors</td>
<td>In a sentence, change “there” to “There.”</td>
</tr>
<tr>
<td>Contributor/Critic</td>
<td>Revise</td>
<td>Add related idea and/or delete minor ideas to existing text to revise ideas</td>
<td>In a sentence, change “a way to get oxygen from water” to “a machine that extracted oxygen from water.”</td>
</tr>
<tr>
<td>Contributor/Critic</td>
<td>Remove</td>
<td>Delete texts permanently</td>
<td>Delete the following sentence: “Things like wood, steel, stone.”</td>
</tr>
</tbody>
</table>
He gradually became an originator who frequently added new ideas in iKOS (Figure 30). The group story included three entries. He originated two major story plots in the first two entries and one minor story plot in the third entry. Nathan, one of the three characters in the story, was the main character in the two major storylines that Nick wrote.

Figure 30. Nick’s iKOS entry text editing activities over time. The area of bubbles represents the number of sentences. Red represents originator and yellow represents contributor/critic.

As described above, Nick not only contributed to and evaluated others’ ideas but also generated new ideas and substantively contributed to the development of their group story. Brandon’s interview responses further evidenced that Nick originated various story ideas and contributed a lot to the development of the team story. Brandon, the writer, described how he and Nick worked in iKOS:

First, we always talked about what will happen next, and then just started adding some implements, like he added the dog (story plot) and then I added other ideas. We had a form of food and some of them mutated. And then Nathan added some ideas, and also edited some of my ideas to make sure that they were implemented well in the story. (Final interview)
Given most of his writings were composed from his own character’s perspective, being able to project himself into his own character in the story might motivate him to contribute substantially in writing story narratives. In this way, he gradually put himself in the position of writer and eventually wrote more than one-third of the story. Overall, Nick not only helped team members in developing existing narratives, but also contributed a lot in originating story ideas through writing.

**Discussion**

![Figure 31](image)

*Figure 31.* Nick’s participation patterns and trajectories. 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.

Figure 31 summarizes Nick’s participation in the STEM+L project. The x-axis is a representation of timeline and the y-axis shows the depth of participation. Nick extended his role of designer to the role of designer and writer. In this case, forms of participation changed in all of the 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.

Taking the role of designer as his primary form of participation, Nick’s interest in being a designer stayed positive. He mainly 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 portray of nuanced actions of characters in his comics and better integration between comic design and narratives, as well as incorporation of science concepts occasionally.

More interestingly, his attitudes toward the role of writer turned from negative to positive. This could be explained with the following reasons: 1) preferences in collaborative teamwork; 2) integrating different disciplinary knowledge and practices; 3) changes from peripheral to central contribution; 4) projecting himself in his own character in the story. First, his preference in working with and helping others enabled him to enter writing practices. 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., making comics) and writing (i.e., producing textual narratives) in multimodal composing enabled Nick to see more 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, overtime, Nick added original story narratives as a more central participant. Lastly, infusing himself in his own character in the story and being able to make himself visible in the team artifact might also contribute a more positive attitude towards taking the role of writer.

In addition, 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, he 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. The expansion also leads to a marked increase in the breadth of participation in writing. Nick developed much more textual narratives in the fall than summer.

Figure 32. The relationship between forms and degrees of participation.

This case reveals the mutual enhancement relationship between improvements in forms of participation and increases in degrees of participation (Figure 32). Nick recognized himself as a writer while helping Brandon to revise texts. The recognition, mediated by his team members’ trust in writing ability and his preference in teamwork,
led to the extension of the breadth of participation. The improvement in the breadth of participation further strengthens the recognition of taking the role of writer. Meanwhile, Nick developed a positive attitude in writing because the revisions gave him the confidence in writing. Furthermore, the stronger recognition and positive attitudes in writing, mediated by the space of projecting himself into characters in the story, enabled Nick to write his own ideas. Writing his own ideas increased both the breadth and depth of participation. In this case, we can clearly see the positive interaction between forms and degrees of participation.

In summary, Nick’s case demonstrates how role taking could be used a tool to extend his comfort zone of design and helped him develop a strong interest in writing and motivated 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.

The Case of Olivia: Strong Writer and Emerging Scientist

Olivia, a white female, was passionate about writing, took 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 is 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, and then he started an adventure in the dark. 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 based on Diego’s comics. To match Diego’s comics, she always asked Diego questions, including specific questions about character names and more general questions about the story plot.

In the fall, because Diego and Bing didn’t return to the program, Olivia 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, she composed a fiction about a female middle schooler who wrote a story to describe her adventure in a new planet (Table 13). Compared to the summer, she was more active in developing the new story and provided Alyssa design ideas to make the story more attractive. The pair ended up with creating a story with three chapters (1787 words in total), two images, and four animations.

Olivia had a strong interest in writing and only wanted to be a writer in the team in the beginning. In the fall, she recognized that she also took the role of scientist. She worked more as a contributor and audience in writing while composing the first story. Realizing the connection between writing and science, Olivia incorporated science about space into story narratives in the second story. While composing the second story, she actively participated in diverse disciplinary practices, including design, science, and writing. These changing trajectories, with illustrative examples, will be described and discussed in the following sections.

**Form of Participation: Role Taking**

Olivia’s form of participation in terms of role taking was manifested in various aspects including consistent high interest in the role of writer, more positive attitudes toward the role of scientist, wavering attitudes toward the role of designer, and
demonstration of improvement in integrating science and design in textural narratives. Each of these aspects will be described and discussed in the following.

**Interests and attitudes.** Overall, Olivia’s attitudes toward the role of writer stayed strongly positive (Figure 33). The persistent strong interest in writing could explain her strong preference in taking the role of writer throughout the project. In contrast, she developed a positive attitude toward taking the role of scientist and had a wavering attitude toward the role of designer (Figure 33). Although her interest in science decreased, she reported an increasing interest in being a scientist in the team. The wavering attitude towards taking the role of designer was reflected in her attitude changes in creating media and learning technology.

![Figure 33. Olivia’s pre-, mid-, and post-survey responses.](image)

Being confident and passionate in writing, Olivia strongly preferred to take the role of writer. As she explained in the pre-survey, “I prefer to take on a role that I know I will be good at, rather than something I have never done before.” She entered the project with a passion for writing:
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. I love to write stories about my experiences, and incorporate a lot of figurative languages. I like to write because it’s fun, and because I can express myself.

Writing is my favorite subject in school. (pre-survey)

The survey responses indicated that she was passionate in writing and regarded writing as a way to express herself.

She “strongly agreed” to be a writer in the team throughout the project (Figure 33). This was consistent with her persistently strong interest in writing. She was also consistent in reporting the preference of taking the role of writer and excelling in writing through role taking. In the pre-survey, she explained that taking the role of writer could strengthen her expertise in writing. Her attitude was the same in the mid-survey, “I like to have my own thing to responsible for and excel in that one thing.” In the final survey, she further explained, “one person takes on one rule it is easier for one person to excel in one specific thing.” Her preference in role taking further reflected the strong interest in writing and being a writer.

Realizing a clear link between writing and science, Olivia developed a more positive attitude towards the role of scientist. Initially, she was “undecided” to take the role of scientist because she felt more confident in taking the role of writer. In the pre-survey, she reported, “I am not really sure if I would want to be a scientist because I feel that I would be better in another job. I would really want to be a writer because I feel that I can express myself easiest and I love to write.” In the rest two surveys, she “agreed” to be a scientist in the team. The attitude change was probably due to being able to link
science with writing. On one hand, she saw that incorporating science into the writing process could contribute to her learning about science. As she expressed, “I would want to be a scientist because I enjoy learning about science while writing” (mid-survey). On the other hand, she witnessed a good example that the integration between science and story writing enriched the story. While nominating the best scientist in the project, Olivia replied:

I would say Alex and his group, because they presented us with a good scientific question that really gets our heads turning. ‘What would happen if the world stopped spinning.’ They also added really cool scientific elements into their story. (mid-survey)

In the final survey, she was proud to acknowledge that she was able to incorporate science into story narratives, “I was the writer in my group. I love to write. I also like incorporating science into my story! This makes the two, writing and science, go hand in hand. I love thinking about the mysteries of the universe.” She was also satisfied with her hybrid role, “I worked well as writer and scientist” (final survey).

In addition to a more positive attitude toward taking the role of scientist in the team, Olivia also put more emphasis on the science component of the future career. In the three surveys, she chose “undecided” when asked preference in pursuing STEM professions because she was not sure about future. However, she identified STEM careers that she might consider. In the pre-survey, she mentioned, “when I grow up, I am considering being an engineer or a doctor.” She expressed the interest of being a scientist or engineer in the mid-survey, “in the future I might want to be a scientist or an engineer.” In the end, she stressed the science component of the future career, “I really want to be an
engineer, because I love the science aspect, however, I do not love math” (final-survey). Over time, she identified that science was the reason she would want to be an engineer when considering future careers.

Although her interest in being a scientist in the team increased, she reported a decrease in interest in science because she had the preference in specific science topics. She “agreed” that she liked science in the pre-survey and pointed out that she liked to learn about space science:

I find sometimes in school when my science teacher didn't really bring science to life, and make it fun, I started to not like it. Although I didn't love my science class last year, I especially enjoy learning about space. (Pre-survey)

It suggested that Olivia had preferences in not only science topics, space, but also how science was taught. In the mid-survey, she emphasized again her preference in science topics, “I love learning about what other planets and life could be out there. I don't really like learning about rocks and stuff in science because it seems that all it is, is memorizing random rock names.” She specifically pointed out that she did not like to study science by memorizing facts. The final survey further indicated her interest in space science, “I do not like chemistry, because there are too many formulas to memorize. But I love learning about space and all the interesting and not mathematical related topics.” The second story that the team composed was related to space science. It made sense that Olivia became more interested in being a scientist in the project but reported a decrease interest in science. The project provided Olivia with the freedom to explore a science topic, space, that she was passionate about.
Olivia reported wavering attitudes toward taking the role of designer. She had very little experience in technology. While explaining the preference in role taking in the beginning, she responded, “I am not familiar with any of the multimedia websites, and I feel that I get confused easily. Therefore, I do not want to be a designer” (pre-survey). But the animation design activity during the summer changed Olivia’s attitude towards the role of designer at the end of the summer, “I rated being a designer as ‘agree’ because I enjoy making comics on Scratch” (mid-survey). During the summer camp, Olivia and Alyssa created a Scratch animation based on Olivia’s comic “Me in 20 Years” (Figure 34). In this activity, Olivia did not need to generate scripts in Scratch, which was done by Alyssa who was a strong Scratch user. Instead, Olivia was able to lead the voice recording of texts in speech bubbles that she wrote. This collaborative experience probably gave her more confidence in creating multimedia.

