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Maker Activities and Academic Writing in a Middle School Science Classroom[1]

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Makerspaces have become prevalent in education. Academic writing is important for middle school students, and maker activities have the potential to enhance students' academic vocabulary. However, few studies have been conducted in a makerspace and writing context. The three primary components of a makerspace include community, space, and tools, but little is known about how they affect motivation and writing in a makerspace. This mixed-methods study examined the impacts of space and collaboration on students' motivation to complete a maker project and the quality of their academic writing. For this study, collaboration consisted of group work under role assignments. Students were in one of the three groups: (1) Assigned Roles Makerspace, (2) Assigned Roles Classroom, and (3) No Roles Makerspace. Students' motivation was measured, and their pre- and post-writings were collected. Students were also interviewed. A one-way analysis of variance (ANOVA) of the survey data and planned comparisons showed that collaboration had a significant effect on students' pressure. A one-way ANCOVA analysis showed that there was no statistically significant difference among the three groups in post-writing. The analysis of interview data suggested that students enjoyed working in makerspaces and that collaboration reduced their sense of pressure.

Keywords: makers activities, academic writing, collaboration, space, motivation

[1] This study was produced from the data of the PhD thesis.

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INTRODUCTION

As a common learning context for promoting science and the engineering design cycle, makerspaces have become more prevalent in educational institutions, particularly in Sweden, Denmark, Singapore, the United States and China (Freeman et al., 2017). Having founded the Make Magazine in 2005 and launched the Maker Faire in 2006, Dale Dougherty is the founder of the maker movement (Lee, 2022). The movement places value on working with materials or objects to solve problems. Within makerspaces, students work to design and create artifacts, either with software or with physical objects. Makerspaces may also serve as effective learning environments for engaging in other iterative cycles, such as the writing process (Tham, 2019). Similar to how makerspaces foster student interaction with the engineering design process to create a physical product, makerspaces may also foster student interaction with the writing process to create a written piece. Through "tinkering," or practicing (Chai & Welz, 2018), with words, students may engage with language through tangible resources to produce an artifact, or written product.

Academic language is an important focus of instruction, as it has been linked with reading comprehension and writing performance ((Fang & Park, 2019; McKeown et al., 2018; Truckenmiller & Petscher, 2019), yet employing academic language remains a struggle for students (Fang & Park, 2019; Kobayashi et al., 2017). Research suggests that students should have the opportunity to discover and "play" with language (Chai & Welz, 2018) and that effective instructional strategies include collaborative writing, discussion, graffiti walls, video recordings, and picture walls (Gallagher & Anderson, 2016; Graham & Perin, n.d.; Own, 2018; Townsend, 2015). Because of the collaborative, creative, and hands-on characteristics of these activities, these strategies that support academic writing lend themselves to the makerspace as a learning context.

Litts (2015) identified three primary components of a makerspace: *community*, *space*, and *tools*. When designing maker activities, teachers need to map out these three components so that students are motivated to complete the projects and achieve learning outcomes. However, little is known about how three components affect students' motivation and academic writing. This purpose of this study was to add to the growing body of literature to attempt to bridge this gap.

Literature Review

Makerspaces

Makerspaces have become predominant in primary and secondary education during recent years. The term *makerspace* refers to a physical space that allows for collaboration, interaction with tangible objects, and engagement in iterative design processes, which result in new skills and/or products. Research shows that makerspaces foster diverse learning arrangements. Expanding on Sheridan and colleagues' (2014) case study, Litts (2015) affirmed that learning, as well as collaboration, occur naturally in makerspaces. Within makerspaces, learners have demonstrated higher levels of motivation (Han et al., 2017) and self-efficacy (Vongkulluksn et al., 2018). While makerspaces vary in physical layout and materials, Litts (2015) identified three primary components of a makerspace: *community*, *space*, and *tools*. *Community* in a makerspace consists of like-minded thinkers collaborate to "make, create, and hack" (Litts, 2015, p. 5). *Space* includes the common space in which these thinkers engage, and *tools* are the resources available in the makerspaces in order to participate in making.

