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Designing discipline-specific roles for interdisciplinary learning: two comparative cases in an afterschool STEM + L programme

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ABSTRACT
The current K-12 educational system often does not engage students in interdisciplinary learning. To address this need, we developed an integrated STEM + L (Science, Technology, Engineering, Math, and Digital Literacies) afterschool programme in which middle school students took discipline-specific roles (writer, scientist, artist, and engineer) and worked in small groups to produce multimodal science fictions. The study aims to investigate the effect of discipline-specific roles on students' interdisciplinary and collaborative learning processes. Two groups were chosen as comparison cases because their final products indicated low and high levels in integrating science and literacy respectively. Analysing and visualising students' individual role-changing patterns and examining their discourse in role-specific interactions revealed the following features for high-quality interdisciplinary learning: (1) Students need to be willing and able to enact not only expected roles, but also other roles; (2) Students need to develop awareness of their own and others' role enactment; (3) Collaboration between students with different roles may follow a possible trajectory from solo-construction, to co-construction, to re-construction. This study also proposes instructional strategies related to the design of discipline-specific roles to facilitate interdisciplinary learning in STEM education.

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Introduction

As working across disciplinary boundaries is penetrating many frontier science, technology, engineering, and mathematics (STEM) fields, interdisciplinary collaboration becomes increasingly demanding in the workspace (Committee on Facilitating Interdisciplinary Research [CFIR], 2005). However, the current K-12 educational system often does not engage students in interdisciplinary learning (Shen, Sung, & Zhang, 2016; National Academy of Engineering [NAE] and National Research Council [NRC], 2014). A number of intertwined factors contribute to this gap. From an epistemological perspective, established knowledge has been passed on from one generation to the next within a disciplinary structure. This is reflected in instruction as most learning materials such as

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textbooks are being organised within disciplines. From an infrastructural perspective, typical instructional units in schools – especially at the secondary level – are departmentalised according to disciplines. Fitting into such a structure, teachers are prepared in a disciplinary fashion, making it hard for them to develop or implement learning activities across disciplines. Furthermore, the tight accountability system including standardised testing is established on disciplinary foundations. Therefore, schools and teachers are hard-pressed to change the status quo to introduce interdisciplinary innovations in classrooms.

To address this challenge, as an exploratory effort we developed an afterschool programme to help middle school students participate in discipline-specific practices while working in interdisciplinary teams. The participating students worked in small groups to produce original multimodal science fictions. To foster students' disciplinary and interdisciplinary learning, we built in our programme differentiated roles that students had to take on (e.g. writers, scientists, designers, and engineers), emulating an interdisciplinary collaboration working environment where people come from different disciplinary backgrounds (Smith & Shen, 2017). These paper reports findings from our pilot implementation in a local middle school with a focus on students' role-taking behaviours.

The project utilised three key design features to facilitate students' interdisciplinary learning: (1) integrating science and literacy, (2) multimodal composition in digital environments, and (3) discipline-specific role taking.

Integrating science and literacy and practicing multimodal composition

Digital literacies naturally serve as conduits for students to integrate different disciplinary knowledge and practices across STEM and literacy (STEM + L) (Nixon & Akerson, 2004; Pinkard, Erete, Martin, & McKinney de Royston, 2017; Ritchie, Tomas, & Tones, 2011). First, literacy itself is a composite entity of various content areas, making it necessary for interdisciplinary learning. Second, new digital literacies have become a norm for everyday life for adolescents, making it accessible for interdisciplinary learning.

There have been a variety of approaches that integrate science and literacy (Guzzetti & Bang, 2010; Hand et al., 2003; Norris & Phillips, 2003). Some approaches emphasise the use of literacy as tools to learn science (Chen, Hand, & McDowell, 2013); others emphasise the use of science as a context to practice literacy (Fang, Schleppegrell, & Cox, 2006). For instance, Reading Apprenticeship (Greenleaf et al., 2011) is a project WestEd developed to support middle and high school students' literacy in content areas including science. Participants conducted science-related reading practices, such as reading a nonfiction science book and the biography of a scientist. It was shown that students became more capable and willing science readers after participating in the project (Creech & Hale, 2006). The project also showed students' improved sense of themselves as readers and learners, evidenced in how they engaged and comprehended a wide range of academic texts (Schoenbach, Greenleaf, & Murphy, 2012).

Multimodal composition has become increasingly prevalent for adolescents in communicating and expressing themselves outside of school (Lenhart, 2015; Smith, 2014). Multimodal composing is a process of using several semiotic modes such as image, text, layout, and animation to convey certain meanings purposely (Kress & Van Leeuwen, 2001). As an example, the STEM Literacy through Infographics (SLI) project (Lamb, Polman, Newman, & Smith, 2014; Polman & Gebre, 2015) explored how making digital infographics challenges students to use visual representations to make sense of scientific data and information. When integrating science and digital literacies, students experienced a variety of multimodal practices, such as using web-based infographic creation tools to design infographics related to science topics. Research has shown that multimodal composition has the potential to facilitate students' development of disciplinary expertise (Binder & Kotsopoulos, 2011; Hand, Gunel, & Ulu, 2009; Kress, 2009; Kress & Van Leeuwen, 2001; Smith & Shen, 2017; Vasudevan, Schultz, & Bateman, 2010).

Typically, these exemplar projects tend to help all students develop competencies in the same discipline (e.g. in science or literacy). Rarely, an individual project is designed to grow differentiated competencies for different students, which is the approach we took and is related to students' disciplinary identity development we envision in our project.

Discipline-specific role taking

People have multiple identities connected to their performances and interactions with others in society. Understanding identity as a trajectory of becoming is critical because it often shapes and is shaped by environments (Barton & Brickhouse, 2006; Bulter, 1990). Identity is conceptualised in this paper as 'kind of person' or 'kinds of person,' at a given time and place, that can change from moment to moment in the interaction and can change from context to context (Gee, 2000). Identity is influenced not only by external forces (e.g. social and cultural structure) but also one's own agency (e.g. what one makes of her/himself) (Archer, 2003; Aschbacher, Li, & Roth, 2010; Cleaves, 2005; Taconis & Kessels, 2009). Thus, deep learning requires an environment in which students take on identities they value and in which they become heavily invested (Gee, 2005).

One of the identities students encounter in schooling is disciplinary identity, the focus of the study. Dressen-Hammouda (2008) defined it as 'an ensemble of socio-historical regularities and norms that practitioners embody as a result of specialising within their disciplines' (p. 235). In the context of typical schooling, students not only develop disciplinary knowledge and skills through attending classes organised in disciplines, but also gradually identify themselves as potential candidates in specific disciplines or professions. New learning standards documents, such as the Common Core Math standards and Next Generation Science Standards, encourage students to grasp core disciplinary knowledge as well as engaging in professional practices.

However, the discipline-based school structure may prevent students from taking on interdisciplinary perspectives. Much research has shown that students are unable to solve complex problems and conceptualise pressing societal issues (e.g. clean energy) that are interdisciplinary in nature (Zhang & Shen, 2015). To enhance students' development in both discipline-specific identity and interdisciplinary learning, our project asks them to take on differentiated roles while collaborating on interdisciplinary tasks.

Role taking is a useful strategy in supporting productive peer interaction because it distributes different responsibilities across group members (Hare, 1994) and provides ownership for their learning (Tagg, 1994). Many role-taking strategies use conversational functional roles, depending on how learners interact with each other and contribute to the conversation (e.g. Salazar, 1996; Strijbos, Martens, Jochems, & Broers, 2004; Wise, Saghafian, & Padmanabhan, 2012). There are conflicting results about the effectiveness of role taking. Schellens, Van Keer, De Wever, and Valcke (2007) showed how using roles led to significantly higher levels of knowledge construction because having roles evoked active participation in group discussion. However, De Wever, Schellens, Van Keer, and Valcke (2008) demonstrated that a negative effect of using roles was that students might focus on their own roles and paid little attention to the activities related to other roles.

