THE EFFECT OF ONLINE CROSS-AGE PEER TUTORING ON STUDENT SELF-EFFICACY IN MIDDLE SCHOOL STEM

BY

JENNIFER A. JOHNSON

A dissertation submitted to

The Graduate School of Education

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree

Doctor of Education

Approved by

____

Dr. Daniel Battey, Chair

____

Dr. Ravit Golan Duncan, Committee

____

Dr. Robert Zega

New Brunswick, New Jersey

(January 2019)

ABSTRACT

Open inquiry offers students the opportunity to gain 21st century skills and expose them to science practices advocated by Next Generation Science Standards (NGSS). While this raises the bar from lower-level inquiry classes, students initially struggle with open inquiry, because they do not know what to expect as they shift from a teacher-directed environment to a student-driven one (Bevins & Price, 2016; Germann, Haskins, & Auls, 1996; Pizzolato, Fazio, Sperandeo Mineo, & Persano Adorno, 2014). Students can feel frustrated, inadequate, and less confident when experiencing open-inquiry activities initially (Gormally, Brickman, Hallar, & Armstrong, 2009). This is notable, because students’ self-efficacy in science effects whether students will choose future STEM classes and majors (Moss, Cervato, Genschel, Ihrig, & Ogilvie, 2018), and can be used to predict academic performance in science, engineering, and math classes (Lent, Brown, & Larkin, 1986; Pajares, Miller, & Hill, 1995). To counter these challenges, I proposed an asynchronous online cross-age peer tutoring program to boost middle school students’ self-efficacy in STEM as they conduct research using open inquiry. The results reveal that a peer tutoring program significantly improved the students’ self-efficacy in open-inquiry science. Furthermore, the findings show that certain factors may influence the effectiveness of an online cross-age peer tutoring program, such as students’ perceptions of their tutors’ knowledge, helpfulness, and quality of support. This paper outlines ways to improve tutor training and better convey the importance of the teacher’s role in an online cross-age peer tutoring program.

Open inquiry can potentially elevate the quality and meaningfulness of science research projects; however, teachers initially face many challenges when initiating this method. Therefore, I showcase a student research project from start to finish, including providing helpful tips that I have acquired during my years of using open inquiry, to help teachers learn how to incorporate open inquiry into their elective classes and after-school programs. This paper also features a professional development (PD) plan that imparts the questioning, feedback, and modeling skills needed to effectively lead open-inquiry activities. This PD plan, coupled with a professional learning community, helps teachers sustain the skills learned in PD.

DEDICATION

First, I am forever grateful to my husband Tim who has been my biggest supporter and offered encouraging words on a daily basis throughout this experience. You are so kind and positive, and motivate me to be the best version of myself. I also want to thank my daughter Alanna for joining me on my third year of this journey and being my sidekick as I wrote papers with her on my lap. Now we will have more time to laugh and play! I love you both so much. To my sister Julie, and my Mom and Dad, thank you for always reminding me that all this work would be worth it. You guys were right.

I also owe a huge thank you to Dr. Battey, my advisor, for being such an amazing guide during the last few years. You made me look forward to class, and your relaxed, positive way of giving feedback made this process achievable. To my classmates, thank you for bringing laughter to each class, and being genuine, caring, supportive, people who help others. You guys made these years so enjoyable. Thank you James Danch, for being my unofficial science research mentor and always being there to support my endeavors. You go above and beyond to help the students and me, and that does not go unnoticed. Without you I would not have been able to study cross-age peer tutoring, so for that I am also grateful. Thank you Dr. Zega for supporting my research by allowing me to conduct my study while teaching. Finally, thank you Dr. Duncan for your feedback regarding science. You helped me see my practice from a new perspective. I appreciate your expertise.

TABLE OF CONTENTS

Chapter 1: Introduction to the Study

Next Generation Science Standards (NGSS) encourage the implementation of science programs that strengthen students' 21st century skills and expose them to science and engineering practices. Attaining this goal requires revising science curriculums to include authentic learning—a learning style that encourages students to create a tangible, useful product that can be shared with their world. Higher-level inquiry, specifically open inquiry, creates these desired authentic learning opportunities. Open inquiry is defined as a student-centered approach that begins with a student's question, followed by the student [or groups of students] designing and conducting an investigation or experiment and communicating their findings (Colburn, 2000; NRC, 1996). Open inquiry represents the ability to analyze, synthesize, and evaluate information or develop a new understanding that indicates a higher level of thinking. As a result, students develop higher-order thinking skills.

Initially, students struggle with this method, because they do not know what to expect as they shift from a teacher-directed environment to a student-driven one. They need help developing their decision-making skills (Mumba, Mejia, Chabalengula, & Mbewe, 2010), time management (Akinoglu, 2008), reasoning abilities (Costenson & Lawson, 1986), ability to focus on the task (Costenson & Lawson, 1986), and building confidence (Mumba et al., 2010). These challenges can negatively affect students' self-efficacy in science, compared with their familiarity with lower levels of inquiry (Gormally, Brickman, Hallar, & Armstrong, 2009). Thus, for inquiry learning to be successful, teachers need to address challenges students may face and implement methods that can help to alleviate such prospective difficulties. Open inquiry improves student achievement gains and prepares them with the skills to compete in an increasingly competitive global market. However, the challenges that accompany this type of learning must be acknowledged and addressed to reap the rewards.

Online cross-age peer tutoring programs can help middle-school students successfully navigate through open inquiry activities, while increasing their self-efficacy in STEM. The benefits of peer tutoring are well established in the literature, have been documented to have positive effects on students, both academically (Cohen, Kulik, & Kulik, 1982; Robinson, Schofield, & Steers-Wentzell, 2005; Topping, 1996; Topping, Peter, Stephen, & Whale, 2004; Zambrano & Gisbert, 2015) and affectively (Ginsburg-Block, Rohrbeck, & Fantuzzo, 2006; Miller, Topping, & Thurston, 2010; Robinson et al., 2005; Topping, 1996; Worley & Naresh, 2014). Based on these findings, I predicted that the advantages of peer tutoring could transfer to students in middle school STEM classes. Specifically, upon examining the effects peer tutoring had on students’ self-efficacy in STEM, I learned that many peer tutoring studies do not focus on middle school science students. Therefore, the findings of this research are intended to add to the existing literature. While building students’ confidence in science is a focal point, it is equally important to have skilled teachers who can effectively use this instruction.

Even though NGSS encourages the use of inquiry, several obstacles make enacting this teaching method difficult. First, a lack of open inquiry knowledge can frustrate teachers, causing them to avoid using this concept in their classrooms (Crawford, 2000; Zion & Sadeh, 2007). Second, teachers worry about losing control and giving students the autonomy and power necessary to make decisions (Costenson & Lawson, 1986). Third, some teachers fail to see students’ ability to conduct science projects autonomously (Costenson & Lawson, 1986). They fear that students lack the maturity to handle the freedom associated with open inquiry and will misuse their time. In addition, teachers can also find themselves overwhelmed by the multitude of roles they are expected to fulfill while teaching inquiry. This includes serving as a guide, coach, mentor, facilitator, diagnostician, and collaborator (Crawford, Krajcik, & Marx, 1999). Finally, the existing literature frequently claims that teachers worry that they will not complete their workload. As a result, they become stressed and anxious about teaching open inquiry (Costenson & Lawson, 1986; Dennis & O'Hair, 2010; Sadeh & Zion, 2011). As can be seen, many variables influence a teacher's success when implementing inquiry. To counteract these challenges, teachers can be trained to effectively lead such activities.

This portfolio contains three distinct components of my study, "The Effect of Cross-Age Online Peer Tutoring on Student Self-Efficacy in Middle School STEM." These components include a scholarly research article, a practitioner article, and a professional development (PD) plan to help middle school teachers successfully design and lead open inquiry activities. Two of the articles will enable me to reach a broad range of change agents, including educators and administrators who have the authority to modify curriculums and include peer tutoring and open inquiry. The PD aspect is designed to help middle school administrators and science teachers recognize the value of open inquiry and successfully incorporate this concept into their classrooms. It is my hope that these three documents contribute to creating change in science education. Each artifact is detailed below.

The first component in this portfolio is a research article that will be submitted to *Research in Science Education*. It reveals how an online cross-age peer tutor program, composed of high school juniors and seniors, helped 8th grade STEM students develop self-efficacy in science as they completed an open-inquiry research project for the first time. Very limited research currently exists pertaining to open inquiry at the middle school level, and even less information is available regarding online cross-age peer tutoring in STEM classes that use open inquiry. Therefore, my findings will contribute to the literature by documenting how online cross-age peer tutor programs can positively affect students’ confidence in science and serve as a viable support for students new to open inquiry.

The second aspect of this paper includes a practitioner article, which will be submitted to *Science Scope (NSTA)*. Providing a relatable, teacher-friendly account of how open inquiry can be integrated into middle school STEM elective classes or afterschool science clubs will help prepare teachers to enact this method in the classroom. Because open inquiry is not as common as lower forms of inquiry at the middle school level, there is very limited literature to help teachers visualize how such learning occurs. Furthermore, many teachers have not experienced open inquiry as learners, themselves. This adds to the mystery of how such learning transpires in the classroom. In this paper, I document my experience with using open inquiry in my 8th grade elective STEM class to show how it can be used in elective classes and after school programs. The goal is to offer practical advice so that educators can gain the confidence, knowledge, and teaching strategies needed to successfully utilize this concept with their students.

The third component of my dissertation features a PD plan aimed at helping middle school science teachers in the Valley Township School District transition towards enacting higher-level inquiry teaching methods. The literature has documented that teachers are more familiar with lower-level, teacher-directed inquiry (Sadeh & Zion, 2009). However, with the push to incorporate STEM into middle school curriculums, teachers are expected to shift to student-directed, higher-level inquiry activities. This PD plan addresses this issue by familiarizing teachers with the different levels of inquiry and their respective challenges and benefits. Specifically, the PD focuses on questioning, feedback, and modeling strategies that strengthen teacher instruction. Furthermore, my PD program gives teachers time to participate and lead higher-level inquiry activities, followed by feedback, reflection, and discussion. The best practices associated with PD frame the program to ensure that teachers partake in an effective experience that hopefully leads to lasting change.

