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DEVELOPMENT ARTICLE

Science identity development: how multimodal composition mediates student role-taking as scientist in a media-rich learning environment

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Abstract
Science identity has been widely discussed in recent years; however, research on its development in multimodal composing environments, especially in formal classroom settings, has yet to be fully investigated. This qualitative study unraveled the science identity development of sixth-grade students as they created multimodal science fiction stories in a STEAM course. Thirty-two students enrolled in the course and worked in groups of 3–5, and each student self-selected one of three roles: designer, scientist, or writer. This study focused on the students (n = 9) who took the role of scientist and examined their science identity development. Data sources include digital surveys, semi-structured group interviews, and multimodal artifacts. Our qualitative analysis suggests that (a) composing with modes of choices could drive interests in science; (b) students connected science practices in classrooms with those in professional domains through taking the role of scientist; (c) taking hybrid roles (i.e., a combination of scientist and other roles) while composing with multiple modes contributed to the recognition of science in non-science careers. Based on these findings, we discuss the implications for cultivating positive science identities and engaging early adolescents in career exploration.

Keywords Science identity · Multimodal composing · Role-taking · Science practice · Career exploration

Introduction

Disciplinary identities, referring to learners' self-identification with disciplinary practices, especially as a producer of artifacts related to a discipline, offer unique opportunities for evaluating past selves, understanding current selves, and pursuing future selves (Kane

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2012; Van Horne and Bell 2017). In science education, it is critical to stimulate a positive science identity for promoting adolescents' performance in the discipline as well as sparking career interest (Barron et al. 2010; Carlone 2017; National Research Council 2017). To cultivate positive science identities, it is vital to guide students to make connections between science learning in classrooms and their current and future lives (Barton and Tan 2010).

With the prosperity of information technologies, multimodal composition technology has drawn increasing attention in developing disciplinary identities (Smith 2019; Cummins et al. 2015; Grapin 2019). Multimodal composition is a popular literacy practice among youth in which they engage in composing digital artifacts (e.g., videos and podcasts) with the orchestration of multiple modes, including text, visual, and sound (Kress 2010). Composing with multiple modes has the potential to facilitate adolescents in seeing themselves as readers and writers (Casey 2012). Moreover, Vasudevan et al. (2010) argued that students' understanding of literate identities shifted in significant ways by extending the composing process beyond print text. However, most of these studies focused on the cultivation of identities as literate persons and there is limited research exploring the effect of multimodal composition on science identity development, especially in formal classroom settings. The literature calls for more work in exploring new ways to implement disciplinary literacy (Fang and Coatoam 2013) and integrate literacy learning into science learning.

Much of the research on science identity illuminates that there is a decreasing interest in science and science careers as students move from primary to secondary school (Anderhag et al. 2016). Carlone et al. (2014) explained that traditional classrooms provided limited opportunities for students to see connections between what they do in science classrooms and what they want to be in the future, especially if future aspirations may not be directly related to science. The failure in making such connections could contribute negatively to the construction of science identities. One common strategy to link science practices with possible selves is offering adolescents access to scientists in professional domains. However, Bamberger (2014) found that interacting with scientists could have a negative impact on students' science identity development when students were afraid of not being smart enough to handle that profession in the future. Therefore, there is a pressing need for effective instructional strategies to facilitate students making a close connection between science learning in the classroom and their future selves.

Taking on these challenges, we developed an integrated Science, Technology, Engineer, Art, and Math (STEAM) course that aims to, among other things, facilitate middle school students' disciplinary identity development. The course had two design features. First, we used disciplinary role-taking (Jiang et al. 2019) as an explicit means to support disciplinary identities development. Second, we wove into the course multimodal composing, through which students could express and explore disciplinary identities in multiple ways. Focusing on the students who took the role of scientist, we investigated the following research question: *How does creating multimodal artifacts while taking disciplinary roles contribute to science identity development for sixth-grade students?*

Theoretical framework

Science identity and role-taking

From a disciplinary perspective, an identity entails norms and standards accepted in a particular field of study. Specifically, a science identity is enacted when a person shows a positive attitude towards science and science careers (Archer et al. 2010), demonstrates normative science knowledge and practices (Carlone and Johnson 2007), and gains recognition as a legitimate participant by self and others in various communities related to science (Lave and Wenger 1991). Its constituent elements (i.e., attitudes, knowledge and practices, and recognition) grow out of one's active participation in disciplinary activities within communities of practice (Carlone et al. 2014; Forbes and Skamp 2016; Tan and Barton 2008). In this sense, science identity is constructed, authored, and changed from time to time and space to space (Bricker and Bell 2012).

Role-taking can be a powerful instructional tool for students to develop science identities. Scholars have made important advances in understanding the relationship between science identity development and playing the role of scientist in gaming environments (Beier et al. 2012). The literature shows that the difference between playing the role of scientist and embracing science identity lies in the degree to which science is integrated into a person's sense-of-self. For instance, Barab et al. (2007) argued that taking the role of ecological scientist in game-based learning was an efficient design move for bringing elementary students to see themselves as experts in investigating the issue of declining fish population. Only a limited amount of work has explored the adoption of the role of scientist at different levels beyond gaming. As an example, when implementing a curriculum in which students acted as biologists, Pitts and Edelson (2004) found that while some students may have adopted the role when they feel like scientists, others may simply pretend to be in that role. Little work has investigated students' understandings of science as a discipline and a future career, and the connection between science learning and career in role-taking environments, which is one focus of this study.

Science identity and multimodal composition

A social semiotic approach to multimodality posits that all forms of representation and communication are multimodal and are the results of meaning-making (Jewitt 2008; Kress 2010). According to Kress (2010), different modes—including visuals, text, movement, sound, and gestures—possess unique semiotic resources for making-meaning. Multimodal composers leverage the communicative affordances of various modes depending on the context, goals, genre, and digital tools (Smith 2019).

Many aspects of identities are shaped and authored through interactions and activities during multimodal composing processes (Cummins et al. 2015; Skerrett 2012; Vasudevan et al. 2010). Research on multimodality suggests that understanding "how the construction of multimodal representation supports identity development processes can help us to bring these new media literacy practices to youth who are most in need of alternative mechanisms for engaging in positive identity work" (Halverson 2010, p. 235). Furthermore, Halverson (2013) argued that by examining the ways that youth engage in the multimodal composing process, researchers can gain a deeper understanding of the ways they make meaning and author identities through multimodal representations. Through composing with multiple modes, one can assert their authority on the artifact, which provides an entry into the academic discourse community as someone with knowledge or expertise.