![Figure 34. Two sequenced comic panels in the comic titled “Me in 20 Years.”](image)

However, again she had a negative attitude towards the role of designer in the final survey, “I do not really enjoy designing and animating. It makes me feel frustrated and aggravated. I prefer doing other tasks besides designing.” The negative attitude toward being a designer in the end could be explained by a lack of practice with digital tools and confidence in media design. In the team, Alyssa had solid knowledge in creating animations in Scratch. Therefore, Olivia decided to focus on the writing aspect.
and did not continue to learn digital tools (e.g., Scratch) for visual design. She expressed anxiety several times about the possibility that she might need to design more media when Alyssa was absent. Lack of exposure to designing practices brought Olivia back to an uncomfortable situation in performing the role of designer.

**Knowledge and practices.** Accompanied with her strong performance in writing throughout, there was a substantial improvement in integrating science ideas and providing design ideas from the first story to the second one.

**Improvement in integrating science into story writing.** Table 20 summarizes the comparison of science component in the first and second story. Clearly, there was an improvement in integrating science into story writing. In the summer, Olivia mainly wrote the story narratives whereas Diego and Bing, the scientists, were in charge of the science component. They proposed to set the science background as solar eclipse stayed in a city for two years and the city was left darkness throughout. After that, Diego and Bing created comics separately. Guided by Diego’s comics, Olivia wrote 162 sentences. While composing this story, Olivia only wrote two sentences containing science words with low integration (Table 20). In addition to limited science components in writing, she barely engaged in discussing science ideas. Sometimes, she had discussions with teammates but these discussions were mainly on story plots.
A comparison of the science component in the first and second story. The level of science explanation shows students’ efforts in explaining science concepts to readers while the level of science integration indicates how well science concepts are integrated into the storyline.

<table>
<thead>
<tr>
<th>Time of composition</th>
<th>Title</th>
<th>Number of sentences</th>
<th>Number of science sentences</th>
<th>Level of Science explanation</th>
<th>Level of science integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>Darkness earth</td>
<td>106</td>
<td>2</td>
<td>1.0</td>
<td>1</td>
</tr>
<tr>
<td>Fall</td>
<td>Haluki Star</td>
<td>162</td>
<td>6</td>
<td>1.7</td>
<td>1.7</td>
</tr>
</tbody>
</table>

In contrast, Olivia wrote more science sentences with both higher level in science explanation and integration in the second story (Table 20). This story had six sentences (out of 162 sentences in total) containing science ideas. In addition to more science sentences in the artifact, she discussed science ideas with researchers and Alyssa.

The second story was inspired by a NASA news release about the discovery of a potential ninth planet. In October 2017, NASA issued a press release\(^1\) stating that the solar system might have a ninth planet. When Olivia came to a physical session in the same month, she discussed the news with one researcher:

Excerpt 2

[Group working on October 14, 2017]

(Olivia showed the researcher a NASA news release)

1 Researcher: Exactly. Like he said, for so many years, we know nothing (about it). And in recent years, we have evidence showing, even though we have not observed it directly. Maybe they have a system to block...

2 Olivia: Is it just a guess?

3 Researcher: It’s more than a guess. We have strong evidence, again, NASA announces that we have different pieces of evidence to show it. We are pretty sure about the existence of this planet. But we have not observed it, yet.

After about three minutes, Olivia explained to Alyssa a new story idea, “I am thinking that we can write something about a new planet. And you can create comics to show the new planet” (group working on October 14, 2017). After around two minutes, Olivia raised her hand and told the researcher the idea of creating a new story based on the ninth planet (See excerpt 3).

Excerpt 3
[Group working on October 14, 2017]
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 excited tone and gesture**): 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 revealed that the second story was driven by a science topic, the ninth planet, that Olivia was interested in.

Missing two scientists, Sarah stepped up to cover the science aspect because she initiated the science topic, a ninth planet. Although being encouraged to integrate what they wrote before into the second story, the pair tried to convince researchers the eager to compose a completely new story. Olivia expressed the passion in writing about a new planet “Haluki” while Alyssa explained that the first story was led by two boys. Together, they tried to convince researchers that they could create a new story in time because one was good at writing and the other was proficient in designing animations.

In addition, Olivia actively searched for science-related news or articles to support the portrait of the new planet while composing the second story. For instance, she brought
up the question of how residents in the new planet communicated with Lucy, the main character:

Excerpt 4
[Group working on October 14, 2017]
1 Olivia: How would Halukinumasanluka (residents in Haluki) talk with human?
2 Alyssa: What do you mean?
3 Olivia: Like, we speak English.
(Silence for 53 seconds)
4 Olivia: Will they understand English?
5 Alyssa: I am not sure.
(Silence for around 2 minutes)
6 Olivia: hmmm. (Pointing at her screen) Here, the science news says that some kind of math stuff predicted, extraterrestrial life forms could speak and understand English.

After reading the science news, she described that residents in new planet “Haluki” were intelligent and could understand English, but had their own language system (Figure 35). However, she needed more instructional support in evaluating the reliability and correctness of the science news.

Figure 35. Olivia explained (texts in the red box) the language system of residents in Haluki.
**Improvement in providing design ideas for story writing.** In addition to improved science elements, Oliva learned to provide design ideas. While writing the first story, Olivia always asked questions about story ideas for matching what she wrote with Diego’s comics. She barely proposed her own ideas during the summer. However, she was more active to discuss with team members in integrating design and story narratives while creating the second story. In the excerpt below, Olivia suggested Alyssa show the nine planets in animation design as a way to support the story context that she was writing.

**Excerpt 5**
[Group working on October 14, 2017]
1 Alyssa: Ok, what should I do on Scratch? (Olivia showed her writing to Alyssa)
2 Olivia: Right now, I am setting up the story context. You could show the position of the new planet in the solar system as a part of the context.
3 Alyssa (drawing circles with gesture): Like rotating in a circle? (Silence for around 5 seconds)
4 Olivia: Ok, yeah yeah yeah. Make all of the nine planets so that people can see the differences when comparing them.

Olivia also developed different views on the relationship between comic design and textual narratives. As illustrated in the following excerpt, Olivia proposed to create a comic to get the audience into the story.

**Excerpt 6**
[Group working on October 14, 2017]
1 Olivia (pointing at her screen): Can you make a comic on this?
(Alyssa read her writing.)
2 Olivia: Like here, where we described the character’s experience in one day. (Alyssa continued with reading her writing.)
3 Olivia: It does not (need) to be exactly the same. Just as a way to get people into the story. You know what I mean?
4 Alyssa: What do you mean?
Olivia: Like... (Operating the computer to try to find examples)
From her perspective, comics and narratives can show different aspects of a story and support each other in engaging the audience.

**Degree of Participation**

Despite the similar amount of effort, Olivia demonstrated two different patterns in the degree of participation when composing the two stories: She worked more as an audience and contributor while composing the first story, but worked more as an originator and contributor while composing the second one.

**Passive participation while composing the first story.** Olivia worked more as an audience and contributor and sometimes as a critic and originator while composing the first story. Most of the time, the group worked in the following sequence: Diego designing comics, Olivia summarizing Diego’s comics in the notebook (Figure 36), Olivia writing story narratives while looking at her notes (Figure 36), Bing designing comics while reading Olivia’s notes, Alyssa creating animations after consulting Olivia.

![Figure 36. Olivia took notes while looking at Diego’s comics (left). Olivia wrote the story while reading her notes (right).](image)

As an audience, Olivia asked Diego to show the comics again to understand story plots (See excerpt 7) when notes were not sufficient for story writing.

**Excerpt 7**

[Group working on August 10, 2017]

1 Olivia: Can I see the cartoon thing?
2 Diego: Yeah yeah.
Diego gave his computer to Olivia and showed her the comic.

3 Diego: Read it.

(After reading the comic in silence, Olivia gave the computer back to Diego. Then she continued with writing)

Olivia read the comic silently to understand it so that her writing would match the comic (Figure 37). After finishing one section of writing, Olivia asked Diego to read her writing to check whether she clearly described the story in the comic.

Figure 37. Olivia read Diego’s comic.

Olivia asked Diego questions constantly to understand the story. While running out of ideas, she stopped writing and asked, “I do not know what to add. What should happen next?” (group working on August 10, 2017) and “What supposed to happen after this?” (group working on August 11, 2017). This was very different from her reflection on her general writing practice - “I cannot stop writing and adding more and more details in the story” (pre-survey).

One researcher showed her how to continue with and enrich the story from the science aspect. But she was not excited about it. Olivia rarely expressed excitement while composing the first story.

Sometimes, Olivia critiqued the story plot when she thought that her writing made more sense. During group working on August 10, 2017, Olivia proposed that Bruce should fell to the ground as her writing (“I fell to the ground, and everything started to go wrong”), instead of lying on the bed (Figure 38) after being stroke by the lighting.
After getting familiar with the overall story plot, she tried to contribute ideas for story development. The excerpt below demonstrated that she was excited to describe the idea of extending the story plot happening in the hospital. However, her enthusiasm quickly dampened and her voice increasingly silenced after Diego added more details. It could be that Diego’s ideas were different from hers or she needed more time to digest Diego’s ideas.

Excerpt 8
[Group working on August 10, 2017]
1 Olivia (in excited tone): Ok. **While he was in the hospital, we can add another backstory.**
2 Diego: Yeah.
3 Olivia (in excited tone): Like he leaves the room and wanders around the hospital.
4 Diego: **And then he finds an archive room and finds the log file that records what happened in the past two years.**
5 Olivia (in plain tone): Ok.
6 Diego: Because he thinks that the doctor is hiding something.

**Active participation while composing the second story.** Although contributing much writing in both stories (1415 words and 1787 words in the first and second story respectively), Olivia’s participation in composing of the second story was much more active. She led the story development and originated most ideas. As described above, she proposed to change the whole story after discussing a science news release with the research team. While composing the second story, Olivia included more sentences containing science ideas (two sentences and six sentences in the first and second story
respectively) and provided design ideas, suggestions, and feedback throughout. In general, Olivia had the power to control the story development.