Importance of Academic Language

Academic language is an important area of focus in education that has been linked to reading comprehension (Fang & Park, 2019; McKeown et al., 2018; Mokhtari & Velten, 2015; Uccelli et al., 2015b). Employing academic language skills has also been linked to preadolescent and adolescent students' writing performance (Fang & Park, 2019; Johnson et al., 2016; Olinghouse & Wilson, 2013; Truckenmiller & Petscher, 2019). Academic language has a particularly significant role in the science classroom. The national Next Generation Science Standards (NGSSs) include writing objectives for secondary grades (*DCI Arrangements of the Next Generation Science Standards,* 2017). The curricular content standards of this study's setting required that students write explanatory texts, using "precise language and domain-specific vocabulary" in a "formal style and objective tone" (citation withheld to maintain anonymity).

Makerspaces and Academic Writing

Making activities, particularly through augmented reality visualizations, can enhance students' academic vocabulary (Own, 2018). Through constructionism, Own (2018) claims that in makerspaces, where students share, create, and participate, students can learn vocabulary by interacting with external artifacts. Despite the promising benefits of integrating makerspace and academic writing, few studies have focused on academic writing in a makerspace context. Three studies investigated writing in a makerspace. In Lee's (2022) study, students in a community college engaged in a making activity, reflected on their making experience, interviewed a peer on the making experience, and wrote a digital literacy analysis paper on how technologies changed their lives. The analysis of the products students created and interview with one student showed how students' digital literacy was cultivated. Summers (2021) did a needs analysis by interviewing students and faculty members in a STEM institution that used a makerspace and found that students did a large amount of writing for their courses and that they separated their writing from making (i.e., left writing to the end of their projects rather than using writing to capture their decision making). The author then identified strategies that integrated writing into the making process. Tham (2019) performed an ethnographic observation of three makerspaces to examine how makerspaces are managed in higher education settings and how students use makerspaces. Based on the observational findings, he designed a maker-based technical and professional communication (TPC) course focusing on technical communication knowledge and skills. In the TPC course, students worked in groups to identify and solve a problem that they experience on campus, and did technical writings including a project plan, solution proposal, an instructional procedure to communicate the solution to a specific audience, and a project presentation. Students had a positive attitude toward the group project in the course and they reported that they developed competencies such as innovation, digital literacy, problem solving, oral and written communication, etc.

Motivation

Motivation is a construct that has been widely researched in education. While various learning and behavior theories frame motivation research (e.g. Bandura, 1986; Vroom, 1995), researchers commonly apply self-determination theory to explore intrinsic motivation (Monteiro et al., 2015). Self-determination theory focuses on three psychological needs: autonomy, competence, and relatedness. As motivation, particularly intrinsic motivation, has been closely tied to student performance and engagement (Deci et al., 1991), self-determination theory provides a framework for exploring motivation in the makerspace context. For example, Schlegel and colleagues (2019) observed that making-based science curricula resulted in significant increases in elementary students' sense of making self-efficacy, science identity, and possible identifies within STEM, particularly among minority students. Vongkulluksn, Matewos, Sinatra, and March (2018) found that students' self-efficacy and situational interest declined over the semester in makerspace. Emotions of excitement were correlated with high levels of self-efficacy, while emotions of confusion were correlated with lower levels of self-efficacy. Despite this trend, both self-efficacy and situational interest remained moderately high throughout the study.

The Present Study

The purpose of this study was to examine the impacts of space and collaboration had on students' motivation to complete a maker activity and the quality of their academic writing. First, as mentioned earlier, despite the potential benefits of integrating makerspace and writing, few studies have been conducted in a makerspace and writing context. Second, Litts (2015) identified three primary components of a makerspace: *community*, *space*, and *tools*. Understanding how these three components affect students can contribute to the design of makerspace. There are empirical studies that have focused on these three components. For example, by analyzing teacher-student intervention videos, Kajamaa et al. (2020) examined when teachers intervene in students' collaboration in a makerspace context and what intervention strategies teachers use. Ryoo & Keels (2018) found that, in a year-long making program, while one group of girls persisted through challenges and their collaboration alleviated the pressure of not knowing answers, the other group did not work productively through failure. Students' responses to a questionnaire in Andres and Roberts' study (2017) revealed what aspects of the space prevented students from working productively and what fostered collaboration. Keune & Peppler (2019) examined the co-development of the materials in a makerspace, its people, and the learning opportunities. How the affordances and constraints of tools affected the making process and final products was examined in Nation & Durán (2019) and Hansen et al. (2019). However, little is known about how space, collaboration, and tools affect motivation and writing. Due to the low-technology housed in the makerspace in the current study, this study examined the impacts of space and collaboration had on students' motivation to complete a maker activity and the quality of their academic writing. The following research questions were addressed:

1. How did *space* affect students' motivation to complete maker activities?

2. How did *space* affect the quality of students' academic writing?
3. How did *collaboration* affect students' motivation to complete maker activities?
4. How did *collaboration* affect the quality of students' academic writing?