Although each component mentioned above is distinct, each demonstrates the knowledge and skills I have developed from both my professors and independent research during my time as a doctoral student. These three artifacts are designed to reach different audiences and create change in multiple areas of the education system. As a change agent, I realize the importance of sharing my findings with educational stakeholders who have the ability to improve the science education students receive.

Chapter 2: Research Article for Research in Science Education Submission

The Effect of Online Cross-Age Peer Tutoring on Student Self-Efficacy in Middle School STEM

Jennifer Johnson

Rutgers University

January 2018

Introduction

The Need for Open Inquiry in Science Education

The implementation of the NGSS has made science, technology, engineering, and mathematics (STEM) an integral part of American education, because leaders believe exposure to this subject matter and its authentic nature is fundamental for students to successfully compete in the international job market Avery & Reeve, 2013; Dejarnette, 2012; Harwell et al., 2015; Isabelle, 2017; Newman, Dantzler, & Coleman, 2015). Higher-level inquiry, specifically open inquiry, provides this desired learning opportunity. Open inquiry involves student-directed research, in which the students propose their research questions and design their procedures to a problem with unknown results (NSTA, 2015; Rezba, Auldridge, & Rhea, 1999). During open inquiry, teachers relinquish much of their control and provide scaffolded support, when needed, as students complete an original science research project and model how professional scientists perform research (Sadeh & Zion, 2009). Open inquiry is fundamental for developing higher-order thinking skills (Sadeh & Zion, 2009) and achieves the goal of providing a science education infused with problem-solving and technological literacy skills (NGSS, 2015). It represents the ability to analyze, synthesize, and evaluate information, and form a new understanding that indicates a higher level of thinking.

However, students initially struggle with this method, because they do not know what to expect as they shift from a teacher-directed environment to a student-driven one (Bevins & Price, 2016; Germann, Haskins, & Auls, 1996; Pizzolato, Fazio, Sperandeo Mineo, & Persano Adorno, 2014). These difficulties can result in lower levels of self-efficacy gains compared to students who perform lower-inquiry activities (Gormally, Brickman, Hallar, & Armstrong, 2009). In fact, research shows that when students initially experience higher inquiry activities, they can feel frustrated, inadequate, and less confident, which can prevent them from engaging in future high-level inquiry activities (Gormally et al., 2009). This is notable, because students’ self-efficacy in science effects whether students will choose future STEM classes and majors (Moss, Cervato, Genschel, Ihrig, & Ogilvie, 2018), and can be used to predict academic performance in science, engineering, and math classes (Lent, Brown, & Larkin, 1986; Pajares, Miller, & Hill, 1995). Despite this concern, research regarding self-efficacy levels of middle school science conducting open inquiry learning is minimal. Consequently, for open inquiry learning to be successful, teachers need to offer supports to boost students’ self-efficacy as they embark in rigorous, autonomous science curriculums.

In general, students’ self-efficacy has been shown to drop as they progress through grades K-12. For instance, the National Center for Educational Statistics (NCES, 2000) documents decreases in students’ self-efficacy levels in science as they move from primary to secondary school. Research shows that 82% of fourth graders believe they can do well in science if they try, compared to 64% of eighth graders, and 44% of twelfth graders (NCES, 2000). That is nearly a 50% decrease in self-efficacy levels from elementary to high school. Coupled with this, students lose interest in science as they transition from primary to secondary school (Tytler, Osborne, Williams, Tytler, & Cripps Clark, 2008). Tie in the fact that students are being asked to learn science in an authentic, student-directed manner that challenges them, where they have little or no prior experience and one can predict that self-efficacy in science can decrease even more (Gormally et al., 2009; Pizzolato et al., 2014). These findings are worrisome and offer an explanation for why interventions are necessary to help alleviate challenges students face with authentic learning and maintain confidence in secondary science education.

The Intervention

I argue that an asynchronous online cross-age peer tutoring program can offer support that helps to reduce student frustration with open inquiry and can positively affect their self-efficacy in STEM. Peer tutoring has been shown to benefit students’ self-efficacy (Burgess, Dorman, Clarke, Menezes, & Mellis, 2016; Johnson & Johnson, 1989; Miller, Topping, & Thurston, 2010), and I predict that the benefits will transfer to middle school STEM students. Determining how such an intervention influences students’ confidence toward STEM is important, because self-efficacy levels indicate the likelihood that middle school students will pursue such studies in the future, specifically high school (Britner & Pajares, 2006).

The primary question this study addresses is: How does peer tutoring support open inquiry to influence middle school students’ attitudes in STEM? The following research questions direct this study: 1) How does peer tutoring affect students’ self-efficacy in STEM? 2) What factors influence the effectiveness of an online cross-age peer tutoring program?

Literature Review

I will use evidence from empirical studies to explain the advantages of peer tutoring to support implementation of middle school STEM research programs in schools. This study explores the role of an online cross-age peer tutoring program in alleviating challenges associated with this type of learning and promoting higher self-efficacy in STEM. The first section of this literature review examines the benefits associated with peer tutoring to portray its usefulness as an inquiry intervention. Next, I will discuss the different characteristics of tutor training needed for successful implementation.

The Benefits of Peer Tutoring

Given the difficulties students face with open inquiry, educators should consider using a research-based intervention that has been shown to support them both academically and affectively. One such approach is peer tutoring, which can decrease the challenges associated with learning and increase interest and self-efficacy in a subject matter. It is defined as “people from similar social groupings who are not professional teachers, helping each other to learn, and learning themselves by teaching” (Topping, 1996, p. 322) and is well-documented as having positive academic (Berghmans, Michiels, Salmon, Dochy, & Struyven, 2014; Cohen, Kulik, & Kulik, 1982; Robinson, Schofield, & Steers-Wentzell, 2005; Topping, 1996; Topping, Peter, Stephen, & Whale, 2004; Zambrano & Gisbert, 2015) and affective effects on students. The affective benefits include improved self-concept, increase in positive attitudes toward subject matter, and dedication to learning (Bowman-Perott, Burke, Zhang, & Zaini, 2014; Ginsburg-Block, Rohrbeck, & Fantuzzo, 2006; Miller et al., 2010; Robinson et al., 2005; Topping, 1996; Worley & Naresh, 2014; Zeneli, Tymms, & Bolden, 2016). Such outcomes can be attributed to the individualized, personable, structured, yet relaxed learning environment commonly found in peer tutoring, compared to a traditional classroom (Chow, 2016; Topping, 1996).

Peer tutoring contributes to the student’s clearer understanding of content knowledge and, therefore, improved academic performance (Bowman-Perot et al., 2014; Cohen et al., 1982; Topping et al. 2004). To illustrate this, a meta-analysis found that student achievement increased with the addition of peer tutoring in 45 of 52 reviewed studies (Cohen et al., 1982). This was later supported by a meta-analysis, in which Rohrbeck, Ginsburg-Block, Fantuzzo, and Miller (2003) revealed a similar rise in academic achievement from peer tutoring at the elementary level. Moreover, peer tutoring has been shown to improve knowledge building in non-targeted subjects, although the reasoning for this is unclear (Scruggs, Mastropieri, & Marshak, 2012). Perhaps the improved knowledge base made it easier to learn related content, or improved the students’ academic confidence to the point that it carried into other subject matters (Worley &

Naresh, 2014). Cross-age peer tutoring has demonstrated equally parallel positive effects as peer tutoring on academic achievement in science at the middle (Korner & Hopf, 2015) and elementary level (Topping et al., 2004). As shown above, peer tutoring can benefit students academically—another reason why such programs should be introduced to STEM students using open inquiry.

This increase in academic achievement is meaningful, because it helps to develop higher levels of self-efficacy, which is a focus of this study. Studies show that having a better understanding of a subject matter can result in improved self-esteem (Johnson & Johnson, 1989; Miller et al., 2010) and this can transfer to other subjects (Worley & Naresh, 2014). This outcome is significant, because it demonstrates that one-on-one interactions can build students’ confidence to the point that they can apply these newly-learned skills in additional classes. The supportive environment consisting of individualized coaching and attention is one way that peer tutoring helps to build self-confidence while learning a subject matter (Burgess, et al., 2016). Equally important, peer tutoring benefits students’ self-concept. For example, Zeneli, Tymms, and Bolden (2016) found that year-eight students’ math self-concept, social self-concept, and math enjoyment improved as a result of peer tutoring. Likewise, seven of nine studies included in a meta-analysis found that students’ self-concept improved with peer tutoring (Cohen et al., 1982). Although there is compelling evidence that peer tutoring can assist in elevating confidence levels, it must be noted that the aforementioned studies did not examine the intervention’s effect in STEM self-efficacy or use an online format. This study aims to address this gap in the literature.

Besides contributing to better grades and improved confidence, incorporating peer tutoring into a school setting influences attitudes toward subject matters (Cohen et al. 1982;

Topping et al., 2004). For instance, according to Topping, Peter, Stephen, and Whale (2004), 90.6% of seven- and eight-year-old students who were tutored by eight- and nine-year olds developed a greater interest in science after a cross-age peer tutoring experience and 68.7% of them enjoyed science more. However, while this study involved peer tutors and science, the tutees and tutors were younger than those in the present study and did not include open inquiry. The hope is that the positive outcomes can be transferred to a middle school STEM class.

In addition to having an influence on student attitudes, peer tutoring also fosters positive behavioral and social outcomes. In fact, a meta-analysis found that peer tutoring in elementary schools can improve social skills and lower disorderly conduct (Ginsburg-Block et al., 2006). These findings were backed by Bowman-Perott, Burke, Zhang, and Zaini (2014). This effect is heightened in programs that use student-chosen rewards and cross-age tutoring sessions (Ginsburg-Block et al., 2006). Therefore, peer tutoring could have the same effect on STEM students’ attitudes and behaviors.

As mentioned earlier, cross-age peer tutoring has specific implications that pertain to this study. For instance, older, more experienced students tutor someone younger. Since the age gap between the student and tutor can influence the tutee’s receptivity to learning and the tutor, Muhoro and Kang’ethe (2014) recommend an age difference of no more than 2-3 years. This helps to eliminate a perceived power imbalance, because, if the tutor is considerably older, he or she can intimidate tutees and impede their ability to learn. Cross-age tutoring provides the same academic and social benefits as same-age peer tutoring, although a recent meta-analysis warns that cross-age tutoring may not produce academic gains at the kindergarten and elementary-school level (Shenderovich, Thurston, & Miller, 2016). The influence of cross-age tutoring on middle school students was not addressed in these studies and therefore requires attention.