Olivia provided Alyssa with design ideas as a contributor. For example, she suggested Alyssa create comics to show some part of the story plot. Olivia also checked the progress of Alyssa’s design as an audience and critic (Figure 39). As shown in the following excerpt, Olivia asked clarifying questions to understand Alyssa’s animation and pointed out that Alyssa should identify the planet in the story.

![Figure 39. Olivia operated Alyssa’s computer to check what Alyssa created.](image)

**Excerpt 9**

[Group working on October 14, 2017]

1. Olivia (looking at Alyssa’s screen): What are those?
2. Alyssa: These are the planets.
3. Olivia (operating Alyssa’s computer): What are they? Where is the ninth planet? **We might need to identify the one in the story, or else it might be in a messy.**

Comparing the passive participation in developing the first story, Olivia was mainly an originator and contributor while composing the second story. Although there was no improvement in the breadth of participation in writing, she contributed more in integrating science into the textual narratives and engaging in discussions about design.
Figure 40. Olivia’s participation patterns and trajectories. 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.

Figure 40 summarizes Olivia’s participation in STEM+L practices. The x-axis represents a rough timeline while the y-axis displays the depth of participation. 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.

Olivia’s case reveals a significant change in the form of participation, from taking the role of writer to taking the hybrid role of both writer and scientist. Initially, Olivia only wanted to take the role of writer because of her passion and expertise in writing. Understanding the connection between writing and science and learning examples of the integration between the two practices 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). This change indicated that learning new things (e.g., new disciplinary practices that one is not confident with) may be better off with stemming from and being connected with knowledge and practices under one’s comfort zone.

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. Olivia led the second fiction while two male students led the first one. Being able to control the story development gave her the sense of ownership. It indicated that the cultivation of a sense of ownership would be helpful for increasing the degree (especially depth) of participation.

![Diagram of the interaction between self and the community, forms of participation, degrees of participation, and a sense of ownership of story.](image)

**Figure 41.** The relationship between forms and degrees of participation.

The case shows that the changes in forms of participation might not change the breadth of participation much, but had a large impact on the depth of participation (Figure 41). 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.

The Case of Saanvi: Conforming Designer and Proactive Writer

Saanvi, a fifth-grade Asian female was a designer and worked in a group with
three other sixth graders, including Valeria (Writer; Latina), Emilia (Scientist; Other),
and Mariana (Designer; Latina). The group created a multimodal science fiction titled
“Tsunami Terror” in which Crystal, Sara, and Keke, the three protagonists, saved people
from a tsunami that was triggered by Kai, the antagonist (Table 13). The four main
characters represented the four group members. While composing the fiction, Saanvi
initially worked as a designer, but ended up with taking all roles, especially designer and
writer.

In the summer, Saanvi had remained on the periphery of the group, participating
slightly in group discussions, but fulfilled her role of designer in spite of her silence and
apparent isolation on the outer stage. She searched for images of characters and made
comics with these images following Mariana’s suggestions. Saanvi became strongly
interested in taking the role of writer at the end of summer camp. In the early fall, she
tried to get access to writing while working on designing comics. After building trust
with Valeria, the writer, she had the opportunity to take the role of writer and put much
effort in both writing and designing in the late fall. In addition, other group members
trusted and valued Saanvi’s suggestions while constructing artifacts or running out of ideas towards the end of the project.

Because of her choice of Pixton and iKOS as the major composing tools and the rich group discussions, we mainly analyzed her comics, iKOS entries, and video (discourse) data. Saanvi’s participation patterns and trajectories, including illustrative examples, will be described in the following sections along with a discussion.

**Form of Participation: Role Taking**

Saanvi’s form of participation in terms of role taking was manifested in (a) more positive attitudes toward the role of designer and (especially) writer, and less interests in the role of scientist, and (b) improvements in comic design, expanding comics into developing textual narratives, and integrating voices narrations of science ideas into story writing. Each of these aspects will be described and discussed in the following.

**Interests and attitudes.** Over the course of the program, Saanvi developed a better understanding and clear preferences in the project roles. Specifically, she started with “undecided” to all of the three roles, but became most interested in being a writer, interested in being a designer, and not interested in being a scientist, according to the pre-/mid-surveys and the final interview (Figure 42; She missed the post-survey). This was consistent with her increasing interests in design, writing, and a decreasing interest in science.
In the beginning, Saanvi selected “undecided” for all the three roles in the pre-survey because, as she explained, “I don't get what to do for the roles. I don’t really like any of the choices. But (if) I have to pick one, I would pick the designer, I think?” (pre-survey). Obviously, she wasn’t clear on what the roles entailed and did not like any of the roles. Given that she was interested in creating media and learning technologies, the research team recommended the role of designer to her. She accepted and became the designer in the team.

After the summer camp, Saanvi became more interested in taking the role of designer. As she reported, “I like drawing and creating comics but sometimes doing animations is a little boring alone” (mid-survey). The response suggested that she had preferences in creating specific modes. Her interest in the role of designer stayed positive in the final interview. In addition, she used the tool for designer to finish in-school assignments, “I can use Pixton for doing things for fun, because one of my teachers said
we're going to get homework about what we learned, so I could use Pixton to help me...” (final interview).

Saanvi expressed an even stronger preference in taking the role of writer than the role of designer. While asked whether her role changed, she explained, “yes. because I didn't like what I was doing, it wasn't fun. But, when I saw Valeria (the writer) typing it looked fun” (mid-survey). She also reported the passion to take the role of writer on the last day of summer camp. Her strong preference to be the writer persisted in the fall. In the final interview, she commented that she “wanted to be an author” who “writes about something that does not really have to deal with the real world.” For her, writing was a way to express imagination and turn away from the real world.

In contrast to her positive change in the other two roles, she developed a more negative attitude towards taking the role of scientist. Although she did not explain the reasons in the surveys, she expressed a passion for fantasy writing and stressed the confliction between fantasy and science in the final interview. As she described, “If you’re supposed to have science while it’s also fantasy, so it’s hard to put them together” (final interview). The conflict between these two might lead to a negative attitude towards the role of scientist.

Although reporting a decreased interest in being a scientist and science, she developed interests in specific science topics. While responding to the question of interests in science in the pre-survey, she reported, “I don’t hate any subject because I think all subjects are important.” However, in the mid-survey, she described specific interested science topics, “I think all subjects of science are important, but some of them are boring. I like to learn more about animals and tsunami.” It is a clear example that
many students liked to learn about science topics that are relevant to themselves. In this case, animals and tsunami were the two main science topics in their team project.

Also, Saanvi saw more relevance in what she wanted to do with STEM careers. In the pre-survey, she “disagreed” that she would pursue a STEM profession. But she explained, “I want to be a vet when I grow up. I might become a math teacher.” Apparently, she didn’t identify these professions as STEM careers. However, she selected “agree” while answering the same question with the same explanation (“I want to be either a vet or a math teacher”) in the mid-survey. When asked about future professions, she replied, “I either want to be a veterinarian, a pet groomer, or a teacher because I like animals and want to learn more about them” (final interview). It suggested that she could connect her future career with STEM practices.

As for attitudes toward role taking in general, the conflict between her strong preference in working with others led to continuous negative attitudes toward role taking. She regarded having roles as the opposite of working with others in the pre-survey, “I like helping everyone, so I’ll do one job but help someone else. But when our group time is almost ending, I will work on the job they assigned me.” In the mid-survey, from her perspective, role taking restricted her access to practices beyond design, “sometimes I like to do other things and help.” In the final interview, she still had a negative attitude towards role taking with the following explanation:

Because I think that everybody can help out in other things instead of having a specific thing. What if they have an idea but since they're not that part, they wouldn't really write it. You could tell them, but it won't be like how they imagined it. (Final interview)
In general, she regarded role taking as restraining in helping others and reaching beyond design practices.

**Knowledge and practices.** Saanvi demonstrated a marked improvement in multiple areas related to her role as a designer and later a writer, including comic design, expanding comic design into developing textual narratives, extending voice narrations into story writing, integrating multiple modes with story writing when comparing her composition before and during late fall.

**Comic design: Improvement in thematic congruence within comic panels.**

Throughout the project, Saanvi learned to combine different online recourses that support thematic congruence in comic design. She used online photos, on average around 1.5 photos per comic panel, as backgrounds and characters in comics. The left design in Figure 43, being created in early fall, showed Kai, the antagonist, with online images of purple background and alpaca. The white background of alpaca caused a low thematic congruence between the alpaca and the purple space where alpaca transformed. However, her designs in the late fall, such as the right design in Figure 43, suggested a noticeable improvement in thematic congruence. In the right design, the background image and objects (e.g., the rope) perfectly portrayed the event when Kai, an alpaca, captured Crystal, a cheetah. Taking the role of designer, Saanvi had opportunities to participate in and sharpen design practices.
Figure 43. Low (left, created during early fall) and high (right, created during late fall) thematic congruence in comic design.

Comic design and writing: Expanding dialogue in comic design into story writing. Saanvi also learned to expand comics into developing textual narratives. During early fall, Saanvi’s major responsibility was designing comics in Pixton such as designing the scene when the four characters transformed into powerful creatures. There were no dialogues in comics created during the early fall. In contrast, her comics had more dialogues in the late fall. In addition, she developed textual narratives based on those dialogues. For instance, Saanvi designed a comic (Figure 44) in which Crystal, one of the three protagonists, proposed to investigate what Kai, the antagonist, was planning and she found out that Kai planned to trigger a tsunami. While Valeria, the writer in the team, stuck with moving the storyline forward, Saanvi proposed to write narratives based on the comic and developed the story plot when Crystal explained Kai’s tsunami plan in iKOS (Figure 45).
Figure 44. Dialogues in Saanvi’s comic design (created in the late fall). It describes the plot when Crystal heard Kai’s plan.

"Run!" exclaimed Crystal. But Sara had dropped her special enchanted bow, the one that helped her fly. Nevertheless, they ran away to their headquarters and closed all doors.

"Come here one second so I can tell you about Kai’s evil plan," Crystal whispered. She told them that the blue apaca was planning a tsunami that will be caused by her huge robot.

"Let me explain how a tsunami forms. Maybe that will help us," she explained.