There are elements in a makerspace that prevents students from enjoying maker activities (i.e., distraction by other groups, noise) and there are elements that foster learning (i.e., open layout, access to materials) (Andrews & Roberts, 2017). Therefore, we could not generate a plausible hypothesis about how space would affect students' motivation to complete maker activities (Hypothesis 1). Space refers to the common space in which makers work. We hypothesized that it would not have any impact on writing (Hypothesis 2).

The literature shows that some students dominate the collaboration process when they work on making activities (Leskinen et al., 2021), which may negatively affect other students' sense of choice and competence. Also, not all groups are able to persist through challenges (Ryoo & Kekelis, 2018). Therefore, we could not state a hypothesis about how collaboration would affect students' motivation to complete maker activities (Hypothesis 3). The supportive atmosphere during collaboration can contribute to students' writing (Yusuf et al., 2019) and enhance their learning performance (Aghajani & Adloo, 2018). It was expected that collaboration would have a positive impact on the quality of students' academic writing (Hypothesis 4).

METHOD

Context and Participants

The study took place in an eighth-grade science course taught by one teacher in a middle school within the Appalachian region of the Southern United States. The teacher in this case taught general eighth grade science to approximately 132 eighth-grade students of varying abilities and academic performances. Her classes consisted of five class periods, each of which included 12-32 students and met for 42 minutes each instructional day. A total of 78 students participated in the study. These participants were of 13 to 15 years of age (M = 13.5, SD = 0.5). Most participants identified as female (67.7%), and the remaining participants identified as male (33.3%). Among the participants, 43 were White (55.1%), 12 were Asian (15.4%), 10 were African American or Black (12.8%), six identified as Other (7.7%), four were Hispanic/Latino (3.8%), two were Black and White (2.6%), and two were Asian Indian (2.6%).

Intervention

Litts (2015) identified three primary components of a makerspace: *community*, *space*, and *tools*. This study examined the three components. The component of *community* was changed to *collaboration*, as collaboration is the major element of *community* as it aims to create a community of learners (Litts, 2015; Oxford, 1997). For this study, *collaboration* consisted of group work under role assignments. Participants worked in groups of characteristics that were correlated with academic achievement: groups of three to four individuals (Bertucci et al., 2010) and heterogenous groups (Crawford et al., 1999). Each member chose a role assignment as a Leader (ensured that opportunities to learn were equitable; example statement to groupmates: *Let's hear from Nevaeh now.*), Facilitator (ensured that all members understood the task; example question to groupmates: *Do you think it's time to ask the teacher?*), or Manager (ensured that all members had necessary resources for the task; example question to groupmates: *We only have 7 minutes left. What do we need to finish on time?*). *Space* and *tools* were grouped as separate yet related components since in this case, the availability of *tools* were dependent on the *space*. For example, the makerspace offered tools to makers that compared to or differed from the tools in the classroom.

There were three subunits. Each subunit consisted of one or two classes. Subunit 1 (Assigned Roles Makerspace) worked in the makerspace to engage in maker activities under role assignments. Subunit 2 (Assigned Roles Classroom) worked in the traditional classroom to engage in maker activities under role assignments. Subunit 3 (No Roles Makerspace) worked in the makerspace to engage in maker activities but without role assignments. Each groups' activity was detailed below.

Subunit 1: Assigned Roles Makerspace

In this subunit, participants worked in the makerspace to engage in maker activities under individual role assignments, which served as the *collaboration* factor. Students collaborated in groups of 3-4 in a space that offered a separate set of *tools* than that of the traditional classroom. Each member of the group chose a role to support and guide collaboration (a description of these roles can be found in the Intervention section).

Subunit 2: Assigned Roles Classroom

This subunit consisted of students, who collaborated in the traditional classroom in groups of 3-4. The *collaboration* piece remained the same as the Assigned Roles Makerspace subunit, as each member adopted an assigned role. However, participants remained in the traditional classroom as they utilized classroom resources.