Research has demonstrated that the construction of science identity is highly dependent on a variety of semiotic tools that learners create to make sense of scientific phenomena (Ainsworth 1999). For example, Hanauer (2010) showed that students tended to personalize their science workspace with multimodal representations (e.g., cartoons of scientific processes) and this allowed them to display their science identity and enhance a sense of belonging. Another example is Tucker-Raymond et al. (2007) study in which young children represented themselves as scientists with multimodal composing tools during a year-long program that engaged students in integrated science-literacy experiences. They found that there was an increase in the number of modes students used to represent themselves as scientists from the pre- to post-interview. A core argument of this study is that multimodal composition might afford positive science identity development as students could choose preferred modes to gain access to science learning, which is a foundational move for expressing and exploring science identities.

Methods

Course design and implementation

The research team developed and facilitated an elective STEAM course for sixth-grade students in a public magnet school (61% Latinx; 29% White; 6% African American; 4% Other) in a large southeastern city in the United States. The classroom teacher assisted with managing the classroom, grouping students, and grading student work. The course met twice every week (approximately 2 h each) for 15 weeks.

The course was driven by a final project to create a multimodal science fiction digital book (see Fig. 1a). Students worked in small groups of 3–5 and needed to propose creative solutions for environmental issues and climate change. Aside from working on their projects, students participated in the following activities:

- *Multimodal composition.* We introduced different tools for digital multimodal composition, such as Pixton to create comics and Venngage to create infographics. Students learned to use these tools to represent science ideas.
- *Science practice.* We provided students with opportunities to interact with faculty members from different backgrounds (i.e., design, engineering, science, and writing) through guest lectures and lab visits. We also provided students explicit feedback about searching for, evaluating, and incorporating scientific resources into their science fiction stories.
- *Career exploration.* During the multimodal composition and science practice, we designed activities for students to reflect on career choices, role-taking, and interdisciplinary collaboration. For example, in the activity "Me in 20 Years", students created Pixton comics to envision their professions and working environments in 20 years.

All students used iKOS (a computer-supported collaborative learning platform, ikos.miami.edu) to create knowledge entries. These entries could be created in different modes, including Wiki, Concept Map, Pictag (Fig. 1b–d, Namdar and Shen 2016), and interactive digital book (Fig. 1a). The Wiki mode is a hypertext editing tool. In the Concept Map

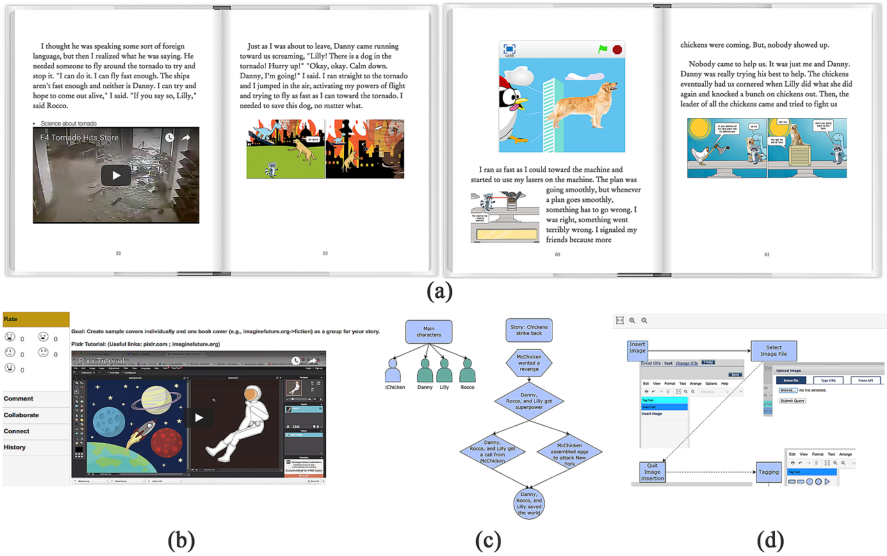

Fig. 1 Interactive book (**a**), Wiki (**b**), Concept Map (**c**), Pictag (**d**)

mode, students can create concept maps (Novak and Cañas 2008) to connect a set of ideas. Pictag is picture tagging, which enables students to tag any area in a self-uploaded picture with texts. The interactive book mode supports integration of external digital artifacts (e.g., Pixton comics) and other knowledge modes (Wiki, Concept Map, and Pictag) within iKOS. In addition, iKOS provides collaboration amongst students and instructors via rating, commenting, and co-editing entries.

A total of 32 sixth-grade students enrolled in the course. Each student picked one of the following roles, with the requirement that each group contained at least one writer and one scientist:

- *Writers* were in charge of developing the narrative of science fiction stories based on brainstorming and input from group members;
- *Scientists* were responsible for monitoring the integration and accuracy of science vocabulary and concepts;
- *Designers* led the creation of visual and audio representations for the characters and scenes in the story.

Importantly, students could choose, create, change, and negotiate roles throughout the course. Besides the specific tasks for the differentiated roles, team members collaborated with each other throughout the process of composing their multimodal stories.

Researchers' participant-observer roles

We took the position of participant-observer (Spradley 1980) in this study. We had a well-established partnership with the school and the classroom teacher. The first author led most of the sessions and interacted frequently with students. Other authors focused primarily on the role of observer and facilitator with the main task of collecting data and giving students feedback when needed. The participant-observer role allowed us to conduct the study as "insiders", which provided more in-depth insights on the learning processes and experiences of the students.

Data collection

We collected multiple sources of data, including individual surveys, semi-structured group interviews, and multimodal artifacts. Students completed three digital individual surveys (pre-, mid-, and post-surveys; Jiang 2018) asking about their science learning experiences and career interests at the beginning of, in the middle of, and upon completion of the course. We developed the surveys using the science identity model (i.e., attitudes, knowledge and practices, and recognition) that builds on the work of Carlone and Johnson (2007) and based on a review of the relevant literature. Specifically, the nineteen items in the pre-survey consisted of four five-point Likert-type items, three three-point Likert-type items, and twelve open-ended questions. The five-point Likert-type items asked students to indicate levels of agreement with statements associated with interests in design, science, and writing. The three-point Likert-type items assessed interests in the roles of designer, scientist, and writer. In addition, we used open-ended questions to elicit their detailed opinions regarding interests and learning experiences in design, science, and writing. The nine open-ended questions in the mid-survey measured students' learning experiences in the project and interests in roles while the five open-ended questions in the post-survey asked students to reflect on learning experiences, interests in roles and future careers.