The peer tutoring studies have limitations that need to be acknowledged. First, many of the peer tutoring studies were conducted at the college level, which focused specifically on medical students’ success with the intervention. Second, the studies performed in K-12 settings mainly focused on reading and math benefits at the elementary level, and not on STEM. For these reasons, the findings may not be transferrable to a middle-school context. Plus, tutor training varied from none to weekly, as did the ability of the tutors, making it difficult to pinpoint what aspects of peer tutoring are the most effective. Also, many of the studies failed to look specifically at online peer tutoring programs, and those that did were nearly all conducted at the college level. Again, this limits the ability to apply the findings to the middle school science context.

Training Peer Tutors

To achieve the aforementioned results, many studies encourage training tutors prior to their assisting tutees to assure the quality of the peer tutoring program (Burgess et al., 2016; McLuckie & Topping, 2004; De Smet, Van Keer, Wever & Valcke, 2010), although some studies showed that training does not necessarily yield more reliable gains compared to programs without it (Cohen et al., 1982). The first advantage of training is that it helps to confirm that learning experiences align with the program’s curriculum and goals. Tutors need to learn what is required of them, such as offering ongoing emotional and social support, and providing clear and valuable feedback (Berghmans et al., 2014; De Smet, Van Keer, & Valcke, 2008). Next, training informs tutors of the program’s preferred tutoring style, such as directive or facilitative. A directive style means that the tutor provides clear direction, along with the tutee being a passive learner, while a facilitative tutoring style encourages the students to take ownership of their learning by reflecting and questioning their and the tutor’s thinking. While the latter method is recommended (Berghmans et al., 2014), tutees may initially feel more comfortable with directive tutors, because they are accustomed to traditional teacher-directed classrooms. This being said, students will usually see the value of being challenged (Berghmans et al., 2014; Worley & Naresh, 2014). Also, training prevents tutors from becoming too friendly and agreeing with the tutees. Instead, training teaches the tutors to challenge students by asking them to reflect on their progress (De Smet et al., 2010). Lastly, training can help tutors feel more confident helping other students (Muhuro & Kang’ethe, 2014; De Smet et al., 2010). In summary, training can improve the tutor’s understanding of the program goals, tutoring styles, appropriate communication, and increase their self-efficacy beliefs regarding their ability to help others.

When tutors and tutees cannot meet in person, a computer-supported collaborative learning (CSCL) environment can be established (De Wever, Van Keer, Schellens, & Valcke, 2010). Today, more and more educational settings embrace online-peer tutoring; however, it comes with challenges, such as scheduling (Chow, 2016; Kirschner, 2001; McLuckie & Topping, 2004) and providing structure and monitoring for learning to occur (De Smet et al., 2008). To achieve this, Salmon (2000) suggests using an e-moderating model to ensure that student exchanges are meaningful and timely. Salmon created her model explicitly for constructivist-based asynchronous online-tutoring programs; however, she focused on the college level (De Wever et al., 2010). Teachers or students can fulfill the e-moderator position by adhering to a five-step e-moderating model that is described below (Salmon, 2000). For the purpose of this study, high school students took on the e-moderator role and were monitored by teachers.

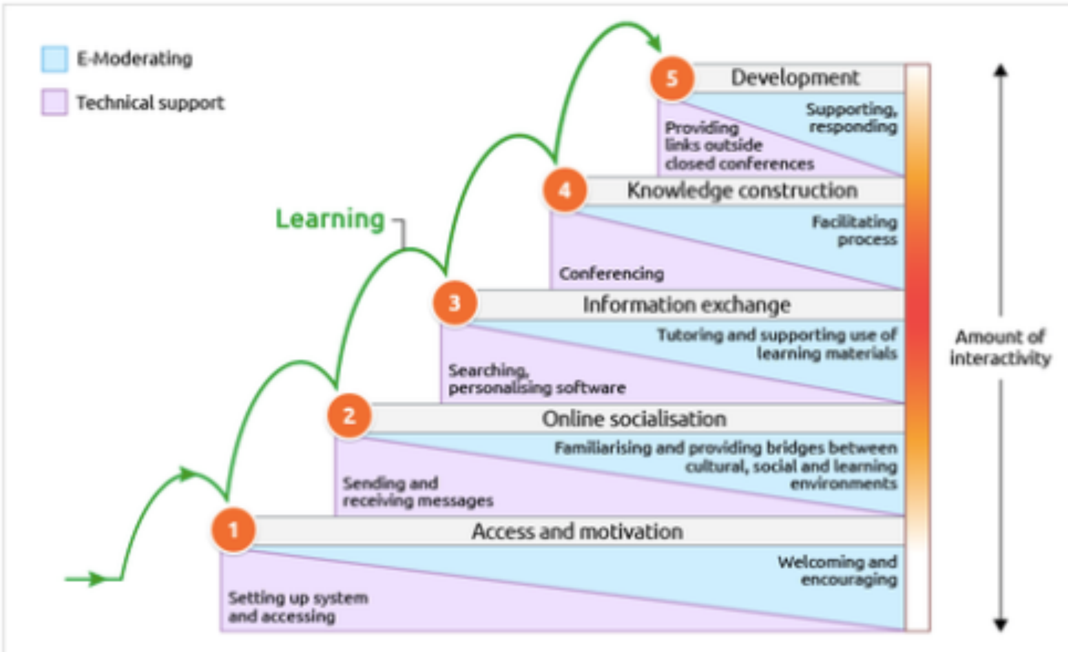


Figure 1: Salmon’s five-step model for e-moderating. Retrieved from: https://www.gillysalmon.com/five-stage-model.html

During the first stage—access and motivation—tutors establish a welcoming environment as students enter the online platform, ensuring that they understand how to maneuver through digital environments, thus promoting group participation (see Figure 1). The second stage—online socialization—involves tutors and tutees creating a sense of community by learning about one another and building trust. This phase is important, because it creates a safe sharing environment (Burgess et al., 2016). Norms, such as online etiquette and appropriate response times, may also be formed to promote a respectful environment. Next, in the information-exchange stage, the tutee offers direction by sending personal, supportive, and task-centered messages designed to keep them focused on the assignment. The fourth stage, knowledge construction, occurs as tutors offer different viewpoints that cause the tutees to negotiate pre-held positions. Tutors act as facilitators by asking questions that help the tutees reexamine their prior beliefs. This ultimately culminates in shared meaning among the students.

Teachers can provide tutors with examples of guided questions to help them provide constructive feedback to the students. Doing so can help tutors avoid being too nice and avoiding giving direction, which commonly occurs in peer tutoring. Development, the final stage, includes students taking charge of their learning by reevaluating their thoughts independent of their tutors. Critical-thinking skills are encouraged and can be fostered by tutors helping their students reflect on peers’ contributions (De Wever et al., 2010). Though rarely achieved, tutors strive for this stage as the ultimate goal (De Smet et al., 2008). Throughout the process, teachers should routinely monitor the tutors’ approach to regulate their effectiveness (Berghmans et al., 2014; Topping, 1996).

Teachers need to observe and analyze student conversations in terms of what is said (or written) as a means of providing feedback (Worley & Naresh, 2014; Zambrano & Gisbert, 2015). They must check whether participants experience transformation as they interact with the tutors and collaboratively construct meaning. To do this, teachers need to focus on the language being used among the dyads and assess whether the tutees are gaining knowledge and forming critical thinking skills. Reading the online communications and discussing the tutees’ responses to tutor posts will let teachers accurately assess this. For instance, tutors are likely to be more concerned with producing a certain number of responses, rather than challenging the tutees intellectually. The teacher should note this (McLuckie & Topping, 2004). Monitoring allows opportunities for the teacher to offer advice to tutors, thus affording the opportunity for tutors to improve future sessions. Plus, students prefer professional oversight that checks and maintains quality (Burgess et al., 2016).

In a study similar to this one, De Smet, Van Keer, Wever, and Valcke (2010) used Salmon’s (2000) five step e-moderating model to analyze tutors’ effectiveness in a cross-age, asynchronous CSCL environment. These authors found that the type of training directly affects the support tutees receive and it should be used to increase the likelihood of desired tutor behaviors. Another training effect featured tutor-improved self-efficacy levels, perhaps because tutors better understood what was expected of them. The researchers also mentioned that if the tutors enhanced their performance with training, then an improvement in the student’s online performance was more likely to occur. It must be noted that this study was conducted at a college level, but I predict the training’s effect can be transferred to a K-12 setting. Likewise, Chow (2016) conducted a pilot study of an online cross-age tutoring program involving high school students (mostly grades 10 and 11) mentoring middle-school students on various subjects. The author monitored the virtual interactions of both the tutors and tutees and, overall, found the initial program’s feedback to be very positive. The tutees favored the fast response time from their tutors, because it was available on a daily basis. While both the college level and pilot studies are promising, this study plans to build on the model that applies cross-age peer tutoring in the middle school STEM context to better understand how this tutoring functions, as well as the added effect of this approach on open inquiry science.

Methods

A New Jersey public middle school offered a STEM elective that solely used open inquiry to fulfill the NGSS requirements during the 2017-2018 school year. However, the students had no experience with open inquiry and were likely to struggle with the high level of autonomy and lack of teacher direction that accompanies this learning style. This could have an adverse effect on the students’ self-efficacy levels in STEM. Therefore, an online cross-age peer tutoring intervention was added to counteract any initial difficulties with open inquiry.

School Context

The school is located in a New Jersey suburb and is one of five middle schools that make up the school district. With a student population of 650, it is the largest, most affluent middle school in the district. The school’s racial composition consists of 57.8% Caucasian students, 16.82% Asian, 15.62% Hispanic, and 9.76% African-American. Also, 17.3% of the student body receives free or reduced lunch. Academically, the school ranks first out of the five middle schools in the district, according to 2016-2017 state test scores. During 2017-2018, the school offered a new one-semester STEM-elective class to adhere to NGSS, which was the students’ first introduction to open inquiry.