Subunit 3: No Roles Makerspace

This subunit of engaged in maker activities within the makerspace. Participants were directed to work in groups, but without the roles that fostered *collaboration*.

Maker Activities

Writing in an academic manner involves using lexical choices (the use of content vocabulary and general academic vocabulary) (Schleppegrell, 2001; Uccelli et al., 2013), organizational strategies (Uccelli et al., 2013; Uccelli, Galloway, et al., 2015), authoritative indicators (Schleppegrell, 2001), and complex syntax (Snow & Uccelli, 2009). There were two activities for content vocabulary (creating representations of content vocabulary terms on Day 1 and viewing peers' creations on Day 3) and one for each of the following features: organizational strategies, authoritative indicators, complex syntax, and general academic vocabulary. So there were a total of six activities. On the first day, all participants created a physical representation of a vocabulary term (see Figure 1 for a sample of the representations students created). Participants of makerspace subunits utilized makerspace *tools*, which included items such as play dough, construction bricks, circuitry kits, and connector straws, to make their creations. Participants of classroom subunit used *tools* that were available in the classroom, primarily clay, pipe cleaners, and construction paper. All of the *tools* in the classroom were also available in the makerspace, while others, such as the circuitry kit, were only available in the makerspace. When they finished, participants took pictures of their creations, which the researcher later uploaded to websites. The purpose of this activity was to develop a deeper understanding of content vocabulary.

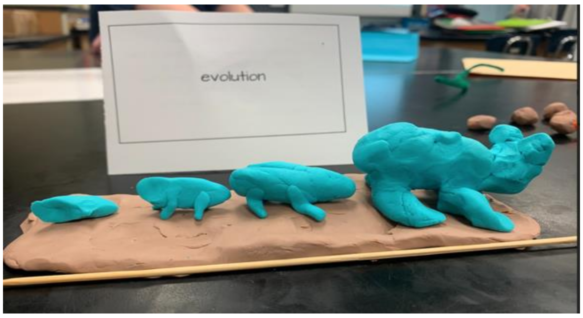

Figure 1
A sample representation students created on the first day

The focus of the second day was organizational strategies. Participants reorganized a set of index cards to form a logical paragraph. Each card consisted of segmented paragraphs of written academic language pertaining to the vestigial nature of the appendix and the significance of evolution. All subunits were given time to revise their original writing pieces following the activity each day.

On the third day, participants engaged in two makerspace activities in order to adapt to an interruption caused by a snow day. They first viewed the Creation Gallery, which was the researcher-made website that contained photographs of other students' creations from the first day. They selected the photographs of their favourite physical structures and discussed their selection with their peers.

Following that activity, participants completed the Tabletop Grammar activity, during which they received a laminated poster or piece of paper displaying a paragraph that included colloquial expressions, interrogative or imperative sentences, and discourse fillers. Using available writing *tools*, participants crossed out these informal features and, when appropriate, replaced them with authoritative indicators (e.g., replace *I think that…* with *It is possible that…*).

Guiding participants in exploring complex syntactic structures, on the fourth day, participants engaged in Blocks to Blocks, which consisted of color-coded building blocks. In a table-top game format, students paired blocks to form complete, complex sentences. See Figure 2 for a picture of the activity.

Figure 2
A picture of students working on the Blocks to Blocks activity

On the final day of the intervention, participants created and viewed Word Walls by making posters featuring a general vocabulary word (e.g., notorious). They created a word wall by writing down a thought or drawing a picture that they associate with each word. After finishing their posters, students displayed their work to the rest of the class. They then viewed each other's' posters in the form of a "gallery walk" and revised their original writing pieces to include general academic vocabulary. See Figure 3 for a picture of the activity.