In addition, we conducted a 1-h, semi-structured interview (Patton 1990) with each group to learn more about students' science learning and multimodal composition at the end of the course. We chose to interview students in groups since they worked in small groups and this would allow them to reflect together on their multimodal composition. In the interviews, students shared experiences of role-taking and processes of creating multimodal artifacts, as well as whether the project affected their views of future careers in science. The interview had three sections: composing process and role-taking (e.g., "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?"), design decisions (e.g., "how did you use technology to create your science fiction?"), and science learning (e.g., "how did your group include science concepts into your project?"). To elicit students' perspectives, we revisited their artifacts on the computer and stopped to discuss processes of composition during the interviews.

Furthermore, we collected multimodal artifacts that students generated, including artifacts for their team projects and self-reflection. As an example of artifacts for team projects, one student created an infographic to explain how dangerous sharks were to set an atmosphere of tension for the fiction. In addition, students used tool/format of choice (e.g., Pixton/comic and Venngage/infographic) to reflect on role-taking, collaboration, or other learning experiences at the end of the course.

Data analysis

Since the purpose of this study was to understand science identity development, our analysis focused on nine students who took the role of scientist at the beginning of the course. This qualitative study (Merriam 1988; Strauss and Corbin 1998) involved four phases of data analysis. In the first phase of analysis, we transcribed interviews and highlighted transcripts related to the following three aspects of science identity for further analysis: (1) attitudes towards the role of scientist and interests in science or other careers, (2) perspectives on science learning and practices, and (3) self-recognition or being recognized by others as a science person who contributed science ideas. Specifically, we carefully read each transcript and highlighted information related to the three aspects of science identity. Then the research team reviewed, discussed, and refined the highlighted information to reach consensus. During this phase of analysis, consensus building was straightforward since the goal was to identify transcripts related to science identity instead of differentiating the three aspects of science identity. After this phase of analysis, we had a general overview of all the transcripts.

In the second phase, we constructed individual scientist profiles (Abell et al. 1998) by categorizing and sorting all data sources (i.e., survey responses, highlighted interview transcripts from the first phase of analysis, multimodal artifacts) related to the same person chronologically. Then the research team closely examined the same topic across these three data sources to build a coherent understanding of students' learning experiences. Moreover, we often referred to the whole interview transcript to ensure that the context of highlighted transcripts was not lost. To achieve validity and reliability, the research team independently read scientist profiles and then discussed our own understanding of each student's learning experiences through weekly meetings. In addition, we took notes of these discussions and used the notes when constructing case summaries in the third phase of analysis.

In the third phase, we generated case summaries on science identity development for each student based on the profiles from the previous phase. The case summary included four parts: attitudes towards the role of scientist, interests in science or other careers, perspectives on science learning and practices, and recognizing oneself or being recognized by others as a science person. Table 1 presents an example of one such case summary regarding attitudes towards the role of scientist. We discussed the case summaries through weekly meetings until consensus was reached among the research team. We often re-visited our notes of discussions from the second phase to understand students' learning experiences.

In the final phase of analysis, we discussed, compared, and contrasted these cases (Patton 1990) to generate cross-cutting themes related to how creating multimodal artifacts while taking disciplinary roles contributed to science identity development. Specifically, we open-coded each case summary and refined our codes for developing common themes across cases (Braun and Clarke 2006). In initial coding, the research team reviewed the case summaries and discussed initial codes that could describe changes in the three aspects of science identity. This process resulted in 36 codes. The research team refined these codes by combining similar codes and developed a focused-coding framework including 22 codes. We applied the focused-coding framework to all case summaries and nine categories of codes emerged (see Table 3). Then we created detailed coding summaries when explicating codes and code categories. We reviewed and discussed these coding summaries extensively to identify and refine emerging themes. The themes were iteratively identified and refined as scientist profiles and case summaries were read and re-read to examine students' science identity development.

Along with triangulating across data sources, we sought to strengthen the trustworthiness (Erlandson et al. 1993) of findings by approaching students and other members of the research team to confirm the subjective construction of our interpretations. In particular, the first author, as an instructor/researcher, frequently asked students to comment on whether her interpretations accurately reflect their learning experiences in the form of ongoing informal

Table 1 Sample case summary: Charles

Overall view of attitudes towards the role of scientist	His attitudes towards the role of scientist changed after creating comics to represent science ideas
Evidence	In pre-survey, he chose scientist as first choice, designer as second, and writer as third In the interview, he explained that he preferred the role of designer but chose the role of scientist to work in teams with friends: *Because I wanted to be in a group. There's not enough space and no one was willing to accept me. So then, when I came to this group, they said that they needed a scientist. Even though I was really thinking about being a designer because I'm like a good artist and I love creating things and I adore Pixton. But then I realized that they needed a scientist and they are very good friends of mine. I just wanted to join with them and I thought that I could be good use. And, I ended up designing too* In particular, he had passion in designing comic books: *I would really, really want to create my very own comic book based on either what assigned, or even whatever I want that's appropriate* (pre-survey) In the mid-survey, he was upset with his role: *No, cause it's* (it refers to the role of scientist) *BOOOOOOOOOOOOOOOOORRRRRRRRIIIIINNNNGG!* Moreover, he wanted to change roles: *If I were designer, and Liam was scientist!* (mid-survey) By the time the mid-course survey was administered, he created two Wiki entries in which he explained science phenomena with pictures of scientific models (the pictures are google images) In the post-survey, he felt accomplished with the role of scientist: *They* (activities) *taught me that as a scientist, I need to gather all the science information for the project* By the time the post-course survey was administered, he created two comics of science phenomena In the interview, he expressed strong passion with the role of scientist: *This is heaven right now. Thank you. I learned that even though you want to be like a different role instead of the one you are right now, still you can make that role that you are now more fun than what you would be if you were in the one that you wanted* Moreover, he shared the process of creating comics to represent science ideas with excitements and linked comic creation with creativity and innovation
Summary	Comic creation provided a venue for him to get interested in the role of scientist

member checking (Merriam 1988) throughout the data collection. For instance, when Charles (Table 1) changed attitudes towards the role of scientist in the mid-survey, the first author had a discussion with Charles about his attitude change during group work time. Furthermore, the research team had debriefing meetings every week to summarize and share classroom observations. We approached students for informal discussions when having questions or different interpretations of their learning experiences during debriefing meetings. We also took notes of discussions with students and used these notes to better understand students' learning experiences throughout the four phases of data analysis.