"The robot will slam the bottom of the ocean floor with its fins. Which will cause the plates in the Earth to shift and cause a tsunami."

After that horrible news, Keke showed them something she has been working on for many years just for this kind of situation. "I have created this flower that—when Kai eats it—she will become good," Keke explained. Okay, let’s go! Keke said very excitedly. "Well, let's go? They hopped on their DJ drone and zoomed into hyperspace.

"Wait a minute! Where is my bow?" Sara exclaimed. "Now we’ve got two problems to solve," sighed Crystal. "Crystal, where are you taking us?" exclaimed Keke. "I am taking you to a secret passageway in the back,” said Crystal mysteriously.

Figure 45. Screenshot of story “Tsunami Terror.” It describes the plot when Crystal explained Kai’s plan.

The comic showed that Crystal went to Kai’s place and heard Kai’s plan while the writing described that Crystal explained Kai’s plan to others. The connection between the comic and textual narratives was the speech bubble from Kai in the comic. Clearly, Saanvi expanded story writings with dialogues in comics.

**Voice narration and writing: Expanding science explanation in voice narration into story writing.** During the summer, the group recorded two pieces of voice narrations,
including a screaming voice (around 2 seconds) recorded by Mariana and a science explanation voice (around 19 seconds; the script was written by Emilia, the scientist) recorded by Saanvi. In the early fall, Valeria proposed to use the recorded screaming voices to represent the following writing: “‘Ahhh!’ shrieked Crystal.” Inspired from Valeria’s incorporating story narratives with voice narrations, as shown in Figure 45, Saanvi extended the science explanation that she recorded before (around 42 seconds) and expanded it in textual narratives about how a tsunami forms in the late fall. She explained the rationale to include voice narrations:

    Fantasy is easier to do but with the science you have to have a little bit of equableness, like with science and fantasy, but in our story, it's more fantasy than science. Still, we tried to make it more scientific with explaining the tsunami part with voice. It feels more scientific. Readers can get more science information by listening to it. (final interview)

From her perspective, voice narration could expand the science component of a fiction and make the story more scientific.

**Multiple modes and writing: Integrating multiple modes with story writing.**

Saanvi learned to integrate multiple modes meaningfully in the late fall. Her initial understanding of multiple modes was doing one thing repeatedly. Later, she could connect modes in meaningful ways after Valeria, the writer, shared with the team the artifact that included multiple modes: texts describing the raining scene, an image showing a quiet city, and a piece of music representing raining (excerpt 10).
Figure 46. Screenshot of story “Tsunami Terror.”

Excerpt 10
[Group working on September 30, 2017]
1 Valeria: Look, look here.
2 Emilia: hum?
3 Valeria (clicked the music button in Figure 46): Can you feel it? It’s raining.
4 Saanvi: Where? I want to see it.
5 Valeria: Ok, one more.
   (Valeria played the music again)
6 Emilia: Yeah, also, also
7 Saanvi: Also, the picture is like a rainy day.
8 Emilia: True.
9 Saanvi: It feels so real. Raining in Riverdale, I mean peaceful Riverdale, before Kai started her evil plan, for sure.
10 Valeria: Yeah.

As shown in the excerpt, Saanvi could connect the picture, music, texts, as well as the story context while interpreting the artifact.

After understanding functions of integration of multiple modes, Saanvi participated in integrating multiple modes in writing when Valeria, the writer, was absent in the next session (October 14, 2017). To cover the writing aspect, Saanvi took the role of writer and added a new chapter describing the trio traced Kai’s moving from Austria to
San Francisco. She not only wrote the textual narratives (e.g., “here is all the way in the Pacific Ocean near San Francisco”), but also added a map (Figure 47) to show the path. When asked the rational to have a map, she explained, “It’s like a reference. Not everyone knows where Australia is, like me (video data).”

Figure 47. Saanvi searched for online images to represent the path from Austria to San Francisco.

The example showed that Saanvi understood why and how to include multiple modes in one place.

**Degree of Participation**

Saanvi demonstrated two different patterns in degrees of participation when comparing her composition before and during the late fall. Before the late fall, she worked more as an audience and contributor but in the late fall worked more as an originator and contributor. In addition, the breadth of participation increased in all disciplinary practices, especially in writing.

**Peripheral participation in the summer and early fall.** Saanvi started with designing comics as an audience and contributor. In the summer, she struggled with group work and was very quiet in group discussions. As a designer in the team, she used Pixton to design two comics by following Mariana’s ideas. Specifically, the comics
showed that the four characters transformed into powerful ones. The idea of transformation was proposed by Mariana during the summer. To fulfill her role of designer, Saanvi worked on the comics of transformation in the summer and early fall.

Besides creating comics, Saanvi commented on and rated others’ comics as an audience during the summer. Illustrating the same future career (i.e., vet) in her comic, she commented on Valeria’s comic titled *My Life in 20 Years*, “I like your creativity.” She also rated other students’ comics who used similar backgrounds in Pixton as hers. Overall, she interacted with those who showed a similar interest as her in Pixton during the summer.

In addition to using Pixton, Saanvi also tried to create animations as a contributor in Scratch. During the summer, she created a few animations but they did not work. This might result in a certain level of frustration and growing disappointment. She described in the final interview, “we didn't really use Scratch, mostly Pixton.” As mentioned before, she regarded creating animations as a “boring” practice. The preferences in using Pixton over Scratch to design visuals could be due to the fact that Scratch requires more technical skills in designing characters and making characters behave as expected.

Although disliking creating animations, she was excited about recording voice narrations in Scratch as a contributor. During the summer, Emilia, the scientist, proposed to record their own voices to explain how a tsunami formed after the team recorded a screaming voice for dialogues in the story. Saanvi volunteered to read the texts that summarized by Emilia and recorded her voices in Scratch with the help of one researcher. While recording the narrations, Saanvi revised and listened to her voice narrations multiple times to make sure that “it was perfect.”
Saanvi also viewed Emilia’s science entry as an audience. On the fourth day of summer camp, she rated Emilia’s science entry and applied to co-edit the entry. Specifically, she updated the entry twice during the summer without any revisions. During the fall, she opened the science entry twice in September and October respectively. Right after viewing the science entry, she edited the story narrative. She might want to incorporate Emilia’s science ideas in the story. As described by Emilia in the final interview, “I did the research (on the science topic), I made a little Wiki of it…and then we'd flip back on and it would help us with the story.”

**Central participation in the late fall.** Saanvi became an originator who contributed significantly to story writing in iKOS during the late fall. She was not always accepted by her teammates as an originator by default. During early fall (the second physical session in the fall), Saanvi had the chance to write the story while Valeria was absent. However, Valeria declined her changes to the story in iKOS after coming back in the next session and removed her from the co-author list (Figure 48). Therefore, Saanvi went back to design comics in Pixton. When Valeria ran out of story ideas, Saanvi proposed to write a story plot based on her comics. Although Valeria was controlling the story plot, Saanvi had the opportunity to write on Valeria’s computer as an originator. This indicated that Valeria began to trust and accept Saanvi’s story writing.

*Figure 48.* Saanvi’s update was declined and she was removed from the co-author list by Valeria.
Afterward, Valeria consistently asked Saanvi for ideas in moving the story forward. Being trusted by Valeria, Saanvi developed much more textual narratives than before. As shown in the following excerpt, Valeria and Saanvi co-developed the story narrative in Figure 49.

Excerpt 11
[Group working on December 02, 2017]
1 Valeria (turned to Saanvi): What should happen after they zoomed in hyperspace? What should happen next?
2 Saanvi (designed comics on her own screen): I actually typed a lot.
3 Valeria: Tell me. I can write here. Tell me what's your idea.
(Saanvi turned to Valeria's screen)
4 Saanvi: Ok. And then, (thinking) Mariana said, (thinking), Nonono, you say (thinking)
5 Valeria: Here. My bow was missing. Maybe I should notice it before we get into the DJI drone. Let's put that.
6 Saanvi: You say, "wait a minute! where is my bow?"
(Valeria typed what Saanvi said (Figure 50))
(Saanvi sit closer to Valeria and then started to type on Valeria's computer. Meanwhile, Valeria was watching her typing (Figure 50))
7 Valeria: Wait, leave a space here.
(Valeria worked on her computer while Saanvi was watching her typing)
(Then they both left the computer and talked about what should happen next)
8 Saanvi: Then I can say, I have a secret way to get to Kai's place.
9 Valeria: And I can say, how do you know it.
(Valeria worked on her computer while Saanvi was watching her typing)
(After around 2 seconds, Saanvi typed on Valeria's computer while Valeria was watching her typing)
10 Valeria: Now we got two problems to solve, right?
11 Saanvi: Yeah.
12 Saanvi (stopped typing): Do you want me to be evil?
13 Emilia: You want to?
14 Saanvi: I do not care.
15 Valeria: So, you turned evil?
16 Saanvi: Yeah.
Figure 49. Valeria and Saanvi co-developed the narratives in the red box.

The excerpt suggested that both Valeria and Saanvi originated ideas while writing the story together. While writing the story, Saanvi and Valeria projected themselves in the story. As shown with bold texts in the expert, they discussed from their own positions (e.g., “we”, “I”, “you”) instead of characters’ positions. In addition, Saanvi proposed ideas both from her perspective (e.g., “I can say”) and other team members’ perspective (e.g., “you say”). She intended to show team members and group interactions in the story. This is also obvious in her writing. For instance, she wrote, “‘well, let’s go!’ yelled Mariana who was always ready to take action.” Her portrayal of Mariana was consistent with Mariana’s personality in group working. This indicated that the reason for her growing passion for writing might be that she was able to project herself, infuse group members, and portray group interactions in the story.
Figure 50. Valeria worked on her computer while Saanvi was watching her typing (left). Saanvi typed on Valeria's computer while Valeria was watching her typing (right).

Being trusted by others as the one who could move the story plot forward, not only Valeria, other group members also asked Saanvi for suggestions. Since each of them represented one animal in the story, they would ask each other for suggestions when the writing or design was related to the animal. For instance, Mariana asked Saanvi for suggestions when designing the book cover on December 02, 2017 (Figure 51), such as “what about this one (an image of Saanvi’s character), Saanvi?” “don’t you think you (Saanvi’s character) look too colorful on the cover?” “do you want this one (an image of Saanvi’s character)?” In these conversations, Saanvi worked more as a critic. While interacting with Emilia, she worked more as an originator. For instance, Emilia asked Saanvi for suggestions on the science aspect on the same day (Figure 51), such as “Saanvi, what other science information do you need?” “what should I do?” “which part could have more science, Saanvi?” In general, the group tended to ask for suggestions from Saanvi.