Instead of conversationally functional roles, students in our project take roles related to academic disciplines. This is because we want to help students develop expertise in the disciplines that they are devoted to and, at the same time, observe and grow awareness of other disciplinary practices their team-mates carry out. Specifically, while working in small groups of three or four to create a multimodal science fiction, each of them self-selects one of the following roles: (1) *Writers* are in charge of developing the science fiction narrative based on discussions with group members; (2) *Scientists* are responsible for monitoring the existence and accuracy of science vocabulary, concepts, and background knowledge; (3) *Artists* lead the creation of visual and audio representations for all main characters and/or scenes in the story; (4) *Engineers* are accountable for designing buildings, vehicles, and settings for the story. These roles are proposed because they are essential for creating the multimodal science fictions in the project, and they cover disciplinary practices that students participate in and out of schools. Nonetheless, students are encouraged to propose their own roles and change roles if needed.

We conceptualise students' role taking from both an intrapersonal and an interpersonal perspective. From an intrapersonal perspective, an interdisciplinary learner needs to integrate different disciplinary knowledge and practices. In this programme, individual students need to see connections among different disciplinary knowledge and practices (e.g. practices that their and others' roles represented) and integrate them to create (parts of the) multimodal science fictions. From an interpersonal perspective, an interdisciplinary perspective enables one to work with others from different backgrounds. In our programme, students work in small groups and communicate with each other while taking different discipline-specific roles. This study pays particular attention to the key characteristics of student discourse interactions related to their roles. Combing both perspectives, this study then explores the relationship between discipline-specific role enactment and interdisciplinary learning.

In sum, the aim of this exploratory study is to examine the features of students' role taking behaviours and offer insights on how these behaviours may explain different qualities of interdisciplinary learning products. The following research questions guided our study:

(1) What are the key characteristics of individual role-taking patterns that could contribute to high-quality interdisciplinary learning products?
(2) What kinds of role-specific interactions could produce interdisciplinary learning products with higher quality?

Method

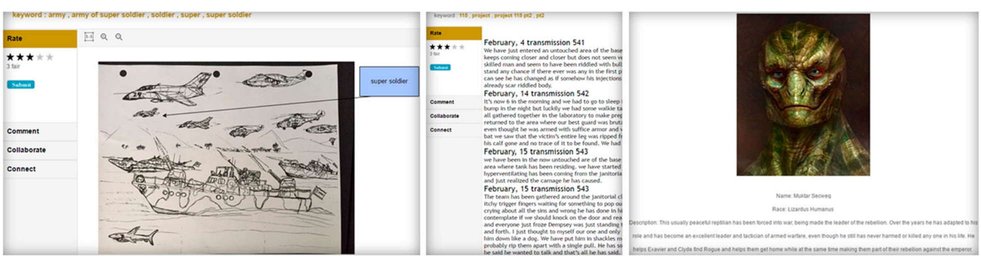
Study context

The study took place in an afterschool programme (i.e. an organised programme that students attend outside of traditional school days/time) we developed to improve middle school students' core competencies in reading and writing, knowledge and interest in STEM, and interdisciplinary learning. The programme was implemented in a public middle school in a large southeastern city in the United States that has a heterogeneous demographic profile. Participating students were recruited on a first-come, first-served basis. There were 17 students (grade 6–8; 13 boys and 4 girls) enrolled in the study. The participants were mainly Latinx students, consistent with the school demographics. The pilot programme consisted of nine-weekly sessions (~1 hour per session). In session one, the instructors introduced the overall goal and schedule, the expected final product, and responsibilities of each role in a team. At the end of the first session, students completed an initial survey to report their interests and rankings of preferences in roles. In session two, students formed small groups using the following means. They first used stickers of different colours to indicate their first and second preferred roles. Then they walked around to form their own groups based on their preferences of roles and familiarity with team members with the requirement that each team had to have a scientist and a writer. Afterward, they brainstormed potential topics in their groups. In the following sessions, in addition to small group working periods, lectures or mini-workshops on writing strategies and relevant technology training were provided for students. Appendix 1 lists the main activities of the sessions.

Data source and selection

We collected multiple sources of data, including the following:

- *Artefacts.* Knowledge entries including the science fiction chapters created in iKOS. We also collected any process work associated with the workshop or the final product. Figure 1 shows three examples of student artefacts.
- *Video records of computer screens and small group work.* Camtasia, a screen recording tool, was used to capture what happens on students' computer screens as well as their conversations. In addition, four cameras were used to capture video data from each of the four working groups.
- *Interviews and surveys.* Semi-structured interviews with individual students were conducted at the end of the programme to better understand students' learning experience in the programme. These interviews were audio recorded. Each interview lasted around



(a) (b) (c)

Figure 1. Sample screenshots from student products including uploaded student drawing related to their fiction (a), story in a lab log style (b), and the introduction of a character in the story (c).

15 minutes. Students were asked to describe their story, contributions, the overall process for creating the story, role-changing, collaboration, and gains from the project. In addition, we administrated a survey (Appendix 2) at the end of the first session to poll students' backgrounds and interests. The survey consisted of eight questions related to students' interests in technology, writing, science, and role preferences, and was mainly used for grouping students.

Analytical procedure and coding schemes

We first examined students' final products by extracting some basic information such as main storylines and coded their final products in multiple dimensions including modality, source, explanation, and integration (Jiang, Shen, & Smith, 2016, April). We coded their final products sentences by sentences and identified those that contained science ideas. For each sentence that contained a science idea, we ranked its science integration in three levels (Appendix 3). We then conducted a comparative case study (Stake, 2006), focusing on the two groups (see the Results section about the composition of the two groups) who created stories with the highest and the lowest integration level between science and writing (Jiang et al., 2016, April).

In order to understand students' role taking processes, we then identified three representative sessions for comparison: in session two they were brainstorming candidate topics for their fictions, in session three they were fleshing out details of the story (e.g. characters, settings, and science concepts), and in session seven they were wrapping up their final products. These three sessions not only represented three critical stages for creating multimodal artefacts (Smith, 2017), but also included extensive group discussions. In other sessions, students either had little time for group work or mostly worked individually on composing tasks. We transcribed the video records of small group work and examined the group discussion closely. We paid particular attention to the interaction between the scientist and the writer in each group. We also counted the total time and number of turns of each student's contribution to the group discussion.

To address our research questions, we conceptualised student role-taking actions in two aspects, *intrapersonal* and *interpersonal*. We first focused on the roles they took individually (intrapersonal aspect) and coded their discourse using a scheme as shown in Table 1. Then, through examining the content of their discourse, we identified the recurring

Table 1. Coding categories for role-changing patterns.

Code	Description	Example
Expected role = In-action role	Students enact roles that are the same as their self-selected roles (i.e. writer, scientist, artist, and engineer) during their speaking turns.	*Student A: 'what is the setting' How about an alternate dimension?' (Student A selected to be the 'writer' who was expected to develop the plot of the fiction.)*
Expected role ≠ In-action role	Students enact roles that are different from their self-selected roles during their speaking turns.	*Student B: 'Patrik (the name of a character), how about Logan?' (Student B selected to be the 'scientist' who was expected to verify and incorporate scientific information related to the story.)*
In-action role is general	Roles that students enact are coordinators.	*Student C: 'what's your idea?' (This statement does not entail any role-specific information and serves to coordinate the discussion.)*

themes of interaction patterns between the writer and the scientist (interpersonal aspect). Two raters coded the entire data together, resolved differences as they coded, and arrived at a single decision for each code. Then, the coding result was visualised to demonstrate students' role-taking patterns.