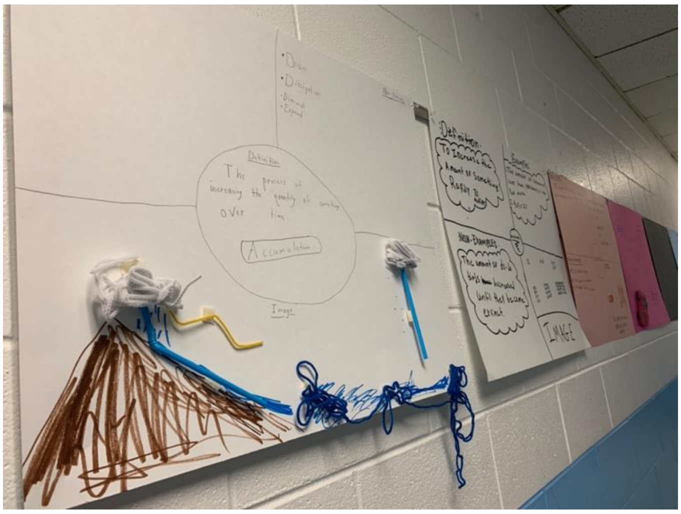

Figure 3
A picture of students working on the Word Wall activity

Data Collection Procedure

Prior to the beginning of the unit, participants responded to a prompt to write about evolution, a topic that had been recently reviewed in class. Following the intervention, participants revised their initial writing piece and completed a survey focused on their motivation to complete the maker activities. After students completed their surveys, 17 participants from the three subunits were selected to participate in an individual interview with the researcher.

Measures

Motivation

Student participants completed a 22-item version of the Intrinsic Motivation Inventory (IMI) (Ryan, 1982) as a post-survey. The IMI measured students' perceived choice, perceived competence, pressure/tension, and interest/enjoyment. Participants responded to each subscale on a 7-point Likert scale (1, indicating not at all true, and 7, indicating very true). In addition to completing survey, 17 student participants were interviewed regarding their motivation to work on maker activities. The questions were adapted from interview questions that Litts (2015) utilized in her study on learning in makerspace. Furthermore, the questions were aligned to the four subscales of the IMI, perceived choice, perceived competence, pressure/tension, and interest/enjoyment.

Academic Language

Participants' pre- and post- writing were assessed by using an academic writing rubric, which was created based on the literature (Fang & Park, 2019; Schleppegrell, 2001; Snow & Uccelli, 2009; Uccelli et al., 2015b; Uccelli et al., 2013). The rubric included criteria of lexical features, organizational strategies, complex syntactic structures, authoritative indicators, and content. Additionally, the interviews were designed to examine participants' perceptions of writing. The questions were adapted from the interview questions in the makerspace study conducted by Litts (2015). Questions focused on the four subscales of motivation, space, collaboration, and writing.

Data Analysis

A one-way analysis of variance (ANOVA) was conducted to analyze the survey data. The two independent variables of this study were *collaboration* and *space*. Results were used to determine the two variables' effects on students' motivation to complete an academic writing task across subunits. Further planned comparisons were conducted to determine which variables had an effect on motivation.

The interviews were transcribed verbatim and analysed through descriptive coding (Saldaña, 2016) to examine students' experiences related to academic writing and motivation in relation to *space* and *collaboration*.

Students' writing were analyzed through magnitude coding, or method that applies numbers to represent the value of data on a scale (Saldaña, 2016), guided a rubric. Following data transformation, an analysis of covariance (ANCOVA) was conducted to examine the post-writing scores and to determine the independent variables', *collaboration* and *space*, effect on students' academic writing performances. Planned comparisons of the post-writing were also performed.

FINDINGS

Survey Results

Descriptive statistics of the survey results are presented in Table 1. To analyze the survey results, a one-way ANOVA was conducted. As Table 2 reveals, results of this test yielded no statistically significant difference among subunits in the first three dimensions of motivation: enjoyment ($F(2, 75) = 1.501$, $p = .230$, $\omega = .08$), perceived competence ($F(2, 75) = 0.838$, $p = .437$, $\omega = -.04$), or perceived choice $F(2, 75) = 0.851$, $p = .431$, $\omega = -.04$). This shows that *collaboration* or *space* did not have impacts on students' enjoyment, perceived competence, and perceived choice. However, the results showed that there was a statistically significant difference in the fourth dimension of motivation, pressure ($F(2, 75) = 3.180$, $p = .047$, $\omega = .16$).