Figure 51. Saanvi responded to Mariana’s question in design (left) and Emilia asked Saanvi’s suggestions in science (right) on December 02, 2017.
Discussion

Figure 52. Saanvi’s participation patterns and trajectories. 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.

Figure 52 summarizes Saanvi’s participation in the STEM+L project. The x-axis denotes a rough timeline while the y-axis refers to the depth of participation. In this case, Saanvi had improvements in all the forms of participation and increases in both the breadth and depth of participation.

In terms of forms of participation, Saanvi’s role changed from taking the role of designer to taking all the three roles. In the summer, she took the role of designer and contributed in designing comics. Inspired by writing themselves into the story, she became interested in the role of writer. Therefore, in the fall, she took the role of writer and made substantial contributions in developing textual narratives. Gradually, she
became an idea provider for group members and ended up with taking all the three roles when needed.

Saanvi’s 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., comics), Saanvi became interested in taking the role of designer. It suggested that flexibilities in choosing modes could help developing interests in design. 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 in 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 in 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. However, she created more artifacts in multiple modes (e.g., comics, textual narratives, and voice narrations) across disciplines and 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. 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 originating 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 was not accepted in the artifact until Valerie trusted and valued her writings. 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. For instance, Mariana, the other designer, asked for her opinions on design, especially when the design was related to Saanvi’s character. Also, Emilia would ask her for science topics that could be used to enrich the story. Clearly, group members trusted and valued her ideas during composing in different practices, including design, science, and writing. Comparing to the apparent silence in group discussions in the summer, Saanvi was open to providing feedback as an originator, contributor, and critic in all disciplinary practices in the fall.
Figure 53. The relationship between forms and degrees of participation.

As depicted in Saanvi’s case, changes in the form of participation lead to changes in both the breadth and depth of participation (Figure 53). Her inspirations of changing from the role of designer to the role of writer were showing herself, group members, and group interactions in writing. Once having opportunities in taking the role of writer, she generated more ideas and artifacts in all disciplinary practices, especially design and writing. 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 flexibilities 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.

In summary, Saanvi started as a quiet, passive participant who did not know in what roles to contribute, but eventually ended up with being a confident designer and writer who worked across multiple disciplinary domains, and an active team member others trusted and sought help.
Chapter Five

Discussion

In this chapter, I discuss the significance of multiple case findings in relation to research literature on adolescents’ participation in integrated STEM learning environments. I also highlighted the implications of these findings for practice and research.

This qualitative study closely examined adolescents’ participation patterns and trajectories in the STEM+L project. This study was designed to shed new light on the complexity and dynamism of changes in forms and degrees of participation. Multiple case study methods (Stake, 2006) were employed to closely follow the participation journeys of four cases as they created multimodal science fictions in small groups.

The research questions guiding this study were the following:

- What are the notable patterns and trajectories of students’ forms of participation in STEM+L practices through disciplinary role taking?
- What are the notable patterns and trajectories of students’ degrees of participation in STEM+L practices in terms of breadth and depth of participation?
- What is the relationship between students’ forms of participation and degrees of participation?
Contributions to Understanding Participation in Integrated STEM+L Practices

This study integrated the perspective of disciplinary identity development and community of practice to examine students’ participation from two dimensions: the form and the degree of participation. We presented the form and degree of participation of four cases at a fine-grained description. When comparing and contrasting these cases, commonalities and variations are revealed that have implications for advancing our understanding of adolescents’ participation patterns and trajectories as they created multimodal science fictions in small groups.

Form of Participation

In accord with prior studies, in an integrated STEM program, students may change attitudes toward disciplinary practices and related careers (e.g., Bouillion & Gomez, 2001; Everman, 2016; Nixon & Akerson, 2004), demonstrate improvements in sectoral disciplinary knowledge and practices (e.g., Bradbury; 2014; Fang et al, 2008; Hurley, 2001; Judson & Sawada, 2000; Nixon & Akerson, 2004; Ritchie, Tomas, & Tones, 2011), and recognize themselves or be recognized by others as disciplinary persons (e.g., Allen & Eisenhart, 2017; Pinkard et al, 2017; Stevens, 2000; Zimmerman, 2012). All of these echoed changes in forms of participation in our study.

As depicted in a comparison of attitudes toward the three roles in the surveys and described in student interviews and reflections, there was a great deal of variation in attitude changes.

- Steve’s attitudes toward the three roles stayed relatively constant. He, taking the role of designer, had positive attitudes toward the role of designer and scientist and negative attitudes toward the role of writer throughout the project.
Different from Steve’s stable attitudes, Nick, the designer in the team, became more interested in the role of designer and (especially) writer while holding neutral attitudes toward the role of scientist.

Exhibiting a less consistent attitude changes, Olivia, who was highly passionate about writing and taking the role of writer in the project, had wavering attitudes toward the role of designer and became more interested in the role of scientist.

Saanvi, the designer in the team starting with neutral attitudes toward the three roles, developed strong interests in both the role of designer and (especially) writer and a negative attitude towards the role of scientist.

The four cases showed three main themes in the change of attitudes and interests in disciplinary roles and associated practices: 1) constant positive or negative, 2) more positive attitudes, 3) differentiated attitudes and interests. Steve’s case represented most students who did not change attitudes in our project. To sustain a change in an individual's attitude is not easy and is bound to take time. But significant attitude changes occurred in some cases. Nick and Olivia represent those who developed more positive attitudes towards roles that they felt less comfortable with in the beginning. In contrast, Saanvi represented those who developed increasingly differentiated attitudes.

The four cases were similar in that they chose roles that fell into their practice comfort zones. In the pre-survey, students took roles that they were confident in performing corresponding practices, regardless of disciplinary interests.

Among the three disciplinary practices (i.e., design, science, and writing), Nick had a much stronger interest in science than the other two. However, he
chose to be a designer in the team because of the high confidence in designing how things look.

- Similarly, Steve selected the role of designer despite a strong interest in science because he was an expert in creating media and learning technology.
- Resembling Nick and Steve’s case, in addition to being highly interested in writing, Olivia emphasized her writing expertise while explaining why she chose to be a writer.
- Although Saanvi was not sure about which role to take, she preferred to take the role of designer since she could learn technologies easily.

Overall, the factor of being able to perform specific disciplinary practices was the main rationale for selecting specific roles in the beginning.

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. Olivia became interested in incorporating science into writing after she was able to incorporate her favorite science topic and witnessed a good example of enriching writing with science ideas. Different from Olivia’s case, Nick developed strong interests in writing after linking textual narratives with comics. Similarly, Saanvi had positive attitudes toward writing while understanding how and why to combine textual narratives with visual and audio designs. Steve learned to represent science ideas with multiple modes within comic designs. The cases reveal that students needed to see connections between disciplinary practices to move beyond practice comfort zone.
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. As evident in the findings, the four cases could integrate different disciplinary practice in multimodal artifacts. In addition, some of them were aware of the integration and changed strategies to integrate different disciplinary knowledge efficiently. Initially, Saanvi regarded the integration as repeating information. Later, she recorded voice narrations to add science components to the group story. In this way, she intended not to break textual narratives but still provided the audience with sufficient science knowledge to understand the narratives. Resembling Saanvi’s initial impression about repeating information, Olivia represented comics with the same information in texts. Her perception of how to connect design and writing changed. She clearly pointed out that one should be complementary to the other in an efficient way. In Nick’s case, he learned to visualize specific writings to show key events. Different from the other three cases, Steve integrated science and design in comics. He learned to represent science ideas with a combination of texts and pictures while designing comics. Clearly, we can see that the four cases developed knowledge and skills in integrating different disciplinary knowledge and practices.

Degree of Participation

Most research has portrayed that participation could reach multiple degrees (e.g., Denault & Poulin, 2009; Handley et al., 2006; Janssen, Erkens, & Kirschner; 2011; Janssen et al, 2007; Preece, 2001; Prinsen, Volman, & Terwel, 2007; Weinberger & Fischer, 2006; Zheng & Warschauer, 2015). In addition, scholars emphasized that learners should be encouraged to become producers and not simple observers and
consumers of knowledge produced by a community (Engle & Conant, 2002; Roth, 1995; Scardamalia & Bereiter, 1994). However, this study adds to the research demonstrating how students changed from consuming ideas to producing ideas.

While the four cases exhibited the different breadth of participation across the program, all of them showed evidence in changing from more peripheral to more central participation - from consumers to producers. Steve displayed a change from being a contributor to an originator in designing comics. He started with creating comics by following Pi’s ideas but later his comics showed complementary but sometimes conflictual ideas. In addition, he became more active in interacting with others through commenting on others’ comics in Pixton. Resembling Steve’s changes in the degree of participation, but in different modes, Nick presented a change from contributing ideas in comics to originating ideas in both comics and texts. Different from Steve’s and Nick’s cases, Olivia changed from being a major contributor in writing to a very active originator in both writing and science. Saanvi became both a contributor and originator in all aspects. All four cases ended up with originating ideas, but the stimuli that triggered their changes were different. The following section discusses factors that contributed to these changes.

Factors that contributed to changes in forms and degrees of participation

The study contributed to our current understanding of participation to demonstrate factors that triggered or contributed to changes in forms of participation and moved students from more peripheral to more central participation. Through examining the nuances in these four cases, it becomes clear that students’ forms and degrees of participation changed due to the following factors: 1) Reflective understanding of the
nature of (inter) disciplinary practices and roles; 2) Exposure and experience in composing in multiple modality; 3) The interaction between self and the community; 4) The relation between self and artifacts.

**Reflective understanding of the nature of (inter) disciplinary practices and roles.** The four cases illustrate various reflective understandings of 1) connections between different disciplinary practices; 2) functions of role taking; 3) disciplinary knowledge and practices.