Results

Table 2 provides an overview of the three complete science fiction stories, including main storyline, total word count, total number of sentences, and total number of sentences that contain scientific ideas.

In the following, we first summarise the discourse interactions for the two selected groups. Then, we address the two research questions by reporting results related to the individual role-taking patterns and their role-specific interaction themes.

Summary of discourse interactions in the two groups

Table 3 shows the distribution of each member's participation in a number of discursive turns and actual speaking time for the contrasting groups of Reptilian King (RK) and Super Soldiers (SS).

Summary of group RK – the high integration group

There were three members in Group RK with three different roles: writer, scientist, and artist. The scientist and the artist picked their roles as their first preference, while the writer picked his second preference (according to the survey). Typically initiated by the writer, the members in Group RK were open to sharing ideas from different perspectives (e.g. story narratives, science ideas, and designs). The group often reached consensus on a topic before moving the discussion forward.

In session two, the discussion began with sharing of ideas, mainly expressing their own thoughts (e.g. ideas on 'designing characters' from the artist, 'time travel' from the scientist, and 'mutated shark' from the writer). These ideas did not necessarily build upon each other initially. In the meantime, the writer would elicit more ideas by stating sentences like

Table 2. Descriptive information for the three stories.

Story Features	Story ReptilianKing	Story Teleportation	Story SuperSoldier
Title	Journey to Empire of the Reptilian King	Teleportation SciFi	Project 115
Main story line	Two characters travel through a wormhole to rescue a partner only to get caught in a war between the Reptilian King and his rebels.	Teleportation technology created by moon colonies is used to overthrow the Earth's colonialism.	A super soldier sent to an underground lab to be cloned is on the run and causing damage.
Total word count	2938	1628	1288
Total number of sentences	160	73	54
Number of sentences that contain science ideas (percentage of total number of sentences)	21 (13%)	28 (38%)	14 (26%)
Level of science integration in storyline	High	Medium	Low

Table 3. Distribution of members' participation in number of discursive turns (time of actual speaking in seconds) for Group RK and Group SS.

Group	Session #	Writer	Scientist	Artist	Engineer	Total
Group RK	S2 (21 min)	16 (46.1)	16 (73.3)	19 (82.5)	NA	51 (201.9)
	S3 (14min)	41 (351.0)	33 (130.3)	31 (100.1)	NA	105 (581.4)
	S7 (39min)	22 (63.0)	14 (47.6)	23 (76.0)	NA	59 (186.6)
Group SS	S2 (10 min)	19 (70.4)	15 (34.6)	8 (18.6)	4 (14.1)	46 (138.7)
	S3 (13min)	30 (97.1)	25 (78.5)	25 (105.7)	24 (87.1)	104 (368.4)
	S7 (31 min)	15 (91.2)	Absent	8 (26.6)	15 (35.4)	38 (153.2)

'What type of science fiction do you guys want to write?' Shortly, the group voted and decided to incorporate the two major elements (time travel and mutated creatures) emerged from the discussion. Then the group started a discussion on relevant science ideas and story plot to develop a rough storyline. Even though the writer did not speak as much as the other two (Table 3), he often guided the group discussion to focus on the main storyline.

In session three, the writer led the discussion on determining details in the story and spoke for most of the time. Usually, the writer initiated story ideas (e.g. settings and characters), and then the others built upon those ideas. While the scientist interacted with the writer back and forth by incorporating science ideas, the artist realised her role as a designer and focused on describing characters. The group created the majority of the story together under meticulous guidance from the writer.

In session seven, the writer started the conversation by explaining what they did and what they should work more on. Afterward, the artist showed the team pictures and descriptions of all characters in the story. The writer, and for a few times the scientist, gave corresponding feedback to the characters. Meanwhile, the scientist discussed with the writer his idea of rewriting the writer's entry in a more scientific way.

Summary of group SS – the low integration group

There were four members in Group SS with all four roles: writer, scientist, artist, and engineer. All the students picked their first preference except the scientist, who picked that role as his third choice in the survey, but ultimately agreed to serve as a scientist for the group. Group SS's discussion was much more media-oriented than Group RK: Students tended to share ideas by introducing and describing different media (e.g. film and game). These media provided more insights on story narratives, but limited opportunities were explored on science ideas.

Similar to Group RK, Group SS' session two began with idea sharing. The scientist suggested to situate the story in outer space; the writer brought up a discussion on *Splice* (a science fiction film). Then the writer continued with describing possible science ideas (e.g. genetic mutation) they could borrow from the movie. However, the scientist ignored the science aspect, but insisted on proposing that their story could be a horror genre. In order to persuade group members to use *Splice* as a reference, the writer further introduced the setting and the major storyline. This part of the discussion did not reach a conclusion. Then the scientist brought up a discussion on a film related to alien. This part of the discussion focused on exchanging ideas of storylines and also ended up without a conclusion. The group did not reach consensus on what topic their fiction would focus.

In session three, the artist proposed the idea of making space shuttle to another planet while the scientist brought up the science film *I, Robot* and suggested that the setting should be on the Earth instead of in outer space. Then the writer reminded the group their ideas from the last session about space and *Splice*. Without a conclusion, the artist continued with a discussion on *Battle: LA*, a science fiction war film. Eventually, after the writer proposed that they should vote for the ideas, the discussion started to move forward to develop a story on an underground experiment on human cloning. The discussion did not involve much science.

The scientist was absent in session seven. Group SS searched for and discussed pictures for the main character in the story (super soldier) together. During the discussion, the writer proposed to use his father's drawings to represent the character and scenes in the story. In addition, the engineer was more engaged in searching pictures for the character than the artist.

Research question 1: comparison of individual role-changing patterns

In response to the first research question, Figures 2 and 3 visualise individual students' role changing patterns in Groups RK and SS, respectively. Each data point represents a turn an individual student took in small group discussion. Data points above (below) the x-axis represent that the student's in-action role is the same as (different from) his/her expected role (Table 1). Data points on the x-axis represent that the student's in-action role is general, meaning that the statement from the student does not entail any role-specific information; instead, it coordinates the discussion (Table 1).

Group RK

The writer

The writer's first preference was to be a scientist or an artist according to our survey during session 1. According to his post interview, he decided to go with the writing role because he tried out the other roles and didn't like them. The writer played a leadership role in the group to coordinate with team members to push the storyline. As shown in Figure 2, he

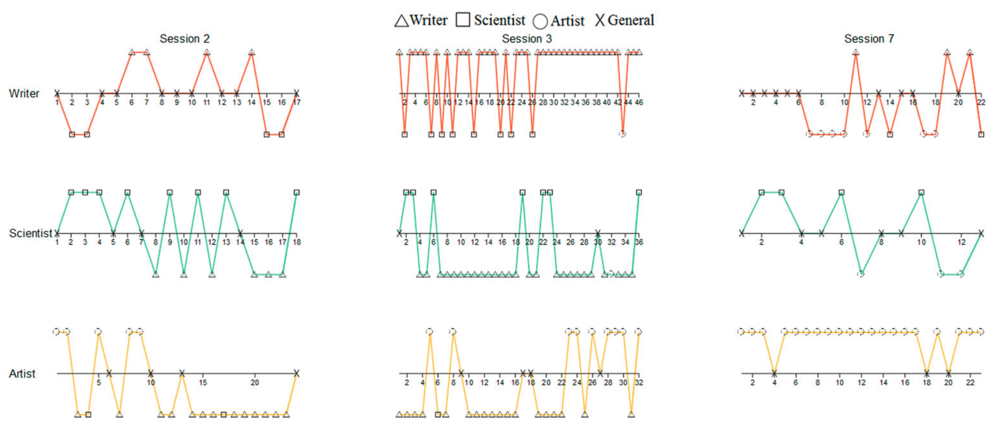


Figure 2. Role-changing patterns in Group RK.