Results

Nine students (4 females, 5 males; age 10–13) from eight groups took the role of scientist. As shown in Table 2, students (all are pseudonyms) chose different modes, such as multimodal comics and infographics, while designing artifacts for fulfilling the role of scientist. In addition, despite a diverse range of interests in science and science careers at the beginning of the course, most of the students recognized the utility of science practices in future careers after the course.

In the following, we present three cross-cutting themes, with each mainly corresponding to a particular aspect of science identity development. We found that (a) composing with multiple modes offered students a venue to find their own modes to develop interests in science; (b) students linked science practices in classrooms and the workforce while taking the role of scientist; (c) students recognized the value of science in future non-science careers. We illustrate these themes using examples from individual students, whose profiles concerning these themes are summarized in Table 3.

Creating multimodal artifacts related to science

We witnessed consistently that multimodal composition provided multiple entry points for different students to author their unique science identities. Specifically, students developed more positive attitudes towards the role of scientist, science, or science-related careers while making infographics, designing comics, and augmenting story entries with a combination of texts, videos, and other multimodal artifacts.

Students redefined the learning of science as an active process of constructing artifacts with multiple modes. For instance, Mark, choosing the role of scientist to cover missing roles in his group, did not like passive learning of scientific facts in school. In the project, he engaged in searching multimedia websites for useful scientific information and creating infographics (e.g., Fig. 2) with data from the internet. He first found information about sharks that two explorers in their story would encounter. Next, he used “danger” as a data indicator to differentiate sharks and selected “size” as a measurement for danger. In this process, Mark needed to decide what information was essential and find evidence to support his point of view. As he explained in the post-survey, “It taught me how to get information from media sites and make charts…I really like to learn new things online, and I would rather find it on my own and create my own things.” For Mark, the process of searching for information and generating multimodal artifacts with the information allowed him to see science learning as an active process of composition.

Providing opportunities to create multimodal scientific artifacts could help students to view science as a creative endeavor, which in turn could lead to more positive attitudes towards science. For example, Charles became proud of taking the role of scientist and developed an interest in pursuing a science-related career after having learned that science could be creative through comic design. He described himself as a creative person and associated science with a lack of creativity at the beginning of the course, which is a common misconception (Masnick et al. 2010). To fulfill role responsibilities, he created three science-related wiki entries in iKOS to explain science concepts in their story. These entries included text explanations along with images of scientific models (see Fig. 3, left) from the Internet. He felt bored while working on the science aspects in the way of explaining models created by others. By the time the mid-course

Table 2 An overview of students who took the role of scientist

Name	Gender (ethnicity)	Pre-survey		Mid-survey	Post-survey and interview			Multimodal artifacts
		Role preference	Rating: I like science	Do you like your role as a scientist?	Did you learn any new concepts of science from this project? (exemplary quotes)	Did your role make you think about possible careers? (exemplary quotes)	Did your role change? (post-survey)	
Charles	M (L)	1: Scientist 2: Designer 3: Writer	Strongly agree	"No, it's boring."	"Collect all science information."	"I could use design to show science knowledge."	**Scientist** **Designer**	Comic Image Text Animation
Dan	M (L)	1: Scientist 2: Designer 3: Writer	Strongly agree	N/A	"Global warming effects."	"A scientist, movie maker, book writer and teacher."	**Scientist** **Designer** **Writer**	Comic Image Text
Ella	F (AA)	1: Designer/writer 2: Scientist	Disagree	"I love my role as a writer/scientist."	"Global warming and the cause of it" and "We used videos to make science points clearer."	"I do not want to be either a writer or scientist."	**Writer** **Scientist** Designer	Comic Image Text Video
Howard	M (W)	1: Scientist 2: Writer; 3: Designer	Strongly agree	"I like my role as a scientist. because it is very fun."	"How global warming was affecting the planet and how to decrease my carbon footprint." "I did some designs for logos and science stuff."	"Yes, it did help me think about some future jobs, like an environmental scientist which could help save global warming."	Writer **Designer** Scientist	Comic Text

Table 2 (continued)

Name	Gender (ethnicity)	Pre-survey		Mid-survey	Post-survey and interview			Multimodal artifacts
		Role preference	Rating: I like science	Do you like your role as a scientist?	Did you learn any new concepts of science from this project? (exemplary quotes)	Did your role make you think about possible careers? (exemplary quotes)	Did your role change? (post-survey)	
Mark	M (L)	1: Designer 2. Scientist 3: Writer	Strongly agree	"I like the scientist role because while you put some facts you learn more about your studies."	"Asteroids and how they have all these minerals." "I created charts to show how deep you can go in feet until you can't see."	"Maybe. Because I haven't thought of what I'm going to do in the future yet."	Writer **Scientist**	Chart Text
Mary	F (L)	1: Scientist 2: Writer 3. Designer	Undecided	"I love my role as a scientist because I love researching."	"Find science materials, like videos and websites and other media."	"I realized that I love to speak in front of people. So, my future career could include speaking to large crowds."	Writer **Scientist** Designer	Image Text Video

Table 2 (continued)

Name	Gender (ethnicity)	Pre-survey		Mid-survey	Post-survey and interview			Multimodal artifacts
		Role preference	Rating: I like science	Do you like your role as a scientist?	Did you learn any new concepts of science from this project? (exemplary quotes)	Did your role make you think about possible careers? (exemplary quotes)	Did your role change? (post-survey)	
Nova	M (W)	1: Scientist 2: Designer 3: Writer	Strongly agree	N/A	"What I learned from the project was how to do research and how to find science from different sites. And then take the most important parts and add them into my research." "charts for fire cases is one science idea."	"This project helped me think more about being a marine biologist. It's because the story my team and I made was water and tsunami related."	**Scientist** Writer	Chart Image Text
Selina	F (L)	1: Scientist/designer 3: Writer	Strongly agree	"I like my role as a scientist because I like to discover and experiment new things."	"Researching things like videos and pictures on the Internet can help you learn things and understand science better."	"An investigation. An investigation needs people to do the science."	**Scientist** Writer	Chart Image Text Video

Table 2 (continued)