**Reflective understanding of connections between different disciplinary practices.** The cases were similar in that they changed attitudes after understanding connections between practices, especially those within their practice comfort zones and other disciplinary practices. Nick’s attitudes toward the role of writer changed from negative to positive because he could integrate comic designs into story writing. Specifically, he used comics to visualize key events in the textual narratives. Similarly, Olivia became interested in the role of scientist after Nick’s group presented a story in which science made the story narratives rich and attractive. Saanvi also developed a strong interest in the role of writer and writing. But the way that she connected comic designs with story writing was different from Nick. In her case, textual narratives and comics were usually complementary to each other. On the contrary, Steve might not be aware of the connections, thus, his attitudes toward the three roles stayed stable. As evidenced in these cases, understandings of connections between disciplinary practices had the power to change forms of participation.

In addition, the four cases became more central participants while connecting different disciplinary knowledge and practices. Although Olivia did not design any
visuals, she originated ideas in design so that Alyssa’s designs could connect with her writing, such as using designs to visualize the environmental context for writing. Conversely, Saanvi originated ideas in writing so that her designs were connected with textual narratives. Different from Olivia’s and Saanvi’s cases, Steve originated science ideas in comics to present science ideas with multiple modes. Nick also proposed new ideas for the purpose of integration. For instance, he was attracted by a “weird” flower and aspired to use it in their story. To integrate the design in the writing, he proposed that the “weird” plant could be mutated from normal plants. Even though having experienced different ways to integrate disciplinary knowledge, the four cases displayed a similar pattern of originating ideas while moving across different disciplinary knowledge and practices.

Reflective understanding of functions of role taking. Although all cases had positive attitudes toward the roles that they took in the project, they had different perceptions about role taking. Steve and Saanvi viewed role taking as a rule one had to follow. They reported that there was a conflict between role taking and collaboration. From their perspectives, role taking restricted them to reach beyond roles that they chose and assist team members. However, they had totally different experiences in teamwork. The writer in the team denied incorporating Steve’s ideas and comics in the group artifact. This might further lead to negative attitudes toward role taking and the role of writer. The fact that Saanvi’s team members were willing to offer ideas on the floor and affirm each other indicated a supportive group context. Sometimes, Saanvi’s team did not pay attention to roles and they helped each other in any aspects when needed. Thus, although
disliking role taking, Saanvi’s attitudes toward the role of designer and writer became more positive.

On the contrary, Nick was inclined to use role taking as a vehicle to try out disciplinary practices beyond his design comfort zone. Besides taking the role of designer, he tried out the role of scientist, but did not continue with it because Alex expressed strong expertise in explaining science ideas. Thus, his attitudes toward the role of scientist stayed neutral. His preference in working with others opened a space for him to practice writing through revising textual narratives for Brandon. Nick linked the revising action with taking the role of writer. Recognizing his role of writer, he ended up with not only revising texts, but also developing textual narratives. As a result, his attitudes toward the role of writer changed from negative to positive.

Different from the three cases, Olivia regarded role taking as a way to show and gain expertise in one thing rather than doing fairly average in many things. She was passionate about taking the role of writer and showed strong expertise in writing throughout the project. Role taking enabled her to focus on one thing, knew what to do, and perform responsibilities efficiently. Consequently, her attitudes toward the role of writer stayed highly positive. These cases demonstrate that perceived functions of role taking could influence changes in the form of participation.

Although their understandings of role taking were different, the four cases all started with fulfilling responsibilities in their selected roles as more peripheral participants and ended up with producing ideas as more central participants in selected roles. Steve and Saanvi, viewing role taking as a rule, performed design practices diligently and later proposed their own ideas in comic design. Despite the perceived
function of trying out different things with role taking, Nick created visuals to fulfill his role of designer and gradually added his own ideas in visuals. Regarding role taking as a way to excel in writing and carry out responsibilities efficiently, Olivia developed textual narratives and eventually originated ideas in writing. These cases reveal that role taking ensured that each individual case clearly defined their own responsibilities and becoming comfortable with producing ideas in the roles.

**Reflective understanding of disciplinary knowledge and practices.** The four cases also had different perceptions of writing, science, and design. Due to the perception of writing as a “typing” activity, Steve took writing as a boring practice and did not want to be a writer. His “typing” perception of writing did not change, thus, his attitudes toward the role of writer stayed negative and his participation in writing stayed at a peripheral stage. Saanvi also viewed writing as typing, but she strongly liked to be a writer and was eager to develop textual narratives. Being able to infuse herself and group members into characters in the story affected her perception of writing. She regarded writing as a way to form a virtual and social world with their own characters. In the story, she showed how the four characters, having similar personalities as themselves, formed a world and interacted with each other. Therefore, her attitudes toward the role of writer became more positive and she became a more central participant in writing. Resembling Saanvi’s group of infusing themselves into stories through characters, Nick’s group also wrote themselves into the story. Nick’s more positive attitudes toward writing and the role of writer as well as more central participation in writing could be due to the desire to express himself through his own character. Different from the other three cases, Olivia used writing as a way to expand her curiosity and imagination of life in outer space.
As for perceptions of science, Olivia viewed science activities in school as “memorizing facts.” Therefore, she was not sure whether she liked the role of scientist or not. But her attitudes toward the role of scientist became more positive due to a change in her perception of science in our project. For her, science in our project was more than just “memorizing facts”, but was exploring and unfolding unknown things (e.g., outer space). This perception of science also motivated her to produce more science ideas in the second story. In contrast, Saanvi developed a negative attitude towards the role of scientist and stayed at a peripheral stage in science because she saw conflicts between fantasy (her interest) and science.

When it comes to perceptions of design, from Olivia’s perspective, one needed to be familiar with digital tools to be a designer. Therefore, although understanding the connection between design and writing, she reported a negative attitude towards the role of designer in the end and rarely involved in creating visuals. On the contrary, Steve had positive attitudes toward the role of designer because of his perception of design as an “abstract” practice. Meanwhile, he proposed his own ideas and became a central participant in design. These cases reveal that changes in perceptions of disciplinary knowledge and practices could lead to changes in the form and degree of participation.

**Exposure and experience in composing in multiple modality.** In our project, students had flexibilities in composing in their preferred modalities. Modal affordances sustained positive attitudes in their selected roles and facilitated developing more positive attitudes while students moved across modalities. For example, Nick became more positive in the role of designer and his attitudes toward the role of writer changed from negative to positive while connecting and moving across visuals and texts. In addition,
modal affordances helped the cases to move to more central participation. For instance, Saanvi designed comics as a contributor, but provided new ideas in developing textual narratives based on comics. This study suggests that flexibilities in composing preferred modalities and moving across modalities served as a vehicle for the four cases to change forms and degrees of participation.

**The interaction between self and the community.** The cases experienced totally different interactions with peers inside and outside of their groups. Steve strongly liked to work with others while his team members preferred working alone. The very limited physical interactions drove Steve to interact with the whole class in the online design space. He had positive attitudes toward design and became a central participant in the online space. Similarly, Nick had strong preferences in teamwork. Although regarding working alone as a more efficient way, Nick’s group members trusted and valued Nick’s contributions. In this way, taking the role of designer, he had the chance to practice writing while helping team members. Eventually, he became interested in the role of writer and move to a more central stage in writing. In contrast, all members in Saanvi’s group preferred working with others and were very supportive to each other. The supportive group context led to Saanvi’s participation in all disciplinary practices. Different from the three cases, although tending to work alone, Olivia contributed in developing textual narratives all the time. Missing two male scientists in the fall changed the group composition. It offered Olivia the opportunity to step up to cover the role of scientist and foster interest and contribute ideas in the role. In general, the interaction between self and the community had impacts on both the form and degree of participation.
The relation between self and artifacts. The four cases made connections between themselves and artifacts in the format of ownership and projecting themselves in the story.

A sense of ownership of the story. Firstly, a sense of owning the story could motivate the four cases to change from peripheral participation to central participation. As made evident in Olivia’s case, she became much more active in proposing new ideas while composing a new story. She had the ownership of the new story because the story was not just from the two male students anymore. Nick’s caring for team projects established a sense of ownership. Thus, he was active in developing the story. As he proposed more and more ideas, his ownership might be stronger and it led to continuous contributions. In Saanvi’s case, the fact that her character was in the story might lead to a sense of ownership. In addition, she was passionate about presenting her group members and group interactions in the story. Although having negative experiences in interacting with team members, Steve tried to propose new ideas because he saw himself as a curator of the team project. Eventually, he added his own ideas in comics. With different ways to build ownership, the four cases were stimulated to originate ideas.

Projecting oneself and presenting group interactions in the story. Nick and Saanvi became more central participants after projecting themselves and showing group interactions in the story. Nick attempted to originate ideas after revising Brandon’s writing. He developed more than one-third section of their story narratives most of which was written from his character’s perspective. In Saanvi’s case, she also wrote from her character’s perspective while originating ideas in writing. In addition, both Nick and Saanvi created artifacts to show group interactions. However, most of Nick’s artifacts
were composed from his character’s perspective while Saanvi’s compositions had more balanced perspectives. The two cases demonstrate that having the opportunity to project oneself and present group interactions could change the depth of participation.

**The Relationship between the Form and Degree of Participation**

We 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. To our knowledge, there is a rare study in connecting these two aspects in the context of STEM education.

![Figure 54. The relationship between the form and degree of participation.](image)

As made evident in the cases, positive attitudes toward disciplinary practices could lead to improvements in both the breadth and depth of participation (Figure 54). Projecting oneself or others into artifacts was the main factor behind this relationship. For example, Saanvi developed more textual narratives after becoming interested in the role of writer and writing. Her interests in writing were triggered by the desire to write about herself and group members in the story. In addition, she added her own ideas while developing textual narratives. Projecting himself into the story through writing, Nick changed from being a contributor to being an originator in writing after expressing a
positive attitude towards writing. This suggests that changes in attitudes toward disciplinary practices had an impact on changes in degrees of participation.

The cases reveal that more breadth of participation, mediated by the factor of composing with multiple modes, and extended depth of participation, mediated by the factor of a sense of ownership, could lead to positive attitudes toward disciplinary practices (Figure 54). For instance, Nick became interested in writing after participated in revising Brandon’s textual narratives. He integrated his own comics with texts in revisions and learned how to connect these two to make coherent multimodal artifacts. Olivia became a more central participant in proposing science ideas while composing the second story. This extended depth of participation built a sense of ownership, which led to more positive attitudes toward science. This reveals that changes in the degree of participation were related to changes in attitudes toward disciplinary practices.