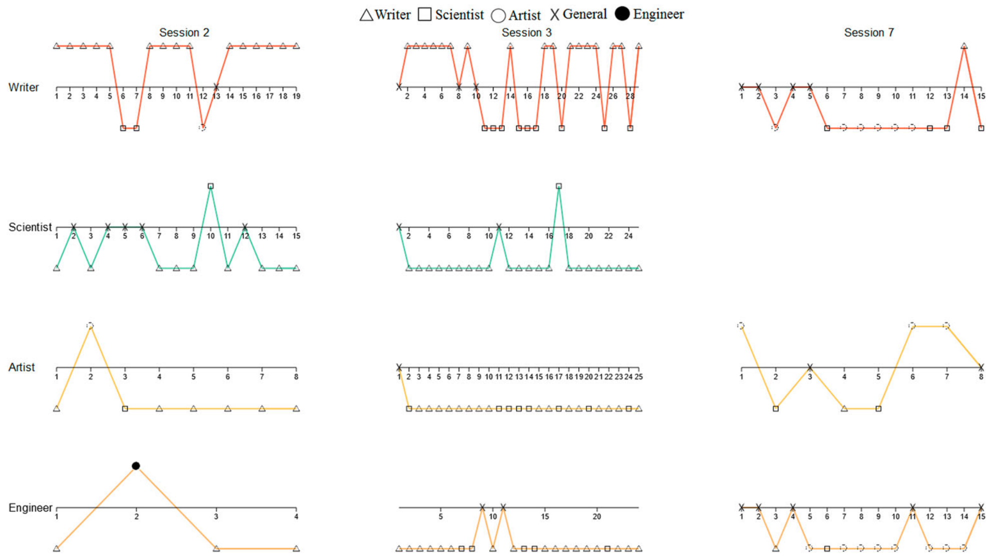


Figure 3. Role-changing patterns in Group SS.

was also flexible at times to act as either a scientist or an artist to provide corresponding ideas or give feedback. In session 2, the writer mainly played the role of a coordinator to ensure that all team members had the opportunity to share ideas. For instance, he invited other team members to express their ideas by saying 'What type of Sci-Fi you want to write about?' In session 3, he led the whole group discussion as a writer to flesh out details of their story. For a couple of times, he took a scientist's lens to respond to the scientist's suggestions. In session 7, he first worked as a coordinator as usual and then switched back and forth between a coordinator and other roles: He enacted as an artist to provide suggestions on the artist's design and enacted as a scientist to discuss the science aspects with the scientist in the group (Figure 2). In reflection, the writer was aware of his leadership role. He remarked in his post-interview, 'Although she [the artist] would probably say I am the leader, … maybe I am.' Furthermore, he acknowledged others' roles. For instance, he pointed out in the post interview that 'the artist just stayed as the artist. She didn't do much writing except for a few ideas.' In sum, the writer's coordinating actions facilitated equal contributions including science ideas from other team members and helped move the discussion forward. This most likely contributed to the high integration between science and their final story.

The scientist

In general, the scientist was faithful to his expected role to a great extent; he was also flexible to enact other roles (Figure 2). In session 2, the scientist started the group collaboration by providing relevant science ideas. He also enacted as a writer a few times later in the session when the team was brainstorming about the story. In session 3, as illustrated in Figure 2, besides providing science ideas for the story he frequently took on a writer's role to discuss the plot. In session 7, he worked more as a scientist and coordinator, but also contributed a few times as an artist. In reflection, the scientist was conscious of his changing roles and stated in the post-interview, 'I was supposed to be the engineer and scientist but turned out I did more work as a scientist or a writer, sort of in between.' Like the writer, he was also conscious of others' roles. For example, he commented in post-interview, 'she worked as an artist, and I was sort of the scientist/writer, and Juan (the writer) was also scientist/writer.' Intuitively, the scientist's changing roles between scientist and writer helped contribute to the high integration between science and story in their final fiction.

The artist

In general, the artist was very clear about her role in the group. At times, she enacted as a writer in order to join the conversation between the other two members. At the beginning of session 2, the artist started in her expected role (Figure 2). Later she took on a writer's perspective to join the discussion between the writer and the scientist on brainstorming topics. In session 3, she began as a writer to engage in the group discussion on describing plots and characters. She disengaged herself from discussing the plots of the story since she was more interested in designing. As indicated in Figure 2, she changed back to be an artist to describe characters and search online for pictures that match the descriptions. In session 7, she showed her designs to the other two members and shared her insights about the designs. She was very articulate about her role as an artist in reflection. She declared in her post interview: 'My role is the artist and I animate everything. And I make sure the animations go smoothly and all of the visual effects. (Researcher: So did your role change?) Kind of, because I also did some of the other information and stuff, mostly I'm the artist.' Like her team members, she was also mindful of others' roles.

Even though the artist's clear self-identification did not necessarily enhance an efficient interaction between the writer and the scientist, sometimes she served as a catalyst that initiated their interaction.

Excerpt 6. (RK, session three: 0:43:46.63- 0:44:19.68)

Artist:	It could be interesting if her age reversed. And her appearance will look differently.
Scientist:	Ok. The trick is due to wormholes, it works with time stuff, and she has aged significantly than they should be. Significantly less, or
Writer:	Yeah, let's do it.
Scientist:	So Rogue reversed her age.
Writer:	She was originally 30 years old.

From the standpoint of design, the artist initiated the idea that the character's appearance would look differently if her age reversed. Stimulated by the idea of reversing age, the scientist explained the relationship between wormhole and time changing and the writer agreed to the idea.

Summary

The individual members in Group RK not only fulfilled self-selected roles but also enacted other roles. They were conscious about their own and others' role enactments. In addition, the writer played a leadership role.

Group SS

The writer

Similar to the writer in Group RK, the writer in Group SS was flexible to act as a scientist or designer at times (Figure 3). In session 2, he mainly worked as a writer to share his ideas on creating a story similar to the movie Splice. In session 3 he worked as both a writer and scientist to persuade team members to use Splice by describing what kind of story plot and science could be borrowed from it. In session 7, he suggested using his father's drawings in the final story. Thus, he acted more as an artist. Although the writers switched roles quite often in both groups, the reason for the switch seemed different: whereas the writer in Group RK changed his role because he intended to coordinate discussion by giving feedback to others, the writer in Group SS changed his role because he attempted to share his own ideas. In his post-interview, he explained, 'we were kind of procrastinating because we really didn't have a certain idea and each time we had a different idea.' In addition, he mentioned, 'my role has always been the writer. But the other drawings that I brought were from my dad so I guess you can also call me the artist.' However, he was not aware of his role as a scientist and other team members' roles.

The scientist

Unlike the scientist in Group RK, the scientist in Group SS rarely enacted as a scientist (Figure 3). Instead, he was more into story narratives as a writer. In session 2, he attempted to coordinate the discussion like what the writer in Group RK did. But no one followed his coordination. Then he joined the group discussion by describing different media and explaining the connections with their story. In session 3, he continued offering ideas from a writer's perspective in the same way as session 2. He was absent in session 7. Overall, he overlooked his responsibilities as a scientist and focused on connecting media with story narratives as a writer.