Name	Gender (ethnicity)	Pre-survey		Mid-survey	Post-survey and interview			Multimodal artifacts
		Role preference	Rating: I like science	Do you like your role as a scientist?	Did you learn any new concepts of science from this project? (exemplary quotes)	Did your role make you think about possible careers? (exemplary quotes)	Did your role change? (post-survey)	
Shadi	F (W)	1: Scientist 2: Writer; 3. Designer	Strongly agree	"I like my role as a scientist, because It is what I like to do and it kind of strange it makes my friend Mary and I who are both scientists, very great."	"As a scientist, you always have to be ready for the worst information (pollution, climate change, extinct and/or endangered animals and many others) going on in our own planet Earth."	"This project really makes me want to be a scientist even more than before."	**Scientist** Writer	Image Text Video

All names are pseudonyms; M and F stand for male and female; L, W, AA stand for Latinx, White, and African American; Bold texts represent major role

Table 3 An overview of three themes and sub-themes

Theme	Sub-theme	Charles	Dan	Ella	Howard	Mark	Mary	Nova	Selina	Shadi
Creating multimodal artifacts related to science	Active process	•		•		•	•		•	
	Creative endeavor	•	•		•					
	Iterative process	•		•					•	
Linking practices in classrooms and those in the workforce	Investigation					•		•	•	
	Arguing about socio-scientific issues				•			•	•	
	Design	•			•	•				
Recognizing the value of science in future non-science careers	Responding to need of others			•		•			•	
	Driving force behind innovation, investigation, and discovery	•				•	•		•	
	Communication and outreach			•			•			•

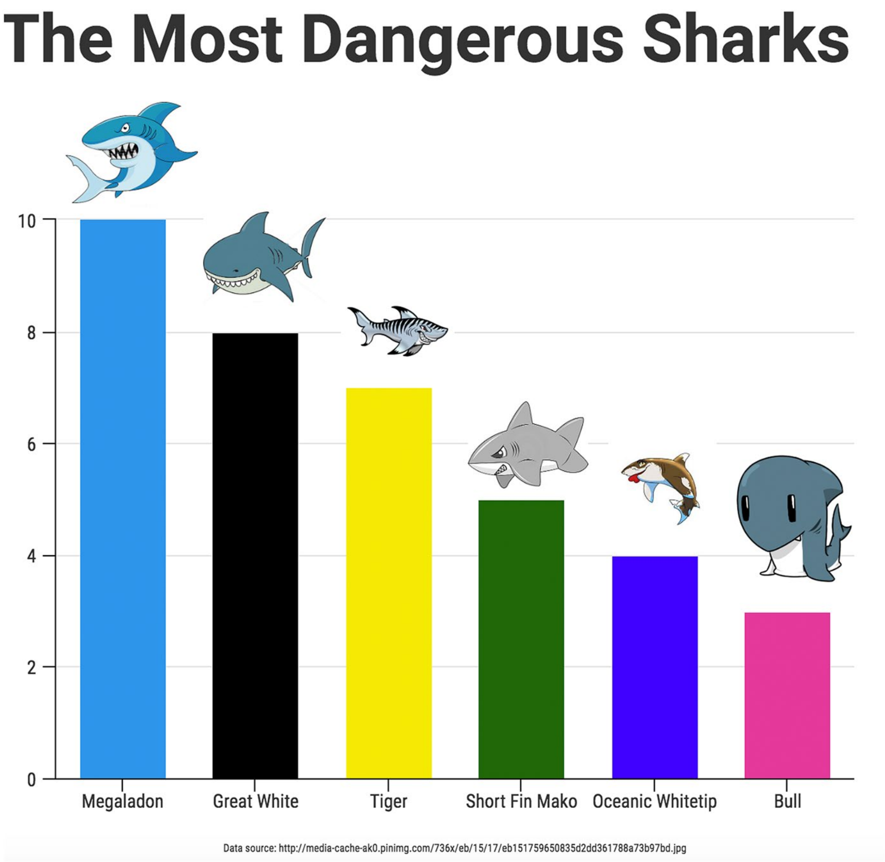

Fig. 2 Mark's infographic that illustrates different species of sharks in the science fiction

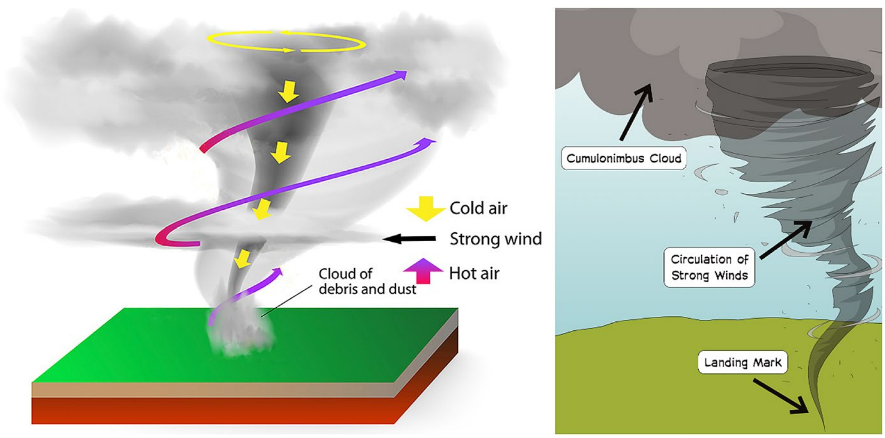

Fig. 3 Charles' artifacts: a tornado model that he obtained from Pinterest (left) before mid-survey and the tornado model that he created in Pixton (right) after mid-survey

survey was administered, he was upset with his role, saying, “It’s boring! I want to be designer. If not, make me do fun stuff!”.

In contrast, after the mid-survey, Charles recreated his own version of a tornado model using Pixton (Fig. 3, right) after searching for different resources and consulting parents. In his words:

> I went to different multimedia and I researched, I went home and I even asked my parents. I did more research. And then I just came up with more, because like, when I was studying like the description for the tornadoes and the hurricanes, it didn’t make sense. And so, what I did was that I just switched it (multimodal comic) around, deleted a couple of words (in the comic), and then I just made more sense and made it more readable for everybody. (group interview).

Accompanied with this kind of reconstruction and sense-making, his understanding of tornadoes and hurricanes advanced. In the beginning, Charles developed a model of “torricane,” a term coined by him to indicate a special weather pattern that was a combination of tornado and hurricane on a remote planet. In his model, the tornado resided in the center of the hurricane of the torricane, which was scientifically unrealistic. We encouraged the group, especially Charles, to conduct further research and he realized that the airflow was downward in the eye of a hurricane while the airflow was upward for a tornado. As a result, he moved the tornado to the arms of the hurricane in the torricane, as depicted in Fig. 3.