The cases also demonstrate that improvements in disciplinary knowledge and practice could lead to more breadth and extended depth of participation (Figure 54). This relationship was attributable to composing with multiple modes. As an example, Steve developed better comic design skills and learned to represent science ideas with multiple modes within comic design. It motivated him to post more comments to others’ comic, which indicated more breadth of participation. In addition, his comments evidenced an extended depth of participation. This suggests that changes in disciplinary knowledge and practice had an impact on changes in degrees of participation.

As illustrated in the cases, recognizing oneself or being recognized by others as disciplinary persons could lead to improvements in the degree of participation (Figure 54). Preferring to work in teamwork and being trusted by team members (i.e., the interaction
between self and the community), Nick recognized himself as a writer while revising Brandon’s textual narratives. He fulfilled his responsibilities in the role of writer with more contributions in writing. Similarly, missing two scientists in the fall (i.e., the interaction between self and the community), Olivia recognized herself taking the role of scientist and wrote more science-related sentences in the second story. This suggests that changes in recognition had an impact on changes in degrees of participation.

In addition, the cases suggest that more breadth of participation and extended depth of participation could lead to changes in recognition (Figure 54). In Saanvi’s case, composing with multiple modes in writing, such as integrating voice narrations in textual narratives to expand the science component, she recognized herself as a designer, scientist, and writer. Different from Saanvi, Olivia’s self-recognition as a scientist was mediated by a sense of ownership while incorporating science into textual narratives. This reveals that changes in the degree of participation were related to changes in recognition.

As explained above, the three factors (i.e., modality, the interaction between self and the community, and the relation between self and artifacts) mediate the relationship between forms and degrees of participation. Firstly, composing with multiple modes helps grow (especially integrated) disciplinary knowledge. Improvements in disciplinary knowledge and practices provide fertile ground for the cultivation of disciplinary identities. Secondly, the interaction between self and the community have impacts 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 ownership or 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 in communities of practice.

**Implications for Practice**

This research has implications for how to broaden and deepen participation in integrated STEM+L practices. As the findings demonstrate, students’ forms and degrees of participation were impacted by 1) reflective understanding of the nature of (inter)disciplinary practices and roles; 2) exposure and experience in composing in multiple modality; 3) the interaction between self and the community; 4) the relation between self and artifacts.

In order to foster positive attitudes toward disciplinary practices and related career fields, it is important for the teacher to learn students’ practice comfort zones, perceptions of and interests in disciplinary knowledge and practices. Based on the understanding of students’ practice comfort zones and interests in knowledge and practices, instructors need to *clearly connect what students are good at with other disciplinary practices*, especially the ones that they are interested in. Also, instructors from different backgrounds can co-teach the class and model the process of connecting different disciplines.

In addition, instructors should provide flexibilities for students to move across disciplinary practices, such as using *flexible role taking*. What should be emphasized is that role taking should be utilized as a way to try out different practices while excelling in one aspect at the same time. Also, instructors should stress that role taking is a way to
help others in different disciplinary practices. As shown in this study, some students might view role taking as a rule one had to follow although we emphasized that they could change roles. Furthermore, instructors should identify those who stayed in a role that s/he did not like, but could not switch roles due to a different perception of role taking. But the most important thing is to figure out how the perception was shaped so that instructors can provide corresponding feedback. Also, role shuffling could also help students to re-direct students’ understanding of (inter) disciplinary practices and roles.

Another important feature of role taking was for students to develop interests in future careers. For instance, an individual, taking the role of scientist, would form a perception of what scientists do and how scientists interact with others in real life. In this case, instructors should provide opportunities for students to interact with real scientists, such as those who study frontier scientific research. Students might connect the role of scientist, practices that they participate in, and practices that real scientists experience. In this way, they might develop an interest in pursuing a scientist’s career.

Additionally, the role taking strategy has both negative and positive impacts on student learning while team members are absent. The absence of team members is a critical challenge for informal learning environments. There need to be strategies to deal with missing members to make sure it will not have negative impacts. As an example, when there is only one student left in a group, instructors can guide the student 1) to join other teams while sustaining the same role or changing roles; 2) to invite members from other groups to cover missing roles. Also, missing members may come back after a long-time absence. In this scenario, instructors can ask each group to keep track of the group progress in notebooks so that missing members can get familiar with the group project
easily. In terms of positive effects, students can participate in other disciplinary practices when there are missing members. In Olivia’s case, taking the role of writer, she covered the role of scientist while two scientists left the program.

As made evident in our findings, students’ perceptions of knowledge and practices also had an impact on attitudes toward disciplinary practices and related career fields. This calls for a need to link students’ out-of-school practices, multimodal composing, with learning disciplinary knowledge. As others (e.g., Bruce, 2008; Dalton, 2013; Dalton & Smith, 2012; Gilje, 2010) have emphasized, adolescents were used to expressing themselves and connecting with others through sharing multimodal artifacts (e.g., Broadcasts and YouTube channels) world widely. Multimodal composing has been integrated into language arts instruction, but not really in STEM learning environments. Instructors should incorporate multimodal composing into STEM instruction. In this way, students might understand that knowledge and practices in STEM involve more than memorizing facts.

This study demonstrated that students developed knowledge and practices in integrating different disciplinary knowledge. On their own, students could connect different disciplinary knowledge in meaningful ways, such as representing science ideas with a combination of textual and non-textual modes. Yet, some students were not aware of the integration or did not integrate them efficiently. For instance, students might use designs and texts to show exact same information. Just as it’s important to explicitly teach students the connection between disciplinary practices, students are also likely to benefit from explicit instruction that helps them learn how to capitalize on the unique
semitic power of modes and learn different ways to orchestrate modes for the purpose of integrating different disciplinary knowledge.

Another instructional consideration this study raises is how to facilitate students in changing from consuming ideas to producing ideas. To increase the depth of participation, it’s imperative for instructors to be aware of students’ interests in disciplinary knowledge and practices. For example, in Olivia’s case, having the opportunity to write her interested science topics changed the depth of participation dramatically. But it’s a challenge to take all students’ interests into consideration, especially in group working. Possible solutions could be to help students to connect group members’ interests or group students based on interests.

Our findings showed that students tended to propose ideas so that their characters’ perspectives were presented in the final artifacts. This suggested that infusing oneself through a character could evoke her/his enthusiasm in “speaking up” for the character. Instructors could design activities that help students project themselves in artifacts, such as avatars. But issues related to group interactions might occur. As an example, four students in Saanvi’s group represented four characters of which three were protagonists and one was an antagonist. The student who represented the antagonist was left out because the other three were more active in developing story ideas for protagonists together.

Also, composing with multiple modes could serve as a vehicle to illuminate students’ ideas. Based on our previous findings, comics, composed of multiple modes, had the following features that might be beneficial for student learning: 1) students could project themselves into avatars; 2) comics could expand topics of discussion by
visualizing details and showing sequenced events. To make it clear, I am not promoting that instructors must use comics. Visual modes that had similar features as comics should work as well. In fact, we should provide modal flexibilities (Smith, 2016) so that students could use ones that work best for them.

Students originated ideas for the purpose of integrating different disciplinary knowledge. This calls for a need to design instructional activities that integrate multiple disciplines. However, some students might not have a solid base for integration. Instructors should provide explicit instructions on how to integrate disciplinary knowledge and practices meaningfully and efficiently. Also, group presentations can contribute to showing examples of integrations from peers.

Lastly, this research suggests that students should have a significant opportunity to establish a sense of ownership. Prior research describes a lack of participation in informal STEM learning environments (Kerr & Robinson Kurpius, 2004; Sadler et al., 2012). Particularly, some members rarely participated in constructing group artifacts. One possible explanation could be that they did not have the ownership of group products. Therefore, it’s critical to facilitate students in building a sense of ownership. Instructors could ask students to create and share multimodal artifacts, which has proved to be an engaging activity for students (Smith, 2017), especially those from underrepresented populations. More importantly, students’ multimodal artifacts should be incorporated in group projects to establish a sense of ownership. The sense of ownership can also be strengthened with frequent within or across group sharing. Alternatively, Instructors could also encourage students to project themselves into group artifact, such as through avatars.
Implications for Research

Along with providing new insights into adolescents’ participation in STEM+L practices, this study points to new areas of exploration. 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 patterns and trajectories with differing students, contexts, tools, and genres. Only a handful of studies examined adolescents’ participation trajectories across multiple disciplines and there is a rare study that connected the form and degree of participation to our knowledge. More studies need to be conducted that acknowledge the great diversity in how adolescents changed the form and degree of participation in integrated STEM learning environments. Furthermore, the scope of this study was confined to how students participated in our 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.

More also needs to be learned about effective instructional methods or technological design for building awareness of disciplinary identity development. In this study, we found that taking disciplinary roles could help students recognize their disciplinary identity development. Still, some students did not recognize their own and others’ disciplinary identities. As there is only a handful of studies on investigating students’ movement across disciplinary identities (Van Horne & Bell, 2017), we still have much to learn about how to facilitate students’ disciplinary identity development.

Finally, although we showed students’ gains in disciplinary knowledge and practices, we did not connect participation patterns and trajectories with student achievements. We described the changes in the form and degree of participation and
explained what contributed to the changes. We also demonstrated students’ improvements in knowledge and practices. However, we did not make clear connections between the changes and improvements. Focusing on the connections would aid in transitioning showing participation trajectories to scaffolding meaningful participation trajectories.

Conclusion

Through examining the diverse participation patterns and trajectories of four cases in the STEM+L project, new light is shed upon how students changed the form, from the perspective of disciplinary identity, and the degree of participation, from the perspective of community of practice. Synthesizing findings from each case suggests that changes in the form and degree of participation, and the relationship between the two, could be due to the following factors: 1) Reflective understanding of the nature of (inter) disciplinary practices and roles; 2) Exposure and experience in composing in multiple modality; 3) The interaction between self and the community; 4) The relation between self and artifacts. Integrated STEM+L 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 in integrated STEM learning.
References


Everman, D. J. (2016). Teacher candidates’ perceptions regarding the integration of fictional literature into elementary science instruction (Doctoral dissertation).


Appendices

Appendix A. Pre-Survey.