The artist

The artist in Group SS only enacted the role of artist a few times. Instead, he worked more as a writer and scientist (Figure 3). He did not talk much at the beginning of session 2. In the end, he contributed as a writer to add ideas about aliens brought up by the scientist. In session 3, he started to participate in the discussion only after the group decided on the focused topic. He provided ideas both related to science (e.g. clone) and story (e.g. soldier). In session 7, he searched for pictures for the main character and provided suggestions on science ideas based on team members' contribution. Although the artist took the role of a writer but was not aware of it. In his post-interview, in response to the question 'did your role change?,' he clarified that 'yes, I was scientist for a little bit and switched to artist because I like to draw. I thought it would be really cool to draw but I also like science and things that involve science.' Additionally, he did not mention specific contributions by his team members in the post interview.

The engineer

The engineer enacted multiple roles in the group. He barely talked in session 2 because he was uncertain about how he could contribute as an engineer. For instance, he explained that 'as an engineer, I cannot draw the engineering thing (that the writer just mentioned).'

He did not interact a lot at the beginning of session 3, but he contributed more from a writer's perspective to give ideas on storyline after the group had a focused topic. In session 7, as demonstrated in Figure 3, he actively acted as an artist to search for pictures online. Interestingly, he asked that 'Is the engineer supposed to know the story?' when the artist was trying to describe the story plot. His post interview indicated that he knew he was supposed to take the role of engineer, as he described 'my goal is to be an engineer, so I had to create the setting – mostly everything was broken, everything in the city was destroyed.' However, he was not able to create these settings for their final story. Moreover, he was not sure about the difference between an engineer and an artist and commented, 'engineer overlaps with the artist.'

Summary

Except for the writer (especially in sessions 2 and 3), the students in Group SS did not enact expected roles. In addition, they were not conscious of their own role enactments. The group lacked a leader who could coordinate the group effort.

Research question 2: comparison of role-specific interaction themes

In response to the second research question, three themes emerged from the discursive interactions between the writer and the scientist when comparing the two groups.

Adding (science) vocabulary in the story

The scientist in Group RK constantly added science vocabulary into discussions whereas the scientist in Group SS barely brought up science ideas and was engaged much more in discussing story narratives. The following excerpt from Group RK shows that the scientist connected the writer's portal technology idea with a science vocabulary 'wormhole technology.'

Excerpt 1. (RK, session three: 0:37:46.77- 0:38:10.63)

Writer:	No, he is a human who is trying to use a new technology, a portal technology
Scientist:	Wormhole technology
Writer:	Yeah, wormhole technology. To use it to transport, two porters, one in the northern part and one in the southern part.

In story RK, wormhole technology became a major science term and appeared multiple times. For instance, in the story they wrote, 'The crowd was astonished as they saw the wormhole opens as the device caused a rift through time and space.'

In contrast, the following excerpt reveals that the scientist from Group SS was more interested in the fiction genre and did not follow up on the writer's science ideas.

Excerpt 2. (SS, session two: 0:31:48.58- 0:32:19.29)

Writer:	So do you like *Splice* [a Horror/Sci-Fi film]?
Scientist:	You guys want to make it a horror?
Writer:	What I am thinking is, like we want to do splice and space. In space, there is a genetically mutation engineering thing, like a scientist doing that thing.

Engineer: As an engineer, I cannot draw the engineering thing.
Artist: I cannot draw either.
Scientist: Should we make it horror based?

Prompted by the film originally brought up by the writer, the scientist suggested making their science fiction story a horror. But the writer did not comment on the genre of the fiction. Instead, he brought up the science concept of genetic mutation. The engineer and the artist expressed the complexity of representing the science idea with visuals. Without commenting on the science aspect, the scientist brought back his idea of making the story a horror genre.

In addition, one of the major science ideas in story SS was cloning. This concept was brought up 7 times (artist: 2; writer: 2; engineer: 3) in session 3 for discussion; however, none of these was brought up by the scientist. Instead, the scientist focused more on developing the storyline despite the fact that he agreed to take the scientist role in his group.

Even though adding science vocabulary itself cannot guarantee high integration between science and writing in final stories, the comparison suggested that the scientist needed to actively bring scientific ideas to make it visible in the discussion.

Co-developing storyline

The writer and the scientist in Group RK built on each other's ideas to develop the storyline. In contrast, team members in Group SS had diverging ideas due to their engagement with different media.

The following excerpt from Group RK illustrates that the writer and the scientist utilised each other's ideas to co-develop the storyline and clarify science ideas.

Excerpt 3. (RK, session three: 0:35:58.73- 0:36:43.25)

Writer: It is kind of like an alternate universe, where, let's see, where men did not evolve; its (reptilian) species dominated. It took its place, like the reptilian.
Scientist: Yeah, the meteor did not hit the (planet) as the Earth. And it did not die out.
Writer: The dinosaurs
Scientist: But that means that they have evolved eventually because it has been a long time.
Writer: Yeah, it's intelligent. So our characters should be intelligent but looks like dinosaurs.

The writer proposed that the story should be set in an alternate universe where reptilian, instead of human, lived there. Building upon the writer's idea, the scientist stated that the alternate universe was different from the Earth because there was no meteor hit (a popular scientific explanation why dinosaurs got extinct on Earth). The scientist's explanation reminded the writer of dinosaurs. Then the scientist clarified that the reptilian should evolve from dinosaurs. The Writer added on the idea that the reptilian should be intelligent. In their final story, they wrote: '"Yes, the meteor you said was supposed to hit our planet as it did to the Earth, but it never hit us, therefore our species (evolved from dinosaurs) didn't become extinct. We managed to survive and evolve." said Muktav.'

In contrast, the following excerpt from Group SS shows that the scientist distracted ongoing discussion by referring to his preference on a different movie than the one proposed previously by the writer.

Excerpt 4. (SS, session three: 0:40:38.76- 0:41:45.77)

Scientist: You know that movie '*I, Robot*'?
Writer: But you cannot clone a robot!
Engineer: Is it possible to clone a robot?
Scientist: You can make a robot.
Writer: But clone machines will make exact the same robot.
Engineer: Cloning machines clone machines [Laughing here].
Writer: So that has to be a being, something actually living.
Engineer: You know what, you should write something down.
Scientist: But Splice is not a good movie!

In session two, the writer proposed the idea of making the story similar to the film Splice. Instead, the scientist proposed to make the story related to the alien by describing another film. As shown in the excerpt from session three here, the scientist suggested using yet another film *I, Robot* as a reference for their story because he believed that 'Splice is not a good movie.' However, their final story did not involve robots.

The comparison illustrates that the co-construction process between the writer and the scientist could help integrate more meaningful science ideas in the story.

Rewriting the science

The scientist in Group RK rewrote the entry that the writer created in a more scientific way and the writer hyperlinked the rewritten version to the final story. This rewriting theme did not occur in Group SS. The following discussion was from Group RK in session seven.

Excerpt 5. (RK, session seven: 0:17:49.45- 0:28:39.35)

Scientist: How about making an entry about the science? The entry you created is more about the story. I will make it more scientific.
Writer: And when you finish everything, I will hyperlink to that one (I created which is less scientific) and it will be a hyperlink on a hyperlink.

In this conversation, the scientist offered to create an entry that is more scientific, and the writer accepted it right away and also offered to hyperlink the proposed science entry. After the discussion, the scientist created an entry on particle collider to elaborate on the science aspect and the writer hyperlinked the entry 'particle collider' with the final story after agreeing on the revisions.

This kind of rewriting instance, only happened once though, indicates that the scientist and the writer in the group had reached a level where they felt comfortable to reconstruct each other's work specific to their roles. It also indicates that the writer and the scientist in Group RK had a good sense of the difference between their own and their team-mates' expertise.