Charles became quite content with the role of scientist after the reconstruction of these scientific models. In the group interview, he commented, “this is heaven right now. We can make science more fun through multimedia.” Clearly, the key factor that triggered his interest in science and the role of scientist, as far as we can tell, was the design of multimodal comics and recreation of their fictitious model. The reconstruction helped him to see science learning as creative production.

Multimodal composition could help students to realize science learning is an iterative process of refining one’s own understanding about a phenomenon, which could in turn stimulate interest in science. Students might view science as complicated (Tan and Barton 2008) because they are expected to explain natural phenomena with simple but scientifically correct models while the complexity of models increases with nuanced understandings of the phenomenon. Ella, for instance, “disliked science” because science was “too unpredictable and complicated” (pre-survey). Gradually, she became interested in the role by creating story entries with a combination of texts and videos from online sources. She chose videos to explain how the tsunami in their science fiction occurred. These videos are simulations of tsunami formation with which she intended to show that tsunami is a series of waves radiating outward from a center. Together with the videos, she wrote in the story, “the Squad knew that tsunamis were caused by seismic activity and the moving of plates, even the smallest movements cause huge waves radiating from a center.”

Furthermore, she explained that she learned tsunami gradually by searching for different videos that introduced it from different angles. These angles represented her journey of exploring tsunami. Specifically, she watched videos showing real tsunami and paid attention to waves moving towards people. Next, she watched videos explaining where the waves came from. This journey of exploration went on as she had more questions about tsunami. Eventually, she chose one video with a simulation to present her understanding of tsunami. Different from her original view of “science is not for me”, after composing with videos and texts, Ella appreciated science learning, a field that she was otherwise entirely uncomfortable with.

In conclusion, while producing artifacts to fulfill role responsibilities, students chose preferred modes to engage in science learning, which in turn increased their interests in science. At the knowledge level, we observed that creating multimodal artifacts helped students change certain misconceptions (e.g., the formation of cyclones) and develop a more advanced understanding (e.g., the formation of tsunami). At the metacognitive level, many students changed their perceptions about science and realized that science learning could be an active process, a creative experience, and an iterative process of refining understandings of phenomena. This study demonstrated that leveraging interests in using multiple modes as resources to access, learn, investigate, engage, communicate, and represent science had the potential to forge science identities in a positive direction.

Linking science practices in classrooms and those in professional domains

As students took on discipline-specific roles, we observed how this role-taking experience shaped their views of science practices in the workforce, repositioned themselves in relation to science, and made them actively think about future careers. Specifically, students linked practices that they performed in their role as a scientist with practices that scientists would carry out in professional domains and reported that taking the role of scientist helped them set professional goals.

Conducting investigations for evaluating scientific evidence was a practice that students noted that practicing scientists would carry out, similar to their role of scientist. For instance, Selina developed a stronger interest in a detective career from the practice of conducting investigation. While taking the role of scientist, she “researched” numerous online resources and equated the “research” as collecting evidence as practicing scientists. She also emphasized the importance of evaluating the evidence as the content in online resources could vary greatly in quality and validity. Taking the role of scientist enabled her to practice investigation and further strengthened the desire of establishing a career in the field. As shown in Table 2, taking the role of scientist did not guarantee that students would pursue a future career in science, but it made students actively think about what professional scientists do and what they would like to become in the future, rather than purely focusing on science practices.

Arguing about socio-scientific issues also provided students opportunities to connect school and professional science practices. In the activity of “me in 20 years”, Howard described himself as a biomedical engineer who created nanorobotics for disease treatment at the cellular level. In addition, he was identified as a technology expert by classmates and the research team and passionate about learning advanced technologies. He ended up taking all three roles with being designer as the dominant role. His comic design was about Joel (i.e., the main character in the fiction) witnessing the toxic level of pollution after escaping from his clones. Howard understood that there would be “cool” technologies, such as cloning machines and nanorobotics, but also challenges to solve in the future, such as pollution. In the final survey, he expressed the desire of becoming an environmental scientist to solve environmental challenges. In his words, “as a scientist, I have learned how global warming was affecting the planet and it helped me to think about some future jobs, like an environmental scientist which could help save global warming.” Composing for showing socio-scientific issues had the potential of cultivating global responsibilities of protecting environments and motivating students to build stronger science identities.

Additionally, students characterized scientists as creative and someone who would generate innovative designs as their roles. As described previously, in the process of representing science ideas with multimodal comics as a scientist in the team, Charles grew to perceive science and creativity to be essentially connected and started the exploration of a career that combines design and science. The fact that his perception change led to interests in science-related careers resonates with results from other studies such as Masnick et al. (2010), who found that the common misperception of science being uncreative could steer students away from STEM careers.

Our findings demonstrate that students linked practices, including conducting investigation, arguing about socio-scientific issues, and generating creative designs, in classrooms and professional domains while taking the role of scientist. In this process, multimodal composition was integrated into authentic science practices. Although students might develop incomplete or even misperceptions about how professionals work, the link between practices in classrooms and those in professional settings motivated students to set professional goals, either related or irrelevant to science.

Recognizing the relevance of science in future non-science careers

Regardless of the level of interest in science or science careers, students recognized the relevance of science in future non-science careers. This recognition was sometimes reinforced in our project as they took hybrid roles, in this case, a combination of scientist and other roles.

Responding to the need of people that they would interact with in the future helped students see the value of science for their own future careers. Ella, for example, was passionate about writing and had little interest in science at the beginning of the course. However, her interest in science increased by having writer and scientist as hybrid roles and she became aware of the importance of science in her future career. She portrayed herself as a teacher in 20 years (see Fig. 4). In particular, she created a comic strip in which she would interact with students in the future. In the mid-survey, it became evident that Ella identified herself as a “writer/scientist” and enjoyed the hybrid role. Responding to the item whether she liked her role as a scientist, she wrote, “I love my roles as a writer/scientist because I get to write and prove things right. That’s what a teacher should do.” This indicates that Ella recognized that teachers were facilitators, motivators, and change agents with the sacred responsibility to transform students to be citizens with scientific literacy. In the final survey, Ella explained that she learned more about global warming but neither wanted to be a writer nor scientist in the future. As shown in Ella’s case, taking hybrid roles enabled her to learn science ideas from the perspective of different roles and more importantly, make connections between science and preferred future career (i.e., teacher).