Table 1
Descriptive statistics

	Assigned Roles Makerspace (collaboration*space) (n=31)		Assigned Roles Classroom (collaboration) (n=27)		No Roles Makerspace (space) (n=20)	
Motivation Subscale[a]	*M*	*SD*	*M*	*SD*	*M*	*SD*
Enjoyment	4.59	1.29	5.08	1.48	5.14	0.95
Perceived competence	5.01	0.98	4.94	1.12	4.63	1.10
Perceived choice	3.59	1.23	4.03	1.60	3.58	1.44
Pressure[b]	2.34	0.69	2.39	1.07	2.97	1.07

Table 2
One-way ANOVA results of survey

Motivation Subscale	*F*	*p*	*ω*
Enjoyment	1.501	0.230	.08
Perceived competence	0.838	0.437	-.04
Perceived choice	0.851	0.431	-.04
Pressure	3.180	**0.047**	0.16

Note. $p < 0.05$

To find out which two subunits experienced different levels of pressure, we conducted planned comparisons. The planned comparisons revealed only one difference: the Assigned Roles Makerspace and Assigned Roles Classroom subunits were significantly different from the No Roles Makerspace subunit for the pressure subscale ($t(75) = -2.359$, $p = .021$, $d = -.68$; $t(75) = -1.570$, $p = .038$, $d = -.62$). This shows that collaboration had a significant effect on students' levels of pressure. Space did not significantly affect pressure.

Pre- and Post-Writing Scores

Pre- and post-writing pieces were scored using a rubric. The total possible points of an essay were 100. Descriptive statistics of writing can be found in Table 3. A one-way ANCOVA analysis shows that there was no statistically significant difference among the three groups on post-writing. Paired-samples *t*-tests show that all three groups' post-writing improved for all features of academic language.

Table 3
Descriptive statistics of pre- and post-writing scores

	Assigned Roles Makerspace (collaboration*space)		Assigned Roles Classroom (collaboration)		No Roles Makerspace (space)	
	M	SD	M	SD	M	SD
Content Vocabulary: Pre-writing[a]	1.35	1.74	1.96	2.08	0.90	1.52
Content Vocabulary: Post-writing[a]	3.45	2.16	4.37	2.44	2.70	2.27
Academic Vocabulary: Pre-writing[a]	0.65	1.08	1.33	2.08	0.90	1.52
Academic Vocabulary: Post-writing[a]	3.39	2.95	3.15	2.40	2.80	2.09
Lexically dense terms: Pre-writing[a]	4.52	2.79	4.15	3.09	4.45	2.52
Lexically dense terms: Post-writing[a]	6.26	2.41	6.11	2.49	6.20	2.04
Complex syntax: Pre-writing[b]	3.29	3.72	3.67	4.08	2.65	3.75
Complex syntax: Post-writing[b]	5.65	4.19	6.04	3.77	5.55	4.11
Organizational Strategies: Pre-writing[b]	2.74	2.58	3.67	3.66	4.05	3.76
Organizational Strategies: Post-writing[b]	5.74	4.19	6.04	3.77	5.55	4.11
Authoritative indicators: Pre-writing[c]	2.45	2.16	2.78	2.38	2.40	1.88
Authoritative indicators: Post-writing[c]	4.26	2.56	5.04	2.01	4.30	2.20
Content: Pre-writing[d]	20.03	14.77	22.63	17.66	19.50	18.63
Content: Post-writing[d]	34.26	14.64	36.04	15.65	28.25	16.57
Total: Pre-writing[e]	35.03	23.70	40.19	5.59	34.85	27.30
Total: Post-writing[e]	63.00	26.06	68.33	5.06	56.65	24.75

Notes.
[a] Possible range of each category: 0-8
[b] Possible range of each category: 0-10
[c] Possible range of each category: 0-6
[d] Possible range of each category: 0-50
[e] Possible range of each category: 0-100

Student Interview Results

The interview results revealed that students enjoyed working in groups. Many students noted how they appreciated how their group mates "worked together" while undertaking the maker activities. Along with collective effort, students experienced peer support in completing maker activities and constructing knowledge. In addition to receiving peer support to complete activities, students also reported that they felt that peers supported in knowledge construction.

Conversely, the lack of such balance presented a challenge. In regard to working in the makerspace, one student stated: “I don't like working with the groups because not everybody does what they're supposed to do.” Others echoed similar experiences, recounting how one of their group mates “kept leaving” the group or was frequently off task. However, this imbalance only seemed to affect these participants’ sense of pressure and not their sense of enjoyment.

All interviewees agreed that working in a group improved their writing. Following each maker activity, the teacher prompted students to incorporate the focused academic language feature in their writing. Of their own fruition, many students switched papers or read their work aloud to their groups in order to peer revise.