Discussion

Through examining two groups' learning processes, new light can be shed upon how to support interdisciplinary learning in K-12 education. The two groups' learning processes reveal several role-changing patterns (intrapersonal aspect) and role-specific interaction themes (interpersonal aspect).

The role-changing patterns demonstrate how individuals took up opportunities in formulating, maintaining, and changing roles as learners in an interdisciplinary, collaborative learning environment. To better contribute to their team's final product, the members in the RK group were willing and able to enact self-selected roles and, oftentimes, transverse to other roles. Enacting self-selected roles ensures that standpoints related to the roles are represented, while enacting other roles facilitates better exchange of ideas across the roles. These findings support our existing understanding of engaging students in interdisciplinary learning. The literature has evidenced the importance of supporting student learning in individual subject areas in an interdisciplinary learning environment (e.g. NAE and NRC, 2014; Nixon & Akerson, 2004). Our study illustrates that discipline-specific role taking can facilitate students in prioritising and focusing on the subject area that they intend to learn more. In addition, students need to contribute to teamwork through drawing on their own expertise (Gouvea, Sawtelle, Geller, & Turpen, 2013). This study demonstrates that the design of discipline-specific roles could be an effective strategy to help students to develop individual expertise and use their expertise in interdisciplinary collaboration.

Furthermore, compared with the SS group, the members in the RK group were more aware of both their individual and others' role changing. This finding echoes our understanding that individuals' awareness of what and how group members contribute to a joint task may improve a team's collaborative actions and their overall productivity (e.g. Carroll, Neale, Isenhour, Rosson, & McCrickard, 2003). Taking on discipline-specific roles may afford students a mechanism to realise this. In this way, students not only have a clear understanding of one's own contribution but also set expectations of contributions from team members through role taking. More specifically, awareness of role changing allows students to better (re)structure their individual activities, avoid duplication of work, and maximise team output.

In addition, reaffirming existing literature (e.g. Kam & Katerattanakul, 2014; Slof, Nijdam, & Janssen, 2016; Waite, McKinney, Smith-Glasgow, & Meloy, 2014), this study shows that an effective model of leadership seems necessary to move the collaboration forward, demonstrated by the writer's actions in Group RK. The design of discipline-specific role taking stresses the value of maintaining each group member's authority in different content areas, which can ease the tension of unequal distribution of the importance for different types of roles in other design (e.g. essential leadership type of roles vs non-essential benchwork type of roles). However, the equally distributed authorities did not guarantee the emergence of a leader (or more desired, a coordinator) who could contribute in driving decision making and ensuring project deliverables.

The role-specific interaction themes reveal that the interaction between the writer and the scientist in the two groups differed in several important ways as described in the results section. This finding suggests a possible trajectory for successful interdisciplinary collaboration: from solo-construction to co-construction to re-construction. The first step is the foundation for the other two because the group would have science ideas to discuss and explore further only if someone brings in science vocabulary. This finding confirms that group members need to negotiate and renegotiate to solve interdisciplinary tasks (Bruffee, 1993; Johnson, Johnson, & Smith, 2007; Kim & Tan, 2013). Our study further highlights that discipline-specific roles might offer students opportunities to experience three critical stages in interdisciplinary learning: developing individual expertise in solo-construction, contributing to collective work in co-construction, and leveraging individual expertise for successful team output in re-construction.

It seems that the interaction trajectory can be mapped onto the individual role-taking patterns. Whereas the majority of research in interdisciplinary learning (e.g. Godemann, 2008) demonstrates that each group member needs to bring her or his own individual expertise in group projects, this study illuminates that discipline-specific role taking affords students to bring in and, more importantly, develop their expertise through legitimate solo-construction. Also, Gouvea et al. (2013) described that members in interdisciplinary teams might have little interactions when focusing on their own tasks and contributions. These members could bring their own expertise but did not expect to learn from others. Our study shows that transversing discipline-specific roles contributes to the co-construction of group products, which not only indicates a higher level of interaction between students and but also has epistemological significance for interdisciplinary knowledge integration (Shen, Liu, & Sung, 2014). Furthermore, the trajectory led to meaningful personal re-construction for the scientist (e.g. creating an independent science entry). In a sense, re-construction signals a strong commitment to personal disciplinary identity (Van Horne & Bell, 2017) in an interdisciplinary environment.

Implications for research and practice

Our study has important implications for research and practice in supporting interdisciplinary learning with discipline-specific roles. First, role takers tend to fit into (expected) roles at the beginning with naïve understanding and may gradually develop a new understanding of their expected and other roles (De Wever et al., 2008; Salazar, 1996). Instruction needs to attend to and facilitates such change of understanding. Similar to conceptual change, future research is needed to examine the development of students' understandings of discipline-specific roles (e.g. the role of scientist in the programme) and the conditions that facilitate a positive change in role taking.

Furthermore, instructors should provide ample time and opportunities for students to understand differentiated roles so that students are willing and able to enact self-selected and other roles. As researchers (e.g. De Wever et al., 2008; Hare, 1994; Wise et al., 2012) suggest, it is critical but difficult for group members to be aware of each other's role changes. Similarly, our findings show that the awareness of self and others' role changes is important for fruitful interdisciplinary collaboration. Thus, to better implement disciplinary role taking, instructors should carefully design explicit role support activities such as individual role reflection logs and small group sharing of role responsibilities. These activities may be supported with role-specific (digital) tools such as role guide map (a map that shows the responsibilities of the roles and their relationship) and role tags (a tag that a student wears all the time). These activities and tools may help reduce uncertainty about personal role-taking actions, and provide greater awareness of each other's activities at the same time. Future research is needed to examine the effectiveness of these possible designs.

Also, instructors need to find practical ways to assist with students' role switching, which can be a very positive outcome. Ideally, an interdisciplinary learning environment should offer students the flexibility to change roles if desired. In reality, the overall learning time is very limited. Given the nature of our learning task, switching roles may cause major disruption in teamwork progress. Another challenge is that the time when students want to switch roles varies from student to student. Our follow-up work will explore how to make role switching more feasible (e.g. having a role-trade market where students can trade their roles with each other).

Naturally, instructors should devise roles by considering the disciplinary knowledge needed for completing group projects. In this study, the creation of multimodal science fiction needs efforts from experts from multimodal design, science, and writing. Therefore, we initially provided the roles of designer (including artists and engineers), scientist, and writer. When choosing the roles, some students would select roles to express existing expertise while others would choose to take on unfamiliar roles they would like to learn more about. Apparently, these two types of students will exhibit different trajectories in terms of role taking and differentiated feedbacks are need to better assist their learning. Related to devising different role options, although this study shows that discipline-specific role taking could maintain group members' authorities, equally distributed authorities might hinder decision making in groups. Therefore, students may be better off to have the option of choosing to be a manager or coordinator. Therefore, in instruction, discipline-general roles (e.g. manager) needs to be considered with discipline-specific roles. How to introduce and combine these different types of roles to be utilised by students remains a researchable question.

The reader should take the implications of the study with caution. The findings of the study are situated in a relatively short programme (nine 1-hour sessions in total) involving technology training, science learning, and writing instruction. Students had limited time for multimodal composing within such a tight schedule. Although the literature (e.g. Applebaum, Vitale, Gerard, & Linn, 2017) has shown significant impacts can be made by short-time interventions in STEM learning environments, much more needs to be done to understand whether effects of discipline-specific role taking will be maintained. Furthermore, the scope of this investigation was confined to how individual students took discipline-specific roles and inevitably did not capture some important aspects of group characteristics (e.g. gender compositions and missing roles) and levels of skills and attainments among group members.