Some students recognized that scientific knowledge itself could be a driving force behind innovation, investigation, and discovery in future occupations. Initially, Charles wanted to be an administrative assistant and ended up seeing himself as a designer in the future. While taking the hybrid role of scientist and designer, he regarded science as a means to get access to innovative design. The integration of practices from these two roles stimulated his realization of science components in a designer career. As another example, Selina portrayed herself as someone who discovered mysterious rocks in the task of “me in 20 years”. In the project, she researched online sources to set the scientific foundation about natural disasters. She viewed researching sources as a practice of investigation and discovery and developed a strong interest in pursuing a career as a detective in which she would carry out investigation with scientific knowledge. As

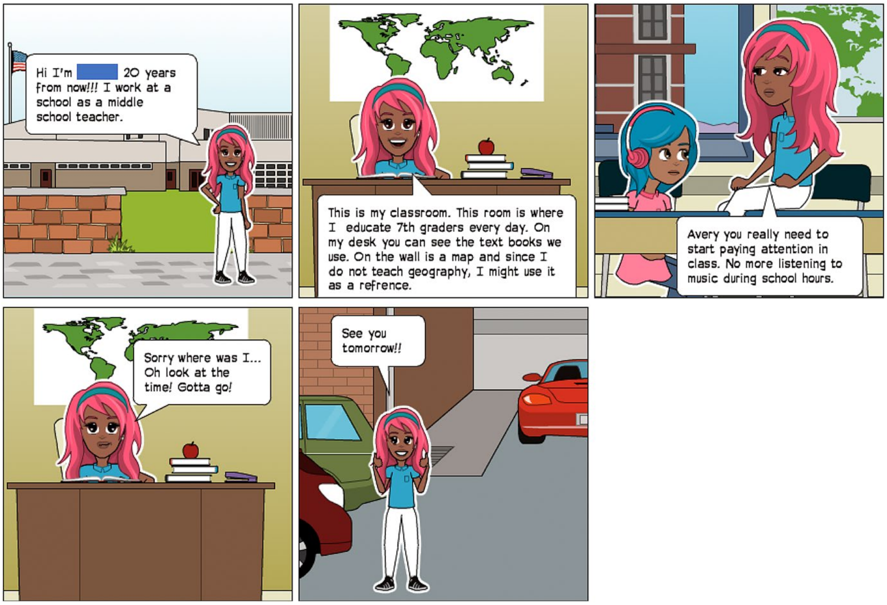

Fig. 4 Ella's portrayal of herself as a teacher in 20 years

shown in these cases, students viewed science as stimulation of creative thought, a method of investigation and inquiry in future careers.

Communicating science ideas with non-experts and presenting it in an easy-understand way for the public contributed to how students see the value of science in future careers. Mary's learning process highlights this finding. In the pre-survey, she was "undecided" about her interests in science, stating, "(in school) I do not like writing very long hypotheses but once we finally start experimenting, I love it." In the project, to address the need from group members, she searched for YouTube videos and explained major science concepts in the video as well as how the concepts were connected to their science fiction (see Fig. 5) to make sure that group members could integrate the concepts into their story easily. She also explained that sometimes she took hybrid role of designer and scientist when combining text and video for augmenting the effects of multiple modes for communicating science ideas for group members as well as other students in the class.

At the end of the course, Mary enjoyed her role as a scientist and communicating science ideas to others. In addition, different from her portray of housewife and being silent at the beginning of the course, she expressed the interest of being a public speaker as a future career at the end. In her words, "I realized that I love to speak in front of people. So, my future career could have something to do with speaking to large crowds." Mary's case, among other cases, illustrates that students appreciated science as a critical component in careers that involve communication and outreach, to name a few, science writer, journalist, museum education officer, and event manager.

In summary, students appreciated the value of science in responding to the need of people they interact with in future careers, providing a driving force for innovation, investigation, and discovery, communicating science ideas to the public. The role-taking experiences, mediated by multimodal composition, planted a seed in their minds early in their

Fig. 5 A science entry created by Mary

desired future careers, a seed that will hopefully grow into a full appreciation of the unique position of science as a critical practice for their lives.

Discussion and implications

In this study, we identified three themes about science identity development in a sixth-grade classroom: (a) composing with modes of choices could drive interests in science when students created science-related artifacts to fulfill role responsibilities; (b) students connected science practices in classrooms with those in professional domains through taking the role of scientist; (c) taking hybrid roles while composing with multiple modes might contribute to the recognition of science in non-science careers. These three themes have implications for designing learning environments that can facilitate early adolescents' development of positive science identities and engagement in career exploration.

This study demonstrates that composing with multiple modes offered the students opportunities to author science identities with their preferred modes and digital formats. Specifically, creating multimodal artifacts could promote students' interest and motivation to learn science concepts and even contribute to the desire of pursuing a science-related career. In accordance with the literature (Smith 2019; Goulah 2017; Halverson 2013), this finding shows that providing students flexibilities in choosing modes for composition could foster interests in certain disciplines, in our study, science. In addition, our findings complemented other studies in highlighting that multimodal composition could help students see science learning as an active process, a creative production, and an iterative process. This directly addressed common misperceptions of science (Masnick et al. 2010) that might turn students away from science learning.

While there is a growing body of research (e.g., Cummins et al. 2015; Skerrett 2012; Tucker-Raymond et al. 2007) examining how composing with multiple modes facilitates identity development, the majority of these studies have been conducted in an informal learning environment where students were limited to only choosing one single digital format (e.g., video). Contributing to this line of research, this study reveals that the flexibility of choosing digital formats (e.g., comic, video, and infographic) to represent science ideas could support students in authoring science identities in a STEAM course. Importantly, we learned that students viewed self-generated multimodal artifacts as not just representations of science phenomena, but also ways to communicate science ideas. In the process of creating artifacts, they paid close attention to the needs of audiences of their products. This study offers new insights that communicating science ideas with preferred modes (Smith 2017; Gunel et al. 2006) and digital formats might position students as owners and active creators of science knowledge.

We carefully selected digital tools that were easy to learn or had step-by-step tutorials for novices. Additionally, we encouraged students to utilize tools that they were already familiar with. In this way, teachers might have less pressure in learning different kinds of technologies and can focus on giving students feedback on the integration of disciplinary knowledge into digital artifacts. However, there were scenarios in which students brought in preferred modes and tools that the instructors had little expertise in. In these scenarios, we explored the tools with students together. This study opens the door to needed conversations about how to bring multimodal composition into classroom practices effectively for engaging students in science practices that they might otherwise be hesitant to participate in.