Sample Selection

To uncover the effect peer tutoring has on students’ self-efficacy in STEM, 33 eighth-grade students were given the opportunity to partake in a STEM class as tutees from September 2017 to January 2018. Purposeful selection was used to enlist participants who met the criteria needed for the study (Creswell, 2014). This meant that only students registered for eighth-grade STEM classes were invited to participate. These students’ seventh-grade science teachers nominated them for enrollment into the STEM class, because these teachers believed the students had the academic ability, social skills, and self-motivation to perform student-driven assignments. These 33 students were divided into two STEM classes. One class served as the control group and did not receive peer tutoring but still experienced open-inquiry science instruction. The other class, in addition to experiencing open-inquiry science instruction, partook in the online cross-age peer tutoring program. A consent letter disclosing the purpose of the study, any potential risks, and confidentiality, was given to parents of select middle school and high school students so they could grant permission for their child to participate, along with an assent form for adolescents.

Purposeful selection was also used to identify tutors. Only high school juniors and seniors enrolled in Level 3 and 4 research classes at one of the district high school were asked to participate in this study. These students had taken research classes for at least two years and had some expertise with the research process needed to tutor the eighth graders. Throughout the project, both the high school research teacher and the researcher monitored student contributions online and all students received a grade for their online participation.

Focus groups were chosen purposefully; four groups from each STEM class were interviewed. These groups were the only ones that had completed their projects one week prior to the semester ending and, therefore, had the time to be interviewed.

Inquiry Intervention

Teaching with open-inquiry is a lengthy process, and an exact timeline of the activities cannot be given because each inquiry project is individualized. For the purpose of this study, a general timeframe is provided to describe how the inquiry process occurred in the classroom. In September 2017, the participants were informed that they would work in groups of three to conduct an original science research project using the engineering design process or the scientific practices. They also knew that their results would be entered into two competitions: an online competition called ecybermission, and a district-wide school symposium. The students received instruction to choose a science problem or phenomena by mid-September from the ecybermission website (ecybermission.com)—one they wanted to research and, once decided, it would define a “real-world” problem they planned to study. Projects had to fall under certain categories, including: alternative sources of energy; the environment; food, health, and fitness; forces and motion; national security and safety; robotics; and technology.

From the middle to the end of September 2017, the students researched what is currently known about their problem or phenomena. They then wrote a design or problem statement. In October, the students formed hypotheses and designed models and procedures to test their supposition. By mid-November, they refined their procedures and gathered all the materials needed for experimentation. Experimentation/testing occurred through the end of December 2017, followed by data analysis, which included making charts and graphs. The data analysis was completed by mid-January 2018. Next, their findings and conclusions were submitted to ecybermission in fulfillment of the competition’s requirements. The students also created research posters by the end of January that were used to compete in the science symposium.

Peer Tutoring Intervention

The researcher presented a one hour in-person training session to the tutors and their teacher at the high school during the third week of September 2017. Discussion topics included the purpose of the peer tutoring program, the definition of peer tutoring, the students’ roles as peer tutors, Salmon’s (2000) framework, how to maneuver Google Classroom, and examples of guided questions to help the students achieve success. Peer tutoring supports used in the training were accessible to the tutors following this meeting. After the training, each tutor was matched with a group of three middle-school students and met for one hour in person to become familiar with each other before starting online communication. Following this, the middle and high school teachers monitored student contributions and informed each other of the students’ progress along the way, specifically, the frequency and quality of tutor responses. Doing so allowed the teachers to intervene when necessary and offer ongoing support to help ensure the consistency of the program. By the end of October 2017, the researcher met again with the tutors at the high school for 90 minutes to provide performance feedback and address any questions or concerns. This also helped to maintain alignment between the tutors’ interactions and the program’s goals. The ongoing training is different than training programs found in similar online peer tutoring studies, which included one or two training sessions (3-6 hours total), but were conducted at the college level (De Smet et al., 2008; De Smet et al., 2010). The continuous support and feedback in this study from both teachers was believed to be more effective for high school students who were new to tutoring.

A Google Classroom was created for each research group. This served as the platform for the tutor-tutee communication. Both student groups were required to post comments related to their research process at least twice a week, and they were asked to respond to posts within 48 hours. Examples of interactions included asking for help, discussing ideas, or inquiring about the tutors’ experiences with research. Other relevant topics were also addressed. Discussion in the eforum was a mandatory component of the STEM class and it counted toward 10% of the tutees’ science grade. The peer tutoring program concluded at the end of January 2018, when the middle-school students completed their project.

Data Collection Procedures and Analysis

Data collection spanned from mid-September 2017 to late January 2018. Table 1 shows the timeframe for the data collection and Table 2 documents the relationship between the research questions and data collection. Details of each measurement are provided below.

Table 1

Schedule of Data Collection Procedures

Measures	Sept 18-29	Oct 1-15	Oct 16-31	Nov 1-15	Nov 16-30	Dec 1-15	Dec 16-31	Jan 1-15	Jan 16-31
S-STEM Survey	x								x
Tutor Training	x		x						

Field Notes	xx	xx	xx	xx	xx	xx	xx	xx	xx
Online Interactions	xx	xx	xx	xx	xx	xx	xx	xx	xx
Student Questionnaires	x	x			x		x	x	
Focus Groups									x

Table 2

Corresponding Research Questions and Data Measures

Research Question	Tool
How does peer tutoring affect students’ attitudes related to STEM and STEM careers?	1. S-STEM survey 2. Online interactions 3. Focus groups 4. Questionnaires
What are the student-perceived challenges and benefits of an online peer tutoring program in science?	1. Questionnaires 2. Focus groups 3. Field notes

Survey Data Collection

A quantitative measure—the Student Attitudes toward STEM Survey (S-STEM) (Friday Institute for Educational Innovation, 2012) —was used to answer the first research question as it related to changes in the students’ self-efficacy in STEM. Both students in the control and treatment groups received the survey via Google Form, which was given before and after the students completed their research projects—in late September 2017 and in late January 2018. All surveys were confidential. The survey consisted of four scales that measured students’ attitudes (self-efficacy and expectancy-value beliefs) in science, math, engineering/technology, and 21st century skills (Unfried, Faber, Stanhope, & Wiebe, 2015). The items used five-point Likert-Scale responses that ranged from strongly disagree to strongly agree. The fifth scale assessed students’ interest in STEM careers using a four-point Likert scale ranging from not at all interested to very interested. All subscales showed excellent reliability levels, ranging from .89-.92.

The pre- and post-S-STEM surveys were analyzed using SPSS to look for changes in the students’ self-efficacy in STEM, as well as any changes in students’ interest in STEM careers. T-tests compared the treatment and control conditions to examine whether peer tutoring affected the students more than simply using open inquiry. Additionally, descriptive data was calculated by group and then nested within the treatment and control to inform my focus group protocol and triangulate the results. Since quantitative measures, such as surveys, lack the ability to uncover greater meaning, obtain reactions, and note human behaviors (Creswell, 2014), qualitative methods were also performed.

Focus Groups

The first section of the interview process investigated the value students’ attach to an online cross-age peer tutoring program. Inquiries about the peer tutoring program helped determine factors that influenced the effectiveness of the peer tutors and will help to improve future program designs. The next section examined student experiences with open inquiry. Questioning the students about open inquiry was necessary to determine if they struggled with such student-directed learning and tease apart the effects of open inquiry science and peer tutoring. Section three uncovered students’ future interests, such as subject matter and career choice. Initial questions were followed-up with more probing questions to further explore their responses (Creswell, 2014). See Appendix A. The interviews lasted approximately an hour and occurred in the classroom after completion of the projects in late January 2018. They were then coded using Dedoose software and analyzed to determine how open inquiry science and peer tutoring affected the students. The interview questions were piloted with a comparable group of students to determine whether they required editing and achieved the intended outcomes. The researcher, a participant observer, asked questions regarding what she observed throughout the inquiry and peer tutoring process to deepen her understanding of the students’ experiences.

The focus group interviews were transcribed and coded to determine any relevant themes. These transcripts provided varying perspectives, including student behaviors, actions, and reflections (Crawford, Krajcik, & Marx, 1999). The interviews either verified or denied preliminary analysis from the questionnaires, field notes, and surveys. The responses helped determine the quality of peer tutoring and explained how some tutees perceived the quality and effect of tutoring on their self-efficacy in STEM.

Questionnaires

In addition to conducting the survey and focus groups, the students completed questionnaires after they completed each science process (see Appendix B). These allowed for real-time data collection during this special STEM elective class. They provided a more exacting portrayal of the students’ experiences regarding peer tutoring and open inquiry. The questionnaires contained short-answer questions and Likert-Scale responses. The responses were triangulated with other data sources.

The periodic questionnaires provided immediate student reactions related to the peer tutoring experience. The answers were coded to formulate themes, which allowed the researcher to give feedback to the tutors in the October 2017 meeting and help improve the program’s effectiveness. The responses were compared with field notes and online interactions to check for validity and to help adjust the focus group protocol. The focus groups both validated and disconfirmed findings from the questionnaires.

Online Communications

Another source of data was student interactions in Google Classroom, which helped document the effectiveness of the tutoring process and the groups’ progress during the semester.

One focus was on the extent to which the tutors used strategies provided in the training and whether the students showed any signs of interest and efficacy that validated survey findings. This data also informed the focus group interviews. Lastly, monitoring the students’ contributions helped the researcher better understand the issues that needed to be addressed and those that needed to be further explored. Observations made in the online discussions helped modify the second tutor meeting to be more relevant and effective. Both the tutees and tutors were expected to post at least twice a week. The posts were checked weekly, numbering approximately 50-100 posts per group.

The online interactions were analyzed to obtain an understanding of the level of tutor support and the tutees’ STEM efficacy. After reading the interactions, broad codes were created to organize the data into different categories. Codes included feedback strategies, seeking assistance, STEM attitudes, tutor encouragement, social talk, and student perceptions of tutors’ knowledge and experience. Then, the codes were refined and child codes were formed. In addition, the online interactions were analyzed to determine the amount of tutor posts. By looking across the codes, I was able to form themes that were validated or disconfirmed based on the focus-group interviews.