Conclusion

In this study, we examined the effect of using discipline-specific roles to facilitate interdisciplinary learning. Findings suggest that for fruitful interdisciplinary learning to happen, students need to enact and change discipline-specific roles, be aware of their own and others' role enactment, and devise and apply discipline-general roles in addition to discipline-specific roles. In addition, this study demonstrates that successful interdisciplinary learning follows a trajectory from solo-construction, to co-construction, and to re-construction.

These findings support the use of discipline-specific role taking as a way to address the pressing need of engaging K-12 students in fruitful interdisciplinary learning.

For research in making disciplinary roles visible in interdisciplinary learning, the design of discipline-specific role taking in this paper serves as a useful starting point for exploring the development of disciplinary identities called for by Van Horne and Bell (2017). Our study has important implications for future research in investigating the relationship between students' enactment of discipline-specific roles and future career explorations associated with the discipline. Furthermore, this study sets the foundational work for preparing K-12 students for developing leadership and collaborative learning skills in interdisciplinary teams with the design of discipline-specific role taking.

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References

Applebaum, L. R., Vitale, J. M., Gerard, E., & Linn, M. C. (2017). Comparing design Constraints to support learning in technology-guided inquiry projects. *Journal of Educational Technology & Society*, *20*(4), 179–190.

Archer, M. S. (2003). The private life of the social agent: What difference does it make? In *Critical Realism* (pp. 29–41). London: Routledge.

Aschbacher, P. R., Li, E., & Roth, E. J. (2010). Is science me? High school students' identities, participation and aspirations in science, engineering, and medicine. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *47* (5), 564–582.

Barton, A.C., & Brickhouse, N. (2006). Engaging girls in science. In C. Skelton, B. Francis, & L. Smulyan (Eds.), *The Sage Handbook of Gender and Education* (pp. 211–235). London: Sage Publication Ltd.

Binder, M., & Kotsopoulos, S. (2011). Multimodal literacy narratives: Weaving the threads of young children's identity through the arts. *Journal of Research in Childhood Education*, *25*(4), 339–363.

Bruffee, K. A. (1993). *Collaborative learning: Higher education, interdependence, and the authority of knowledge*, Baltimore, MD: Johns Hopkins University Press, 2715 N. Charles Street.

Bulter, J. (1990). *Gender trouble*. London: Routledge. 92.

Carroll, J. M., Neale, D. C., Isenhour, P. L., Rosson, M. B., & McCrickard, D. S. (2003). Notification and awareness: Synchronizing task-oriented collaborative activity. *International Journal of Human-Computer Studies*, *58*(5), 605–632.

Chen, Y. C., Hand, B., & McDowell, L. E. A. H. (2013). The effects of writing-to-learn activities on elementary students' conceptual understanding: Learning about force and motion through writing to older peers. *Science Education*, *97*(5), 745–771.

Cleaves, A. (2005). The formation of science choices in secondary school. *International Journal of Science Education*, *27*(4), 471–486.

Committee on Facilitating Interdisciplinary Research (CFIR). (2005). *Facilitating interdisciplinary research*. Washington, DC: National Academies Press.

Creech, J., & Hale, G. (2006). Literacy in science: A natural fit; Promoting student literacy through inquiry. *The Science Teacher*, *73*(2), 22.

De Wever, B., Schellens, T., Van Keer, H., & Valcke, M. (2008). Structuring asynchronous discussion groups by introducing roles Do students act in line with assigned roles? *Small Group Research*, *39*(6), 770–794.
Dressen-Hammouda, D. (2008). From novice to disciplinary expert: Disciplinary identity and genre mastery. *English for Specific Purposes*, *27*(2), 233–252.
Fang, Z., Schleppegrell, M. J., & Cox, B. E. (2006). Understanding the language demands of schooling: Nouns in academic registers. *Journal of Literacy Research*, *38*(3), 247–273.
Gee, J. P. (2000). Identity as an analytic lens for research in education. *Review of Research in Education*, *25*, 99–125.
Gee, J. P. (2005). Learning by design: Good video games as learning machines. *E-Learning and Digital Media*, *2*(1), 5–16.
Godemann, J. (2008). Knowledge integration: A key challenge for transdisciplinary cooperation. *Environmental Education Research*, *14*(6), 625–641.
Gouvea, J. S., Sawtelle, V., Geller, B. D., & Turpen, C. (2013). A framework for analyzing interdisciplinary tasks: Implications for student learning and curricular design. *CBE—Life Sciences Education*, *12*(2), 187–205.
Greenleaf, C. L., Litman, C., Hanson, T. L., Rosen, R., Boscardin, C. K., Herman, J., … Jones, B. (2011). Integrating literacy and science in biology: Teaching and learning impacts of reading apprenticeship professional development. *American Educational Research Journal*, *48*(3), 647–717.
Guzzetti, B. J., & Bang, E. (2010). The influence of literacy-based science instruction on adolescents' interest, participation, and achievement in science. *Literacy Research and Instruction*, *50*(1), 44–67.
Hand, B., Alvermann, D. E., Gee, J., Guzzetti, B. J., Norris, S. P., Phillips, L. M., … Yore, L. D. (2003). Message from the "island group": what is literacy in science literacy? *Journal of Research in Science Teaching*, *40*(7), 607–615.
Hand, B., Gunel, M., & Ulu, C. (2009). Sequencing embedded multimodal representations in a writing to learn approach to the teaching of electricity. *Journal of Research in Science Teaching*, *46*(3), 225–247.
Hare, A. P. (1994). Types of roles in small groups A bit of history and a current perspective. *Small Group Research*, *25*(3), 433–448.
Jiang, S., Shen, J., & Smith, B.E. (2016, April). *Assessing students' scientific literacy in collaborative science fiction writing*. Poster presented at the 2016 Annual Meeting of the American educational research Association (AERA), Washington, D.C.
Johnson, D. W., Johnson, R. T., & Smith, K. (2007). The state of cooperative learning in postsecondary and professional settings. *Educational Psychology Review*, *19*(1), 15–29.
Kam, H. J., & Katerattanakul, P. (2014). Structural model of team-based learning using Web 2.0 collaborative software. *Computers & Education*, *76*, 1–12.
Kim, M., & Tan, H. T. (2013). A collaborative problem-solving process through environmental field studies. *International Journal of Science Education*, *35*(3), 357–387.
Kress, G. (2009). *Multimodality: A social semiotic approach to contemporary communication*. New York, NY: Routledge.
Kress, G. R., & Van Leeuwen, T. (2001). *Multimodal discourse: The modes and media of contemporary communication* (p. 2). London: Arnold.
Lamb, G. R., Polman, J. L., Newman, A., & Smith, C. G. (2014). Science news infographics: Teaching students to gather, interpret, and present information graphically. *The Science Teacher*, *81*(3), 29.
Lenhart, A. (2015). *Teens, social media and technology overview*. Retrieved on July 22, 2016 from http://www.pewinternet.org/files/2015/04/PI_TeensandTech_Update2015_0409151.pdf
National Academy of Engineering (NAE) National Research Council (NRC). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, DC: National Academies Press.
Nixon, D., & Akerson, V. L. (2004). Building bridges: Using science as a tool to teach reading and writing. *Educational Action Research*, *12*(2), 197–218.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*(2), 224–240.

Pinkard, N., Erete, S., Martin, C. K., & McKinney de Royston, M. (2017). Digital Youth Divas: Exploring narrative-driven curriculum to spark middle school girls' interest in computational activities. *Journal of the Learning Sciences*, *26*(3), 477–516.

Polman, J. L., & Gebre, E. H. (2015). Towards critical appraisal of infographics as scientific inscriptions. *Journal of Research in Science Teaching*, *52*(6), 868–893.