Students in the Assigned Roles subunits reported that assigned roles helped group members contribute and recounted challenges related to consensus. With roles, students were more likely to recount a challenge related to developing a group consensus. Some students recalled that “it was hard to agree on something.” On the other hand, students in the No Roles Makerspace subunit were more likely to report a challenge in collaboration due an imbalance in group cooperation. Students reported that their group members were “off task a little bit” or would leave the group and was not presented when needed. In summary, without the presence of roles, students in the No Roles Makerspace subunit noted more instances of distraction and work imbalance.

Overall, the Assigned Roles Makerspace and No Roles Makerspace subunits directly related their enjoyment to the physical space of makerspace. One student noted how the makerspace is different than the “traditional classroom environment.” He added, “You’re not staying in a desk. You’re not stationary.” Some students commented on the resources within the space and the creativity that the materials afforded. For example, one student stated that she was able to be more creative in the makerspace because there were more “arts and crafts stuff” available to her.

Interviewees revealed that during the maker activities they developed skills in applying some of the academic language features. Participants claimed that they learned how to make their sentences “flow” by omitting colloquialisms, reorganizing their writing, and creating more complex sentences. While the focus of the intervention was on academic language features, many interviewees noted that they learned course content by carrying out the maker activities. They said that they learned about the appendix or how humans have evolved. Almost all students claimed that their final drafts were better than their first drafts and credited this to either learning more content or learning about language strategies. Some students even acknowledged how the acquisition of both content knowledge and language strategies resulted in enhanced writing.

DISCUSSION

This study investigated the effects of collaboration, or having role assignments, and space on middle school students’ motivation and academic writing quality through makerspace activities. One-way ANOVA of the survey data showed a statistically significant difference among the three subunits in only one dimension of motivation, perceived pressure. Planned comparisons revealed that role assignments had a significant effect on students' levels of pressure, as the Assigned Roles Makerspace and Assigned Roles Classroom subunits were significantly different from the No Roles Makerspace subunit for this subscale. A one-way ANCOVA analysis shows that there was no statistically significant difference among the three groups on post-writing. All subunits' writing scores increased following the intervention.

The analysis of interviews indicates that across the subunits, students enjoyed working with peers to attain a common goal. Their enjoyment was influenced by groups' social dynamics. All students reported facing challenges in their groups, which affected their sense of pressure; however, role assignments seemed to determine the type of challenges that students encountered. Students who did not have assigned roles reported challenges related to group mates being distracted or not completing group tasks, but students of the Assigned Roles subunits reported less pressure. When they did face challenges in collaboration, they were more likely to experience difficulties in making group decisions. A possible reason for this result may be that most students in assigned-roles subunits contributed to the project. These results suggest that students with assigned roles focused more on creating a learning community as opposed to simply completing a task, effectively achieving collaborative learning (Oxford, 1997). Operating under group roles helped to decrease students' pressure as they worked on maker activities. Interview data suggest that group roles helped students to focus on a task that resulted in collaborative discussion, which may have resulted in less off-task behaviour. These findings mirror those of prior research on the efficacy of collaborative learning with group roles (Moore et al., 2019). Especially within STEM, the present study also supports prior research, which indicates that peer collaboration with group roles can lead to increased motivation, which other authors have defined as taking an active role one's responsibility with an element of interest (Taylor & Baek, 2018).

This study adds to previous research that suggests role assignments can significantly decrease student stress while working in groups (Sofroniou & Poutos, 2016). Though the current study did not measure stress, the pressure subscale of the IMI (Ryan, 1982) utilized terms such as "nervousness," "anxiety," and "tensions," which could be applied to stress. Students with group roles may have felt such alleviation of pressure because their energy was more devoted to a specific task, which resulted in more interaction with their peers; subsequently, they were able to provide more help and support, which students valued. As a result, they were less likely to engage in a distraction, a behaviour that students particularly did not enjoy from their group mates. Previous research on makerspaces as a learning environment found that students experience a variety of stress, depending on individual skills and expertise (Jalal & Anis, 2020). This study contributes to the literature by suggesting that a possible strategy to alleviate students' stress during maker activities is to assign individual roles to students.