Field Notes

To identify any teacher-perceived challenges and advantages related to the peer tutoring program and open-inquiry process, the researcher—also a participant-observer—attentively looked for problems and benefits during the inquiry-learning and tutor/tutee communications and documented her findings as anecdotal records in a journal. These observations helped to provide an insider’s viewpoint into the students’ experiences (Creswell, 2014). To increase the validity of the study, notes were compared against the focus group data and online forums to better understand why some groups excelled and others struggled with peer tutoring.

Validity

The continuous loop of online interactions and student questionnaires was studied to improve the October 2017 tutor meeting and ensure that the intervention met the program’s goals (Figure 2). In order to increase validity of the study, both the data collection and analysis were designed to be sequenced in such a way that early analysis informed subsequent data collection, as shown in Figure 2 below. Throughout the study, changes in tutee-tutor communication were reviewed and the teaching methods were adjusted, based on the continued analysis. Likewise, field notes helped to provide a picture of classroom interactions that may or may not have benefited from peer tutoring and the open-inquiry experience. The field notes also helped to adjust the teacher’s awareness of being more supportive. In addition, the field notes were also compared against the online interactions and questionnaires to identify any overlap or disconformity, again, helping to increase validity of the study. The online interactions informed the interviews and validated or disconfirmed the preliminary analysis. The interviews were used to verify changes the teacher perceived from the other data sources. In other words, the interviews were triangulated with the field notes, questionnaires, and online interactions to better understand what changes occurred and why. Member checks were also done to increase validity of the study.

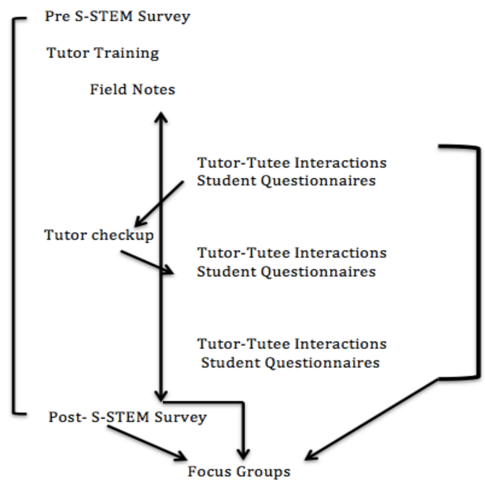


Figure 2: Data Analysis

STEM is an ever-growing science discipline wherein students develop skills that are highly favored in the global workforce. Currently, there is a shortage of students who master these skills in America, and that is why examining STEM interventions, such as peer tutoring, are important. This study addresses a gap in the literature that explores the influence of an online cross-age peer tutoring program on students' self-efficacy in STEM, which is an educational area that is hardly represented in the research and requires more attention. The ongoing data collection allowed for an in-depth view of student perceptions that portrayed a descriptive picture of how peer tutoring intervention affected the students' STEM experience. The findings offer suggestions that can improve students' peer tutoring experience.

Results

The results are divided into four parts. The first section uses statistical analysis to compare the effect peer tutoring had on the treatment and control groups, while the second section reveals the quality of peer tutoring in each group within the treatment class. The third section presents the nature of the tutees' experiences in each student group. This section explores the tutees' perceptions of tutor knowledge and quality of help. Lastly, student recommendations to help improve the peer tutoring program are provided.

Peer Tutoring Effect on Self-Efficacy in STEM

A t-test analysis of student self-efficacy levels in STEM before and after peer tutoring revealed that the intervention had a significant effect on students' confidence in open inquiry science. The treatment groups (M=.25, SD=.37) reported significantly more change in self-efficacy in science than the control groups (M=-.05, SD=.31), p=.022. This suggests that peer tutoring increased the students' attitudes more so than open inquiry alone. A descriptive analysis of each treatment groups' initial and final science self-efficacy, followed by the change in self-efficacy, is shown in Table 3. Notably, there was no significant effect on the groups' self-efficacy in technology and engineering (p=.773), mathematics (p=.773), or STEM career attitudes (p=.553). An internal reliability analysis found that the S-STEM survey was reliable for all scales (α=.70-.95). In addition, comparing the students' changes in confidence shows that even within the treatment group, not all students increased their self-efficacy in science. This by-group descriptive analysis suggests that the quality of peer tutoring differed by group. The next section discusses the quality of peer tutoring by group to better understand the intervention's effect.

Table 3

S-STEM Survey Results of the Treatment Groups' Change in Science Self-Efficacy (n=18)

Group	Avg. Initial Self-Efficacy	Avg. Final Self-Efficacy	Percent Change in Self-Efficacy
A	3.81	4.37	+15.7
B	4.11	4.59	+11.7
C	3.48	3.81	+9.5
D	3.81	3.96	+3.9
E	3.41	3.41	0
F	4.3	4.3	0

Quality of Peer Tutoring

This section examines two dimensions of the quality of peer tutoring: the amount of tutor communication and the extent of low- and high-level support the tutees received. First, the amount of tutor communication was determined by examining the number of tutor posts per group as depicted in Figure 3. Student groups were arranged from the highest change in science self-efficacy (left) to the lowest (right). The analysis shows that groups A and B: the two groups that showed the greatest increase in open inquiry science self-efficacy, received the least amount of tutor posts, while the remaining treatment groups received between 9%-54% more communication. Since the most affected groups received less tutor interaction, the quality of the posts could be a more important factor in what affected students' self-efficacy.

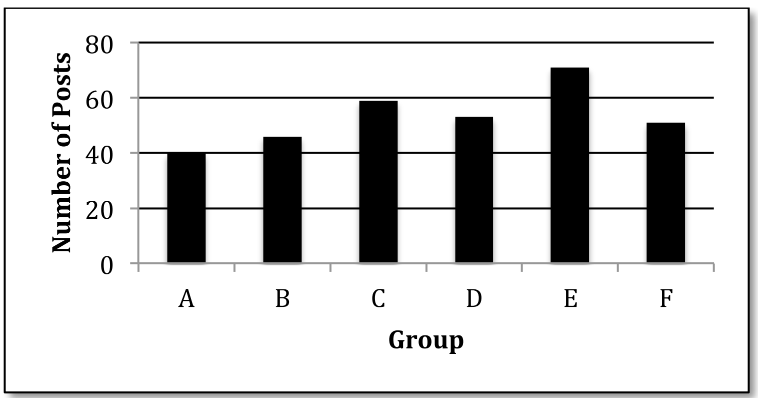


Figure 3: Total Number of Tutor Posts by Group

Next, the analysis looked at the percentage of low-level support each group received, as defined by levels 1-3, from Salmon's (2000) emoderator framework. Figure 4 shows the treatment groups organized from highest (left) change in self-efficacy to lowest (right) and gives the percentage of low-level posts each group received. Overall, the data supports the notion that low-level feedback did not differ significantly between groups with increased or unchanged self-efficacy levels. For instance, on average, the two most affected treatment groups (A and B) received 83% low-level forms of communication from tutors, while the unaffected groups (E and F) received 91%. In short, the small variance in the amount of low-level support among the groups does not appear to explain why some groups were affected by the intervention. Examples of low-level tutor posts are provided in Table 4.

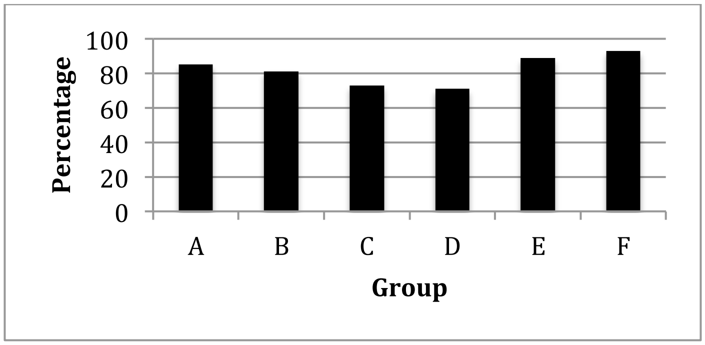


Figure 4: Percentage of Low-Level Tutor Support (Levels 1-3)

Table 4

Examples of Tutors Demonstrating E-moderator Levels 1-5, Based on De Smet et al., 2010).

Level	Indicator	Example
1-Access and Motivation	Being Accessible to Computer Problems	If you are not well-acquainted with Google Classroom, please ask me any questions.
	Encouraging Participation	Yep, that's how science research works, ha ha! I'm proud of you guys, you are all doing really good work. Let us know if you need anything.
2-Socialization	Informal Conversation	What are you guys interested in? Also, tell me more about yourselves and ask me if you have any questions about high school!
	Expression of Appreciation	Thank you guys, too, you gave us a pretty cool insight into mentoring, and we appreciate how responsive, respectful, and overall how cooperative you guys have been.
	Showing Commitment	Coming up with ideas is a process and we are here to make sure that you present research that you can achieve success with. Best of luck!
3-Information Exchange	Bringing in Other Content	This is my mission folder statement from 8^{th} grade. Please use this as a guide.
	Modeling the Content	Personally, we believe that the most feasible idea is Kinley's second idea. After more thought into the topic, we have realized that it is more than practical, and testable under the smaller-scaled circumstances that we will be provided with.
	Org Management and Planning	As far as picking an idea, we should narrow it down to your top three and pick the one that is viable and ALSO [the one] that you're interested in!

	Breaking down the Learning Task	Identify the goal of your project.
4-Knowledge Construction	Asking for Content Clarification and Explanation	If you guys were to proceed with this project, would the idea be to attach the filters to the tailpipe of the car?
	Asking to Summarize	Have you compared the net energy output of the new panel vs. a standard one yet? If so, what were your results?
	Giving Feedback	Please check online resources to make sure that these projects have not been studied in the past by other researchers.
5 Development	Call for Further Reflection	Any who, what is your goal with this project? In what ways could you make it more effective?

Lastly, the amount of high-level support, levels 4 and 5, from Salmon’s (2000) e-moderator framework, was examined to discover how it differed among treatment groups. Figure 5 shows the percentage of levels 4 and 5 help each student group received. The results show that student groups with increased self-efficacy in open inquiry science received more high-level support than the two unaffected groups. This suggests that tutor quality may have influenced the students’ self-efficacy in science. Notably, only group A’s tutors demonstrated the highest level of emoderator support (level 5) by asking two reflection questions. Level 4 help was predominantly the type of high-level help the students received and may indicate that it was the more influential of the two levels. Moreover, among the four groups affected by the treatment, there was an inverse relationship between how much student confidence changed and the amount of high-level help that was provided. In other words, the most affected group received the least high-level help and the least affected group was given the most. This implies other factors, besides tutor quality, such as student perceptions discussed in the next section, can effect students’ science self-efficacy. Examples of high-level tutor posts are provided in Table 4.