Ritchie, S. M., Tomas, L., & Tones, M. (2011). Writing stories to enhance scientific literacy. *International Journal of Science Education*, *33*(5), 685–707.

Salazar, A. J. (1996). An analysis of the development and evolution of roles in the small group. *Small Group Research*, *27*(4), 475–503.

Schellens, T., Van Keer, H., De Wever, B., & Valcke, M. (2007). Scripting by assigning roles: Does it improve knowledge construction in asynchronous discussion groups? *International Journal of Computer-Supported Collaborative Learning*, *2*(2–3), 225–246.

Schoenbach, R., Greenleaf, C., & Murphy, L. (2012). *Reading for understanding: How reading apprenticeship improves disciplinary learning in secondary and college classrooms*. San Francisco: John Wiley & Sons.

Shen, J., Liu, O., & Sung, S. (2014). Designing interdisciplinary assessments in science for college students: An example on osmosis. *International Journal of Science Education*, *36*(11), 1773–1793.

Shen, J., Sung, S., & Zhang, D. M. (2016). Toward an analytic framework of interdisciplinary reasoning and communication (IRC) processes in science. *International Journal of Science Education*, *37*(17), 2809–2835.

Slof, B., Nijdam, D., & Janssen, J. (2016). Do interpersonal skills and interpersonal perceptions predict student learning in CSCL-environments? *Computers & Education*, *97*, 49–60.

Smith, B. E. (2014). Beyond words: A review of research on adolescents and multimodal composition. In R. E. Ferdig & K. E. Pytash (Eds.), *Exploring multimodal composition and digital writing* (pp. 1–19). Hershey, PA: IGI Global.

Smith, B. E. (2017). Composing across modes: A comparative analysis of adolescents' multimodal composing processes. *Learning, Media and Technology*, *42*(3), 259–278.

Smith, B. E., & Shen, J. (2017). Scaffolding digital literacies for disciplinary learning: Adolescents collaboratively composing multimodal science fictions. *Journal of Adolescent & Adult Literacy*, *61*, 85–90.

Stake, R. E. (2006). *Multiple case study analysis*. New York: Guilford Press.

Strijbos, J. W., Martens, R. L., Jochems, W. M., & Broers, N. J. (2004). The effect of functional roles on group efficiency using multilevel modeling and content analysis to investigate computer-supported collaboration in small groups. *Small Group Research*, *35*(2), 195–229.

Taconis, R., & Kessels, U. (2009). How choosing science depends on students' individual fit to 'science culture'. *International Journal of Science Education*, *31*(8), 1115–1132.

Tagg, A. C. (1994). Leadership from within: Student moderation of computer conferences. *American Journal of Distance Education*, *8*(3), 40–50.

Van Horne, K., & Bell, P. (2017). Youth disciplinary identification during participation in contemporary project-based science investigations in school. *Journal of the Learning Sciences*, *26*(3), 437–476.

Vasudevan, L., Schultz, K., & Bateman, J. (2010). Rethinking composing in a digital age: Authoring literate identities through multimodal storytelling. *Written Communication*, *27*(4), 442–468.

Waite, R., McKinney, N., Smith-Glasgow, M. E., & Meloy, F. A. (2014). The embodiment of authentic leadership. *Journal of Professional Nursing*, *30*(4), 282–291.

Wise, A. F., Saghafian, M., & Padmanabhan, P. (2012). Towards more precise design guidance: Specifying and testing the functions of assigned student roles in online discussions. *Educational Technology Research and Development*, *60*(1), 55–82.

Zhang, D.M., & Shen, J. (2015). Disciplinary foundations for solving interdisciplinary scientific problems. *International Journal of Science Education, 37*(15), 2555–2576.

Appendices

Appendix 1. Session plans

Session	Research team	Student activity	Expected outcome
1	- Introduce the project - Prepare some science fiction topics for discussion	- Understand the different roles for the project - Brainstorm/share fiction topics	-Students understand what participation in this project entails.
2	- Science topic/resources presentations - Tutorial on XXXX for writing science fictions - Scratch training session	- Create XXXX accounts - Learn Scratch for creating animations - Students form groups with guidance	- Student groups formed - Student roles decided - User accounts created - Students learn how to and Scratch
3	- Tutorial on story writing - Share ZEE's story (and elaborate on the roles)	- Small group works on their plot and further discuss each person's role and responsibility - Small group debrief	-Each group has an outline of a story
4	-Bitstrips Training session	- Small group discusses their story - Peer feedback session - Learn Bitstrips for creating characters	- Each group learns what their peer group works on - Students learn to use Bitstrips
5	-Tutorial on how to include different science resources	- Small group works on their story/final product - Science knowledge check, search and sharing - Peer feedback session	- Each group learns what their peer group works on - Students understand the science involved in their fictions
6	-Milestone checks with each group	- Small group works on their story/final product - Group progress check	- Students meet the milestone check (Need to provide specific criteria/guidelines)
7	-Role debrief	- Small group works on their story/final product - Role debrief (with groups of students of the same roles)	- Students refine understanding of their roles in relationship to their team work
8	NA	-Small group works on their story/final product	-Finish final products
9	-Evaluation	Final Presentation	-Present final products

Appendix 2. Survey for role preference and group formation

Name: ___________________________

1. Rate the following statement: ***I feel comfortable using technology to create things:***

Strongly Disagree Disagree Undecided Agree Strongly Agree

Please explain your response:

2. Please circle any of the technological activities below that you take part in at home or outside of school:

video games texting online chatting fanfiction creating videos programming

writing a blog Facebook Twitter taking photos recording music

Other activities with technology not listed:

3. People take on different roles when they work on school projects. How do you like to contribute to a team?

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

Strongly Disagree Disagree Undecided Agree Strongly Agree

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

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

Strongly Disagree Disagree Undecided Agree Strongly Agree

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

6. Do you read science fiction (books, fanfiction, comics) or watch science fiction movies/tv shows at home? If so, which are your favorites?

7. Based on what you know at this time, please rank your interest in the four roles you can take in the Science Fiction club (1=most interested; 4=least interested):

Artist (create animations, costumes, and characters) ___

Engineer (make maps, buildings, and scenes)___

Scientist (verify/include scientific information) ___

Writer (develop plot and write up fiction) ___

Why did you rank the roles in this order?

8. Is there anything else you'd like for us to know?

Appendix 3. Level of integration between science ideas and story lines

Code	Level	Description	Example
Low integration	1	Science concepts are integrated into the story line superficially. The science is added on. The science idea has less than two connections with actions or emotions of the story plot.	"On Earth and the moon, there was already rudimentary teleportation technology where you were taken apart and scanned, atom by atom, and sent as computized data to another teleportation station, where you were built back up, atom by atom and then charged with the exact same electrical pulses that were in your brain at the time of "take parting" as it was so aptly named by the people who knew of it."
Mid integration	2	Science concepts are somewhat integrated into the story line. The science idea is related to two or more actions or emotions of the story plot.	"John Smith was dragged away to the prison block, when he passed by the station's control room, where the speed of the platform on its rail to create centrifugal force was controlled, as well as where the acting conference room was."
High integration	3	Science concepts are well integrated into the story line. The science is inherently part of the story.	"The rebels released a gas Exavier had produced called Antidotum that could render Vennenum useless by having it combine with the Anidotum producing a harmless gas (a new substance) instead, in a chemical reaction." The sentence demonstrated that an imaginary chemical reaction was incorporated in its key plot: Exavier, the main character, developed a material called Antidotum to protect the rebels from chemical weapon attack. It could form chemical reaction with Vennenum (a substance mined and used by the army of the Reptilian King as a chemical weapon) and release harmless gas.