There was no statistically significant difference among the groups in post-writing scores, which shows that assigned roles did not contribute to the improvement of students' writing. There are two possible reasons. The first reason may be that students adhered to their roles strictly during the hands-on segment of the maker activities. When students finished the interactive portion, they revised their writing and may not have applied their roles during this segment of the activity. As an example, the facilitator of a group was to read the directions of each maker activity, which included revising their written work. However, the instructions for the hands-on portion of the activity varied widely from day-to-day, while the writing instructions remained relatively the same (e.g. "When you're done…revise your [writing] to include [respective academic language feature]"). The facilitator may have stopped reading the writing instructions due to their predictability. Also, the roles may not have carried over to student writing was due to the wording of the instructions. Most days, the written instructions read "When you're done, revise…" The intent of the instructions was to guide students when they were finished the hands-on segment, but students may have interpreted it as the entire group activity being finished. Consequently, they ceased carrying out their roles' responsibilities during the writing segment. When the groups edited peers' writing at the end of each day, they did not fulfill their responsibilities. Second, although only students in the Assigned Roles Makerspace and Assigned Roles Classroom subunits had roles, it is possible that students in the No Roles Makerspace subunit were already practiced at collaborative work, so they unwittingly assumed cooperative roles.

When considering the component of *space*, it is possible that this factor had no effect on students' motivation or writing due to the original layout of the science classroom. Interview results revealed that students enjoyed working in the makerspace because of their ability to walk around and the physical layout, which allowed for collaboration. However, the students who worked in the classroom had similar opportunities to walk around and work with peers. Like the makerspace, the science classroom housed tables that were conducive to working in groups. Along similar lines, the science classroom offered resources comparable to that of the makerspace. Although the makerspace stored a wider variety of resources for creating, for example, newspaper connectors, cardboard toolkits, and electronic kits, students in the makerspace subunits generally chose to work with materials that students in the classroom also used. Such resources included markers, pipe cleaners, clay, and play dough.

All subunits' writing quality significantly improved, in terms of both academic language and content. These findings indicate that, the maker activities had a positive effect on students' academic writing and content knowledge. A recent review of the literature (Schad & Jones, 2020) on maker activities suggests that "there is significant lack of quantitative research with measurable outcomes." (p. 75). Our study contributes to the literature by showing quantitative evidence of the benefits of makerspace. One possible explanation for enhanced academic language may be that, regardless of role assignment or working space, all students were given the opportunity to apply maker activity objectives to their writing. They were able to focus their attention to individual features of academic language or specific acquired knowledge instead of the overarching task of improving their writing.

Students' writing also improved due to their increased content knowledge. This may have been due to students' exposure to content that was integrated into the maker activities. Though content knowledge was not a variable of focus in this study, the results imply that students learned content knowledge related to the human appendix and evolution. This may be due to the fact that the maker activities were themed around the content. For example, when students reorganized the paragraphs of an article to practice organizational strategies, they read about the latest research about the human appendix. Prior research shows that maker activities increase student content knowledge (Doran et al., 2012) , and the present study's results suggest similar findings in that students' content knowledge increased after engaging in maker activities.

This study also demonstrates that students can acquire content knowledge through maker activities, affirming the theory of constructionism. Learning transpired when students interacted with tangible objects that promoted examination and discussion (Papert, 1993). Students manipulated materials to create representations of vocabulary words. They physically moved segments of an academic article. They combined building blocks to create complex syntax. They annotated and created posters to discuss the meaning of academic terms and colloquial discourse. Through this process of personal interaction with external artifacts, students learned science content and academic language strategies by making. These findings are significant because outside the area of programming, few studies address makerspaces and the construction of content knowledge that relate to curricula learning standards (Papavlasopoulou et al., 2017). As the present studied explored the impact of makerspace activities related to NGSS and English Language Arts standards, this finding may help to fill the gap in makerspace literature, which fails to address the role of makerspaces in direct relation to standards-based curricula in K-12 education.

LIMITATIONS

The first limitation is that, due to the small sample size, the results of this study are not widely generalizable. Furthermore, researcher bias may be present in this study. For example, bias during data analysis may have taken effect since the pre-writing samples were handwritten, and the post-writing scores were typed. Following the intervention, the teacher requested that all students submit their final writing pieces through a computer. During the analysis of pre- and post-writing samples, the researcher consequently knew which samples were composed before and after the intervention. Another limitation pertains to the duration of the study. The space and role interventions were only carried out once for about four weeks. If the treatment had been implemented for a longer time and repeatedly, students might have been able to perform their roles in the way that was expected. The impacts of the treatment might have been different.

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