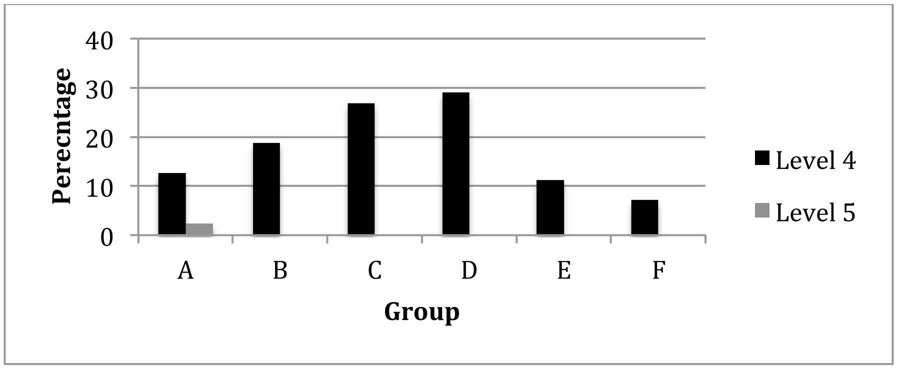


Figure 5: Percentage of High-Level Tutor Support (Levels 4 and 5)

Nature of Tutee Experiences

As described above, the amount of feedback and low-level support remained fairly consistent among all groups and did not seem to influence the students' self-efficacy in open inquiry science. However, high-level feedback was greater for groups that gained confidence in science and may be one factor that affected the students. This section proposes other reasons why groups responded differently to the intervention, such as group perceptions of their tutors' knowledge level and quality of help are discussed.

Student perception of tutor knowledge and experience.

Similar trends regarding the groups' quality of help and perception of their tutors' knowledge were discovered in the survey and questionnaire responses. Table 5 shows that all groups with increased self-efficacy, except for group C, viewed their tutors as more knowledgeable and helpful than the two unaffected groups. Group C and the two unchanged groups had the lowest opinions of their tutors' knowledge and help.

Table 5

Average Likert Scale Ratings of Student-Perceived Tutor Knowledge and Help

Group	Average
A	4.4
B	4.2
C	3.6
D	4.0

E	3.6
F	3.5

The questionnaire responses help explain why some groups viewed tutors favorably. Overall, groups A, B, and D thought their tutors’ knowledge and experience helped to facilitate their learning and eased the transition from teacher-directed to student-directed learning. For instance, Kinley from group A said, “They were more experienced and they told us what would be good for our project and we don’t have a lot of experience so that could’ve been harder for us.” Kinley appreciated that her tutors performed the scientific processes in the past and had the skillset to alleviate her stress doing research. By the same token, Max in group B stated, “Our peer tutors helped us set a direction for our hypothesis. They gave us a good foundation to build upon and gave lots of pointers on how we can twist our original ideas into things that are more coherent, reachable, and specific. They didn’t completely take over the project, nor did they ignore it. They guided us and gave some pretty good advice.” Just like Kinley, Max noticed how his tutor’s knowledge helped provide valuable feedback that led his group to success. These perceptions align with the quantitative data (Figure 5) that shows these groups did, indeed, receive high quality support. Perhaps groups A, B, and D’s positive views of their tutors’ knowledge and help are a result of the high-level support they received and explains why their confidence to learn science improved. Trusting that their tutors’ support was worthwhile may have made these students feel more confident in completing the scientific processes. This data suggests that student perceptions of tutors’ skills may influence their science attitudes.

Moreover, students from these three groups specifically mentioned that tutor assistance helped boost their self-efficacy in open inquiry science. This feeling was disclosed when Pat in group A said, “Because they are older than us, they know more scientifically. When I asked them questions and they gave me feedback, I felt like I knew more what I was doing.” Jeanne in group

D affirmed Pat’s newfound confidence by stating, “They did make us feel more confident, because we had more organization and knew what to do [in] each class instead of wasting time.” Furthermore, having additional support seemed to alleviate the stress that accompanies such student-driven work. This notion was depicted when Kinley, in group A stated, “I thought we were going to be completely on our own. When I got to this class, I was like, ‘Uh-oh, how am I going to do all of this?’ And then I realized we’d be in groups. But then, even then, I was like, ‘Uh, I don’t know if we can do this all by ourselves.’ And then we had tutors and [our teacher] and it’s like really easy.” Kinley’s comment illustrates that tutor support gave her the confidence to successfully complete a once seemingly challenging task. Likewise, Francis in group D said, “It’s like an extra boost.” These testimonials demonstrate that peer tutors can help students believe in themselves and feel supported while maneuvering through a style of learning that is unlike their previous science classes.

On the other hand, group C was the only group with increased confidence that did not view the tutors’ knowledge and help favorably, although they did receive high-level support. This seemed to result from one group member believing that he was as intelligent as his tutors, so much so that he often challenged their knowledge with cynicism. For example, Tom said, “OKAY, are you saying that making cloth for oil-covered stuffed animals in a science fair is a good idea? Yeah right,” and, “Wait, if we use different cloth materials and solutions, as well, then we need to test every solution for every cloth. Do you understand?” Tom had difficulty accepting tutor feedback, which is not necessarily a bad thing, but he was dismissive and rarely agreed with his tutors. In fact, he was the only student to use sarcasm, as noted in this quote, “Jim, thanks for bolding half our abstract.” This student’s attitude dominated the group dynamics and caused power struggles, which may explain why all three students rated their tutors’ knowledge and help low in the surveys. Group C seemingly believed that they had the necessary knowledge to succeed sans tutor help, which may explain why they did not see the benefit of having tutors who did indeed provide them with high-quality help.

The two student groups with unchanged self-efficacy also viewed their tutors' knowledge and help more negatively than the other groups, and they did indeed receive lower-level support. For example, Marie in group F stated, "I feel like we only have one tutor, because Bella wasn't really doing much. She kept saying, 'It's good.' She wasn't saying anything about what we were writing down or giv[ing] any suggestions or anything like that." Likewise, another student from group F commented, "And also I feel like they didn't have that much experience, because they were just, we were like basically learning at the same time and stuff. So, it's kind of like they had kind of just as much experience. They did do [research] before, so they know how this goes and what you have to do in it, but they weren't that helpful with it." Group F thought so poorly of their tutors' help that they ignored the tutors' advice as noted in this statement, "They said to change the color. We didn't listen." Generally speaking, the quotes echo the theme that they perceived their tutors' feedback as ineffective. According to the quantitative data, these two groups received the most low-level tutor support, which means that they did accurately assess the quality of tutor help. Their negative perceptions of tutor quality may have made them believe that the tutors were not useful, which may explain why the intervention help did not increase their self-efficacy in science.

Student Recommended Program Improvements

When students were asked how to improve the program, their responses were almost unanimous: they wanted faster feedback. Untimely responses made the students in all groups question how invested their tutors were in the program, which could have negated the effect peer tutoring had on all of the students’ attitudes. When asked what if felt like when her tutors did not respond quickly, Pat in group A answered, “We kind of felt like, not that Anita didn’t care, but I guess maybe she had other stuff to do. But Dan was really dedicated to helping us finish it, so I was kind of like, ‘Oh, Anita doesn’t feel that way about us.’” This statement suggests that the students favor tutors who respond faster and feel let down by less active tutors. Pat’s group was the most affected by the intervention, but one can wonder if the effect would have been greater had the tutors responded with more immediacy.

When asked how to remedy the communication problems that arose, all of the students agreed that a hybrid format, including weekly face-to-face meetings and online communication, would be a good solution. They believed that the online component could be beneficial, because of its around the clock accessibility and ease of updating progress. Julie noted this by stating, “There’s a lot of things that change quickly. Progress changes and so [tutors] have to communicate constantly if they really want to help.” However, students found the online could deter their progress if communication was slow. They also thought that online messages were limited to editing and direct feedback and did not encourage more complex conversations. To remedy this, the students suggested meeting in-person once a week. This would be an important element to include in the future, because it could foster faster communication and result in more higher-level-of-engagement communication. Tim in group D explained this by sharing, “Being able to meet them in-person more often would make it a lot easier to explain what you’re doing.” Kinley’s (group A) opinion paralleled Tim’s thought when she said, “…in person, you get a lot more done in one day than like a few weeks [of] communicating to them [online].” These statements show that the students believed that talking in-person would help to facilitate productive conversations and make the most of their time. Particularly, face-to-face meetings could help engineering students better execute their design, because the tutors could see the physical setup and help them build their prototype in real-time. In other words, the students felt time was wasted explaining procedural information, especially the engineering students who had many specialized steps to complete. In brief, face-to-face meetings may help foster deeper conversations that can increase efficiency.

Discussion

The academic (Berghmans et al., 2014; Cohen et al., 1982; Robinson at al., 2005; Topping, 1996; Topping et al., 2004; Zambrano & Gisbert, 2015) and affective benefits (Bowman-Perott et al., 2014; Ginsburg-Block et al., 2006; Miller et al., 2010; Robinson et al., 2005; Topping, 1996; Worley & Naresh, 2014; Zeneli et al., 2016) of peer tutoring are well documented in the literature. However, the effect of a cross-age online peer tutoring program on students’ self-efficacy in STEM is rarely studied at the middle school level. This study sought to determine if an asynchronous online cross-age peer tutoring program affects the self-efficacy levels in STEM of a group of middle school students experiencing open inquiry for the first time. Such studies are exceedingly scarce, which made studying the effect of online cross-age peer tutoring pertinent. The results indicate that the peer tutors were a viable resource that generally influenced the students’ self-efficacy in science, a major component of STEM, and should be considered as a student support when introducing students to open inquiry science. This especially important because self efficacy in a subject matter is linked to academic performance and future enrollment of science, engineering, and math classes (Lent, Brown, & Larkin, 1986; Pajares, Miller, & Hill, 1995).