Furthermore, while composing with modes of choices could guarantee access to science learning, students needed guidance to learn and integrate science ideas. The literature suggested that digital literacy educators and content specialists should collaborate with each other to help students use digital tools to learn discipline-specific knowledge (Casey 2012; Fang and Coatoam 2013). Our study provides guidance to this kind of collaboration by showing that the development of digital literacy skills went hand in hand with learning science ideas (Manderino and Castek 2016). The interplay between multimodal composition and science learning would be a promising area for classroom research on helping students learn science effectively.

This study shows that taking the role of scientist could help students connect practices in science classrooms with those in professional domains and engage students in career exploration. The investigation of how students view science and science careers is critical as these views might shape their interest in science learning and pursuing corresponding fields (National Research Council 2017). The field has devoted a lot of effort into investigating ways to engage early adolescents in exploring science careers. Common strategies include providing access to practicing scientists (e.g., Bamberger 2014) and carrying out authentic scientific investigations (e.g., Meyer and Crawford 2015). These strategies emphasized the importance of establishing close relationships between students and science careers. Contributing to this line of research, this study proposes that playing the role of scientist could also be an effective strategy in this pursuit. Importantly, this study illuminates that role-taking has the potential of engaging early adolescents in actively thinking about whether science careers are desired future professions and exploring their own career preferences. This implies that teachers could guide students to develop career interests by reflecting on role-taking experiences.

While taking the role of scientist, students created multimodal artifacts. This indicates that multimodal composition might be integrated into authentic science practices (Grapin 2019; Zheng et al. 2014). In particular, the composition provides opportunities for students to investigate scientific information, arguing about socio-scientific issues, and generate innovative design with scientific knowledge. This finding makes an important contribution to studies that have explored bringing authentic science practices into classrooms. In addition, we purposefully created activities for students to link classroom learning and professional practices while introducing different tools for composition, such as the activity of creating multimodal comics to represent future professions and working environments. These activities might also contribute to students' linking between science practices in the classroom and workforce. Thus, identifying tools, materials, and activities to link practices in classrooms and professional domains through multimodal composition is a fruitful area for future exploration.

Students' perceptions of scientist were not stable in early adolescence and they would create different versions of scientist based on practices they engaged in (Tucker-Raymond et al. 2007). However, their perceptions could reflect a shallow mapping between practices. In our study, students searched for online information to provide scientific background for their fiction, such as using a YouTube video to show the danger of hurricane. Based on this online searching practice, some students viewed that scientists would engage in similar activities in the workforce and some regarded this practice as research. Scientists would search for information, but not as simple as finding multimedia information—a critical part of being a scientist is discovering and creating new knowledge to push the field forward. The shallow mapping could lead to a naïve understanding of scientific inquiry, experimentation, and research. Thus, instructors should help students to develop a nuanced understanding of the activities that scientists engage in when making connections to classroom activities.

This study suggests that taking hybrid roles has the potential of helping students to realize the relevance of science in future non-science careers and embrace alternative recognition of future selves. Similar to Nurra and Oyserman's (2018) findings, we found that the learning context could have an impact on early adolescents' negotiation between "what I am" and "what I would like to be." Furthermore, Anderhag et al. (2016) argued that failing to incorporate current selves ("what I am learning") into future selves ("what career I want to pursue") could explain the decreasing interest in science during early childhood. This study extends this line of research by demonstrating that most students recognized the relevance of science in future professions via taking hybrid roles. Taking hybrid roles enabled the students to recognize alternative future selves and incorporate the component of science in the recognition. Students regarded science as a need of people who they interact with, a driving force behind innovation, investigation, and discovery, background knowledge in communication and outreach in future non-science careers. This recognition could contribute to lifelong learning of science no matter what career interests they have (Feinstein et al. 2013). Therefore, it's critical to explicitly teach students the application of science in different careers, especially their preferred non-science careers.

Although this study provides compelling evidence that multimodal composition is beneficial for science learning and the cultivation of positive science identities in classrooms, it should be recognized that it was of short duration and involved a relatively small sample size. It would be beneficial to study the long-term outcomes of multimodal composition on science identity formation with various groups and settings. While we focused on students who took the role of scientist, it would be worthwhile to explore science identity development for students taking other roles and compare patterns of identity development for those who started with the role of scientist and those who started with other roles. Furthermore, while pretending in roles (Pitts and Edelson 2004) was not the major theme in our observation, we acknowledge that the role of scientist might provide a venue for students to pretend in the role, especially for those who were not interested in science at the beginning. It's worthwhile to examine how students move beyond pretending in the role and to gradually develop comfort with the role.

As with similar studies in science identity (e.g., Barton and Tan 2010; Carlone and Johnson 2007), we have a small sample size. Identity is a complex and dynamic construct. To capture the complexity and nuances, we need much in-depth discourse and other types of observations or interactions to develop a full picture of an individual. That needs more qualitative approach, implying small sample size, especially in explorative type of study. Recently, researchers explored ways to predict disciplinary identities with communicative languages, such as messages that students sent to a pedagogical agent (Crossley et al. 2020). This methodology holds the promise of studying disciplinary identities at scale while still maintain the nuances and dynamics of identity development.

Conclusion

In this study, we examined sixth-grade students' science identity development in a multimodal composing environment. Our findings indicate that multimodal composing created an alternative space for students to author science identities. This highlights the importance of allowing multiple points of entry for students to practice science. We also found that students actively investigated and reflected on what scientists would do as a profession while taking the role of scientists. It suggested that embedding students in the role of scientists had the potential to foster students' interest in science and motivation to develop career interests. It also indicates that composing with multiple modes had the potential of integrating authentic science practices. In addition, all focal students ended up taking hybrid roles. This phenomenon calls attention to helping students make connections between science identities and preferred future professions, especially non-science ones.

This work contributes to the research on science identity development by exploring ways that playing the role of scientist while multimodal composing provided unique opportunities for early adolescents to engage in science, to develop identities in science, and to see and understand science differently. Additionally, this study contributes insights for designing and studying learning environments to facilitate the development of disciplinary identities and engage early adolescents in career exploration.

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Conflict of interest The authors declare that they have no conflict of interest.

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