Name: ___________________________ Date ___________________

STEM+L Academy Pre Survey

[Part I: General Questions]

1. Rate the following statement: *I feel confident learning new technology:*

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agreed</th>
</tr>
</thead>
</table>

Please explain your response:

2. Rate the following statement: *I feel confident creating products using different types of media (e.g., visuals and audios):*

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agreed</th>
</tr>
</thead>
</table>

Please explain your response:

3. Rate the following statement: *I prefer working with others, instead of working by myself:*

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agreed</th>
</tr>
</thead>
</table>

Please explain your response. For example, you can describe a project that you worked on before.
4. Rate the following statement: *I prefer taking on a specific role while working on a team project:*

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response. For example, you can describe a project that you worked on before.

5. Rate the following statement: *I like to write*

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response. For example, what types of things do you like to write? Why?

6. Rate the following statement: *I like science*

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response. For example, what science topics do you like the most? What science topics do you not like? Why?
7. Rate the following statement: *I like to design*

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response. For example, what types of things do you like to design and create? Do you consider yourself creative? Why?

8. Rate the following statement: *I like science fiction (e.g., books, comics, movies, or TV shows)*

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response. For example, which aspects of science fictions do you like or not like?

9. Rate the following statement: *My future career/job will be closely related to STEM (Science, Technology, Engineering, and Math).*

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response. For example, what do you want to do in the future?

[Part II: Questions Specific to the STEM+L Academy]
1. Based on what you know at this time, please rate the following statements regarding the three roles you can take in the STEM+L Academy:

| I like to be a Designer (create multimedia related to the science fiction) |
|-------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| Strongly Disagree                               | Disagree        | Undecided       | Agree           | Strongly Agree  |
| Agree                                           |                 |                 |                 |                 |

| I like to be a Scientist (verify/include scientific information) |
|---------------------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| Strongly Disagree                                             | Disagree        | Undecided       | Agree           | Strongly Agree  |
| Agree                                                         |                 |                 |                 |                 |

| I like to be a Writer (develop plot and write up fiction)      |
|----------------------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| Strongly Disagree                                             | Disagree        | Undecided       | Agree           | Strongly Agree  |
| Agree                                                         |                 |                 |                 |                 |

Please explain your response. For example, why did you rate the roles in this way?

2. In addition to the three roles (designer, scientist, and writer), are there any other roles that you want to take in the STEM+L Academy? Please explain your response.

3. Is there anything else you’d like for us to know?
Appendix B. Mid-Survey.

Name: ___________________________

STEM+L Academy Mid-Point Survey
[Part I: General Questions]

1. Rate the following statement: *I feel confident learning new technology*:

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
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<th>Undecided</th>
<th>Agree</th>
<th>Strongly</th>
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</table>

Please explain your response:

2. Rate the following statement: *I feel confident creating products using different types of media (e.g., visuals and audios)*:

<table>
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Please explain your response:

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Please explain your response. For example, you can describe a project that you worked on before.

4. Rate the following statement: *I prefer taking on a specific role while working on a team project*:

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Please explain your response. For example, what science topics do you like the most? What science topics do you not like? Why?
7. Rate the following statement: *I like to design*

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<tbody>
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<td></td>
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</tr>
</tbody>
</table>

Please explain your response. For example, what do you want to do in the future?

[Part II: Questions Specific to the STEM+L Academy]

1. Based on what you know at this time, please rate the following statements regarding the three roles you can take in the STEM+L Academy:

   **I like to be a Designer** (create multimedia related to the science fiction)

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agree</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   **I like to be a Scientist** (verify/include scientific information)

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agree</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   **I like to be a Writer** (develop plot and write up fiction)

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agree</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please explain your response. For example, why did you rate the roles in this way?

2. In addition to the three roles (designer, scientist, and writer), are there any other roles that you took in the STEM+L Academy? Please explain your response.
3. What did you do to fulfill your role in the Academy? Please be as specific as possible.

4. What do you learn by taking the specific role?

5. Did you role change? Why or why not?

6. What roles did your teammates take? Did their roles change? Why or why not?

7. Out of the whole class, could you nominate the best designer, the best scientist, and the best writer? Explain why you pick the students.

8. Is there anything else you’d like for us to know?
Appendix C. Post-Survey.

Name: ____________________________

STEM+L Academy FINAL Survey
[Part 1: General Questions]

1. Rate the following statement: I feel confident learning new technology:

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response:

2. Rate the following statement: I feel confident creating digital products using different types of media (e.g., visuals and audio):

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response:

3. Rate the following statement: I prefer working with others, instead of working by myself:

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response. For example, you can describe a project that you worked on before.

4. Rate the following statement: I prefer taking on a specific role while working on a team project:

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response. For example, you can describe a project that you worked on before.

5. Rate the following statement: I like to write

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response. For example, what types of things do you like to write? Why?

6. Rate the following statement: I like science

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

Please explain your response. For example, what science topics do you like the most? What science topics do you not like? Why?

7. Rate the following statement: I like to design

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

8. Rate the following statement: I like science fiction (e.g., books, comics, movies, or TV shows)

Please explain your response. For example, which aspects of science fictions do you like or not like?

9. Rate the following statement: My future career/job will be closely related to STEM (Science, Technology, Engineering, and Math).

Please explain your response. For example, what do you want to do in the future?

[Part II: Questions Specific to the STEM+L Academy]

1. Based on what you know at this time, please rate the following statements regarding the three roles you can take in the STEM+L Academy:

   I like to be a Designer (create multimedia related to the science fiction)

   I like to be a Scientist (verify/include scientific information)

   I like to be a Writer (develop plot and write up fiction)

Please explain your response. For example, why did you rate the roles in this way?

2. In addition to the three roles (designer, scientist, and writer), are there any other roles that you took in the STEM+L Academy? Please explain your response.

3. What did you do to fulfill your role in the Academy?

4. What did you learn by taking your specific role?
5. Did your role change over time? Why or why not?

6. What roles did your teammates take? Did their roles change over time? Why or why not?

7. Out of the whole class, could you nominate the best designer, the best scientist, and the best writer? Explain why you pick the students.

8. What did you learn from STEM+L Academy that you would use again in the future? Please explain your response.

9. Did this project help you to think about possible careers to pursue in the future? Please explain your response.

10. We plan on having this project again next year. Do you have any suggestions for improving it?
Appendix D. Reflection on Video Creating Activity.

Video Reflection Questions

- What was your goal when creating your video reflection? Please explain (at least 2 complete sentences)

- How did you decide what information to include in your video reflection? (at least 2 complete sentences with specific examples in your video)

- How did you use different modes (pictures, sounds, video, voice, animations, text) to create your video reflection? (at least 2 complete sentences)

- What did you learn from the video reflection activity?

- What did you like about creating the video reflection?

- What was challenging for you when creating the video reflection?

- Anything else you’d like for us to know about your experience creating your video reflection?
### Appendix E. Graphic Organizer.

<table>
<thead>
<tr>
<th>Role:</th>
<th>Name:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific goals for your role:</td>
<td>1.</td>
</tr>
<tr>
<td>2.</td>
<td></td>
</tr>
<tr>
<td>What you need from others group members:</td>
<td>1.</td>
</tr>
</tbody>
</table>

<table>
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<tr>
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<th>Name:</th>
</tr>
</thead>
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<td>1.</td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>What you need from others group members:</td>
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<td>2.</td>
<td></td>
</tr>
<tr>
<td>What you need from others group members:</td>
<td>1.</td>
</tr>
</tbody>
</table>
Appendix F. Interview Protocol.

STEM+L Academy Focus Group Interview Protocol,
Planned time – 30 minutes

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewer</td>
<td>Students Present for Interview</td>
</tr>
</tbody>
</table>

CHECK THAT THE AUDIO RECORDER IS ON!!! AT THE BEGINNING, GO AROUND AND HAVE EVERY STUDENT SAY THEIR NAME AND THE NAME OF THE GROUP.

**Introduction:** During STEM+L Academy, you have done a great job creating a multimedia science fiction project with your peers. In this interview, we will ask you to share what you liked, how you worked with your team, as well as your process for creating your project. We’ll look at your project together as I ask you questions about your experience. So that I can hear everyone’s opinion, I’d like for each of you to try to answer each question. Everyone needs to get a chance to talk and it’s ok if you have different opinions. Is that all right with you?

If yes, we want to remember what you say, so we’re going to audio record you and also take some notes. We’re interested in your thoughts and ideas, so there are no right or wrong answers. What you say will not affect your grades in school and the UM researchers will be the only ones to hear your responses.

NOTE: For questions that are underlined, it is especially important to try to get responses from all students. Please try to say the student’s name before they speak to help the transcriber.

**Part 1: Composing Process, role taking, and Collaboration**

1. Describe for us step-by-step what your overall process was for creating your multimedia science fiction. What did you do first, second, third, last? Does everyone agree with that? Anything you would change about how the process was described?

2. Where did the ideas come from for creating this multimedia story and how did the group work to make them happen? Is there anything anyone would like to add?

3. Now, I’d like for us to talk about your roles during the project. Can each of you go around and explain what your role was for the project. What have each of you done specifically to fulfill your role?

4. Did you like having specific roles? Why or why not?

5. Did your role change at all over the course of the workshop? Why or why not?

6. Did your role make you think about following any specific careers that are similar to what you did for your role or use similar skills?
7. How did you work with your other team members to create your science fiction? How did you settle any disagreements during the process?

Part 2: Design Decisions
8. General question:
   a. How did you use technology to create your science fiction?
   b. Specific modes:
      i. How did you use iKOS? Anything anyone else would like to say?
      ii. How did you use Scratch? Anything anyone else would like to say?
      iii. How did you use Pixton? Anything anyone else would like to say?
      iv. How did you use hyperlinks? Anything anyone else would like to say?
      v. How did you use images? Anything anyone else would like to say?
      vi. How did you use music? Anything anyone else would like to say?
      vii. Did you use any other multimedia elements to create your science fiction?

9. What is your favorite part of the project? Why?

10. If you had more time to work on your science fiction project, what would you add or change? Why?

Part 3: Science Learning
11. What do you think you learned from creating this project? (probe for technology skills, reading/writing skills, and science learning)

12. How did your group include science concepts into your project?

13. Did you incorporate anything you learned from the guest speakers or WISE? If so, what?

14. Did this project help you to understand these science concepts better? Why or why not?

Part 4: Community of Practice
15. Out of the whole class, could you nominate the best designer, the best scientist, and the best writer? Explain why you pick the student.

16. Anything else you’d like for us to know?