This study adds to the literature by finding that such programs can increase middle school students’ self-efficacy in open inquiry science. The results align with Johnson & Johnson (1989), and Miller, Topping, and Thurston (2010) findings that peer tutoring developed higher levels of self-efficacy in science, although said studies did not use an online format or concentrate on middle school students. The findings of this present study also add to the list of other peer tutoring benefits found in the literature, such as improved student self-concept (Burgess et al., 2016), science interest (Topping et al., 2004), and improved social skills and better behavior (Ginsburg-Block et al., 2006). Learning that peer tutoring can increase self-efficacy in science is meaningful, because interventions can potentially reverse the trend of decreased self-confidence in science as students transition from elementary to middle school (NCES, 2000) and encourage student participation in STEM programs. Plus, the findings show that online cross-age peer tutoring can help increase self-efficacy in open inquiry science, which is known to be challenging to students.

The quantitative results revealed that the peer tutoring program increased students’ self-efficacy while using open inquiry in science class, and supports the inclusion of such programs in middle school. However, self-efficacy in technology, engineering, and mathematics, as well as STEM career interest were not significantly affected. One explanation for this is that math was not a focus of the class, and therefore was unlikely to be affected. Also, a small percentage of students (17%) chose to do an engineering/technology project, which makes it hard to establish if the intervention had any significant effect on self-efficacy in these subjects. More research is needed to determine how peer tutoring can influence students’ self-efficacy in these domains.

Furthermore, the findings show that middle school students’ perceptions of tutors’ knowledge and helpfulness can contribute to the effect peer tutoring has in open inquiry science. Overall, their perceptions were accurate and suggest that teaches should attach value to and explore their opinions. Three of four groups that viewed their tutors as knowledgeable and helpful did receive high quality help and experienced an increase in self-efficacy in science. Both groups that received lower-level help were also accurate with their assessment. Therefore, discussing tutor feedback with students can help teachers identify problem areas that need to be addressed with tutors providing low-quality support. This can hopefully correct their performance and improve students’ perceptions, which may result in higher self-efficacy. However, even though five of the six groups accurately assessed their tutors’ abilities in this study, it is still important to discuss the quality of tutor help with students. Perhaps doing so could have helped Group C recognize the high-level help they received and cause them to excel even more. This signifies the importance of teachers actively processing and monitoring student interactions to ensure that the tutees correctly assess the level of tutor support. Future studies can examine why some tutors offer more high-level support than others. Maybe some tutors need more training, or perhaps poor group dynamics prohibit tutors from offering more in-depth help.

The study also contributes to the literature by finding that the quality of tutor posts, not quantity, can influence students’ self-efficacy in open inquiry science. Specifically, high quality posts seem to affect student confidence, although they were not often found in online communications. This finding suggests the importance of promoting knowledge construction and development (levels 4 and 5) from Salmon’s (2000) framework during training, especially because tutors tend to take on a more directive than facilitative role and use low-level questioning (Berghmans, Neckebroeck, Dochy, & Struyven, 2013; Roscoe & Chi, 2007), Therefore, training programs need to focus on familiarizing tutors with higher level questioning and how to implement it. Doing so is critical because according to De Smet, Van Keer, and Valcke (2008), tutors commonly doubt their performance and question if they are using the right responses. This would likely be true among high school tutors who have very little, if any, tutoring experience. Generally speaking, paying careful attention to training design and supervising online communication can cultivate the desired dialogue needed to capitalize on the effect of online peer tutoring in open inquiry science.

Lastly, these results add to the peer tutoring literature by finding that the benefits of peer tutoring in open inquiry science can be attained with an online format. This is significant for two reasons. First, online tutoring is a cost-effective intervention that can foster a middle school and high student partnership in STEM by eliminating the difficulties that accompany face-to face tutoring between different schools, such as scheduling and transportation and finding common meeting times (Topping & Ehly, 2001). Second, students can collaborate using a format they are comfortable with: computers. These details indicate that an online cross-age peer tutoring program can be an efficacious support that increases self-efficacy of middle school students in open inquiry science. However, it must be noted that the students in this study desired a hybrid program that could foster faster response times and deeper conversations.

Implications

First, to help students correctly assess their tutors’ level of knowledge and helpfulness, it is recommended that teachers take time to discuss tutor posts with the students. Processing tutor comments with student groups can add validity to their tutors’ help and allow them to view tutor support properly. This can especially benefit students who receive high-level support but do not acknowledge it. Discussions can also offer opportunities to clarify terms or suggestions that tutees may not understand, thus reducing student frustration. Additionally, the teacher must play an active role monitoring the online interactions to ensure that the help is courteous, appropriate, meaningful, and accurate. This can help develop trust between tutors and tutees and help maintain positive perceptions of tutors. Overall, teacher participation can help middle school students develop truthful perceptions of their tutors, and maximize the benefit peer tutoring can have in open inquiry science.

Second, to help ensure that students receive high quality tutoring, the structure of training program can be designed to reinforce the importance of moving through the information exchange. The training session and follow up meeting in this study were both one hour, but allocating more time for tutor training can allow for additional opportunities to understand and practice higher-level communication. For instance, having bi-weekly or monthly focus groups with the tutors can promote meaningful contributions with tutees (De Smet et al., 2008) because they allow opportunities for teachers to discuss with tutors possible prompts and responses that align with level 4 and 5 support. However, this may be difficult if the cross-age tutors attend a different school than the teacher in charge of the program. Along these lines, focusing on tutor skills more so than content-knowledge during training can improve tutor feedback (Hsiao, Brouns, Van Bruggen, & Sloep, 2015). Teaching and strengthening tutors’ skills can help boost the tutors’ confidence in their performance, which typically wavers, as noted earlier, and possibly increase the likelihood that they deliver higher level feedback. However, keep in mind that high school tutors are not tutoring experts, which limits the extent that the training techniques can be implemented (Iwata & Furmedge, 2016).

Other recommendations to encourage more reflective knowledge building between tutors and tutees include providing more examples of higher-level questioning (Berghmans et al., 2013), and monitoring tutor posts throughout the program (Topping & Ehly, 2001). Giving tutors prompts can make them feel more comfortable providing the desired help, especially when they are new to tutoring, and can make incorporating higher-level help easier. Another way to foster knowledge construction and reflection is to grade tutors on the quality of their online posts, rather than on the number of posts. Having a required number of posts can make students feel forced to participate with short comments such as, "Sounds good" and "Me too," and reduce the quality of communication (Murphy & Coleman, 2004). Perhaps using a rubric to assess the quality of tutor posts can encourage more meaningful communication. Further studies are needed to find if these training strategies can magnify the effect of peer tutoring in open inquiry science.

This study is not without limitations. First, the sample size was small, which limits the generalizability of the study. Plus, the tutees had similar academic backgrounds, so it is unknown how the results would transfer to groups of higher or lower achieving students. Second, this research took place in a semester (90 days), which is a short time to change student's attitudes and determine if an intervention reached its full potential. Perhaps a longitudinal study that follows students completing three years of middle school research with online peer tutors would offer a more comprehensive analysis of the effect peer tutoring can have on students and the factors that influence it. Lastly, the students' teacher was also the researcher, making it possible that the students' responses may have been influenced by her presence and may not accurately portray how they perceived their self-efficacy level or the peer tutoring program.

Conclusion

This study provides evidence that an asynchronous cross-age online peer tutoring program can have a significant effect increase the self-efficacy levels of middle school students in open inquiry science. This finding is valuable to school administrators who want to develop middle school research programs that encourage student participation in STEM programs. Furthermore, the results show that certain factors may influence the effectiveness of a cross-age peer tutoring program. These include student perceptions of their tutor's knowledge, helpfulness, and the quality of tutor support (specifically high-level support). This article highlighted recommendations to maximize the program's potential, such as how to improve tutor training and understanding the importance of the teacher's role in an online cross age peer tutoring program. Training improvements include teaching tutors how to be facilitative rather than directive, providing examples of high-level support prompts, and having focus groups to discuss the program's success. Teacher duties include processing tutor posts with tutees, monitoring online interactions and interjecting when necessary, and grading tutors on the quality of their posts. This study also notes the benefits of a hybrid peer tutoring format to enhance the tutees' experiences and promote deeper conversations. The results are intended to add to the literature regarding online peer tutoring and middle school students in STEM.

References

Avery, Z. K., & Reeve, E. M. (2013). Developing effective STEM professional development programs. *Journal of Technology Education*, *25*(1), 55-69.

Barron, B. (2003). When smart groups fail. *Journal of the Learning Sciences, 12*(3), 307–59.

Berghmans, I., Michiels, L., Salmon, S., Dochy, F., & Struyven, K. (2014). Directive versus facilitative peer tutoring? A view on students’ appraisal, reported learning gains and experiences within two differently-tutored learning environments. *Learning Environments Research, 17*(3), 437-459.

Berghmans, I., Neckebroeck, F., Dochy, F., & Struyven, K. (2013). A typology of approaches to peer tutoring: Unraveling peer tutors’ behavioural strategies. *European Journal of Psychology of Education, 28*(3), 703-723.

Bevins, S., & Price, G. (2016). Reconceptualising inquiry in science education. *International Journal of Science Education, 38I(*1), 17-29.

Brown, P., Concannon, J., Marx, D., Donaldson, C., & Black, A. (2016). An examination of middle school students’ STEM self-efficacy with relation to interest and perceptions of STEM. *Journal of STEM Education: Innovations and Research*, *17*(3), 27–38.

Britner, S. L., & Pajares, F. (2006). Sources of science self-efficacy beliefs of middle school students. *Journal of Research in Science Teaching, 43*(5), 485-499.

Bowman-Perrott, L., Burke, M. D., Zhang, N., & Zaini, S. (2014). Direct and collateral effects of peer tutoring on social and behavioral outcomes: A meta-analysis of single-case research. *School Psychology Review, 43*(3), 260-285.

Burgess, A., Dornan, T., Clarke, A. J., Menezes, A. & Mellis, C. (2016). Peer tutoring in a medical school: Perceptions of tutors and tutees. *BMC Medical Education*, *16*(85), 1-7.

Chow, R. (2016). A pilot project of an online cross-age tutoring program: Crescent school virtual learning (vLearning). *International Journal of Adolescent Medicine and Health, 28*(4), 451-453.

Cohen, P. A., Kulik, J. A., & Kulik, C. C. (1982). Educational outcomes of tutoring: A meta-analysis of findings. *American Educational Research Journal, 19*(2), 237-248.

Crawford, B. A., Krajcik, J. S., & Marx, R. W. (1999). Elements of a community of learners in a middle school science classroom. *Science Education*, *83*(6), 701-723.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative and mixed methods approaches* (4th ed.). Thousand Oaks, CA: Sage.

De Smet. M., Van Keer H., & Valcke, M. (2008). Blending asynchronous discussion groups and peer tutoring in higher education: An exploratory study of online peer tutoring 45ehavior. *Computers and Education, 50*(1), 207-223.

De Smet, M. D., Van Keer, H. V., Wever, B. D., & Valcke, M. (2010). Cross-age peer tutors in asynchronous discussion groups: Exploring the impact of three types of tutor training on patterns in tutor support and on tutor characteristics. *Computers and Education, 54*(4), 1167-1181.

De Wever. B., Van Keer. H., Schellens, T., & Valcke, M. (2010). Structuring asynchronous discussion groups: Comparing scripting by assigning roles with regulation by cross-age peer tutors. *Learning and Instruction, 20*(5), 349-360.

Dejarnette, N. K. (2012). America’s children: Providing early exposure to STEM (science, technology, engineering and math) initiatives. *Education*, *133*(1), 77-84.

Friday Institute for Educational Innovation (2012). *Middle and High School STEM- Student Survey*. Raleigh, NC: Author.

Germann, P. J., Haskins, S., & Auls, S. (1996). Analysis of nine high school biology laboratory manuals: Promoting scientific inquiry. *Journal of Research in Science Teaching, 33*(5) 475-499.

Ginsburg-Block, M. D., Rohrbeck, C. A., & Fantuzzo, J. W. (2006). A meta-analytic review of social, self-concept, and behavioral outcomes of peer-assisted learning. *Journal of Educational Psychology, 98*(4), 732-749.

Gormally, C., Brickman, P., Hallar, B., & Armstrong, N. (July 01, 2009). Effects of inquiry-based learning on students' science literacy skills and confidence. *International Journal for the Scholarship of Teaching and Learning, 3*(2), 1-22.

Harwell, M., Moreno, M., Phillips, A., Guzey, S. S., Moore, T. J., & Roehrig, G. H. (2015). A study of STEM assessments in engineering, science, and mathematics for elementary and middle school students. *School Science and Mathematics*, *115*(2), 66-74.

Hsiao, A., Brouns, F., Van, Bruggen, J., & Sloep, P. B. (2015). Effects of training peer tutors in content knowledge versus tutoring skills on giving feedback to help tutees' complex tasks. *Educational Studies, 41*(5), 499-512.

Isabelle, A. (2017). STEM is elementary: Challenges faced by elementary teachers in the era of the Next Generation Science Standards. *Educational Forum*, *81*(1), 83-91.

Iwata, K., & Furmedge, D. S. (2016). Are all peer tutors and their tutoring really effective? Considering quality assurance. *Medical Education,* 50(4), 393-395.

Johnson, D. W., & Johnson, R. T. (1989). *Cooperation and competition: Theory and research.* Edina, MN: Interaction Book.

Kirschner, P. A. (2001). Using integrated electronic environments for collaborative teaching/learning. *Learning and Instruction: Supplement 1*(10)*,* 1-9.

Korner, M., & Hopf, M. (2015). Cross-age peer tutoring in physics: Tutors, tutees, and achievement in electricity. *International Journal of Science and Mathematics Education, 13*(5*)*, 1039-1063.

Krajcik, J., Blumenfeld, P., Marx, R., Bass, K., Fredricks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school Students. *Journal of the Learning Sciences*, *7*(3-4), 313–350.

Lent, R., Brown, S.D., & Larkin, K.C. (1986). Self-efficacy in the prediction of academic Performance and perceived career options. *Journal of Counseling Psychology*, *33*(3), 265–269.

McLuckie, J., & Topping, K. J. (2004). Transferable skills for online peer learning. *Assessment and Evaluation in Higher Education, 29*(5), 563-584.

Miller, D., Topping, K., & Thurston, A. (2010). Peer tutoring in reading: The effects of role and organization on two dimensions of self-esteem. *The British Journal of Educational Psychology, 80,* 417-433.

Moss, E., Cervato, C., Genschel, U., Ihrig, L., & Ogilvie, C. (2018). Authentic research in an introductory geology laboratory and student reflections: Impact on nature of science understanding and science self-efficacy. *Journal of Geoscience Education*, *66*(2), 131–146.

Muhuro, P., & Kang’ethe, S. M. (2014). Exploring the importance of age factor in the delivery and implementation of tutorship programme in institutions of higher learning with empirical examples drawn from one institution of higher learning. *Mediterranean Journal of Social Sciences, 5*(27), 924-930.

Murphy, E., & Coleman, E. (2004). Graduate students’ experiences of challenges in online asynchronous discussions. *Canadian Journal of Learning and Technology*, *30*(2), 29–46.

National Center for Educational Statistics. (2000). *The Nation’s Report Card*. Retrieved from: http://nces.ed.gov/nationsreportcard

National Science Teachers Association. (2015). Books and resources. Retrieved from http://www.nsta.org/publications/news/story.aspx?id=50983

Newman, J. L., Dantzler, J., & Coleman, A. N. (2015). Science in action: How middle school students are changing their world through STEM service-learning projects. *Theory into Practice, 54*(1), 47-54.

Next Generation Science Standards. (2015). The need for new science standards. Retrieved from http://www.nextgenscience.org/overview-0

Pajares, F., Miller, M., & Hill, C. (1995). Mathematics Self-efficacy and mathematics performances: The need for specificity of assessment. *Journal of Counseling Psychology*, *42*(2), 190–198.

Pizzolato, N., Fazio, C., Sperandeo Mineo, R., & Persano Adorno, D. (2014). Open-inquiry driven overcoming of epistemological difficulties in engineering undergraduates: A case study in the context of thermal science. *Physics Education Research*, *10*(1), 010107–1–010107–25.

Rezba, R. J., Auldridge, T., & Rhea, L. (1999). Teaching & learning the basic science skills. Retrieved from www.pen.k12.va.us/ VDOE/instruction/TLBSSGuide.doc.

Robinson, D. R., Schofield, J. W., & Steers-Wentzell, K. L. (2005). Peer and cross-age tutoring in math: Outcomes and their design implications. *Educational Psychology Review, 17*(4), 327-362.

Rohrbeck, C., Ginsburg-Block, M., Fantuzzo, J., & Miller, T. (2003). Peer-assisted learning interventions with elementary school students: A meta-analytic review. *Journal of Educational Psychology*, *95*(2), 240–257.

Roscoe, R. D., & Chi, M. T. H. (2007). Understanding tutor learning: Knowledge-building and knowledge-telling in peer tutors’ explanations and questions. *Review of Educational Research, 77*(4), 534-574.

Sadeh, I., & Zion, M. (2009). The development of dynamic inquiry performances within an open inquiry setting: A comparison to guided inquiry setting. *Journal of Research in Science Teaching, 46*(10), 1137-1160.

Salmon, G. (2000). *E-moderating: The key to teaching and learning online.* London: Kogan Page.

Scruggs, T. E., Mastropieri, M. A., & Marshak, L. (2012). Peer-mediated instruction in inclusive secondary social studies learning: Direct and indirect learning effects. *Learning Disabilities Research and Practice, 27*(1), 12-20.

Shenderovich, Y., Thurston, A., & Miller, S. (2016). Cross-age tutoring in kindergarten and elementary school settings: A systematic review and meta-analysis. *International Journal of Educational Research, 76*(1), 190-210.

Topping, K. J. (1996). Effective peer tutoring in further and higher education: A typology and review of the literature. *Higher Education, 32*(3), 321–345.

Topping, K., & Ehly, S. (2001). Peer assisted learning: a framework for consultation. *Journal of Educational and Psychological Consultation, 12*(2), 113–132.

Topping, K. J., Peter, C., Stephen, P., & Whale, M. (2004). Cross-age peer tutoring of science in the primary school: Influence on scientific language and thinking. *Educational Psychology, 24*(1), 57-75.

Tytler, R., Osborne, J., Williams, G., Tytler, K., & Cripps Clark, J. (2008). Opening up pathways: Engagement in STEM across the primary–secondary school transition. Brisbane, Queensland, Australia: Australian Department of Education, Employment and Workplace Relations.

Unfried, A., Faber, M., Stanhope, D. S., & Wiebe, E. (2015). The development and validation of a measure of student attitudes toward science, technology, engineering, and math (S-STEM). *Journal of Psychoeducational Assessment, 33*(7) 622-639.

Worley, J., & Naresh, N. (2014). Heterogeneous peer tutoring: An intervention that fosters collaborations and empowers learners. *Middle School Journal, 46*(2), 26-32.

Zambrano, V. V., & Gisbert, D. D. (2015). The coordinating role of the teacher in a peer tutoring programme. *Social and Behavioral Sciences, 191*(3), 2300-2306.

Zeneli, M., Tymms, P., & Bolden, D. (2016). The impact of interdependent cross-age peer tutoring on social and mathematics self-concepts. *International Journal of Psychology and Educational Studies, 3*(2), 1-13.

Zion, M., & Slezak, M. (2005). It takes two to tango: In dynamic inquiry, the self-directed student acts in association with the facilitating teacher. *Teaching and Teacher Education, 21*(7), 875-894.

Appendix A
Interview Protocol

Section 1: Determining Student-Perceived Value of Peer Tutoring

1. Describe a time when peer tutoring helped you with your project.
2. Would you recommend that schools use a peer tutoring program in a research class? Why or why not?
3. What were some difficulties you encountered while working with your peer tutor?
4. Did you feel like your peer tutor created a welcoming environment online?
    a. What did they do or not do to make you feel that way?
    b. How important was is it for the peer tutor to be kind?
    c. How important was it for the peer tutor to come across as supportive?
5. How did communicating with your peer tutor affect your confidence to complete your project?
6. How would doing your project be different if you did not have a peer tutor?
7. How would you improve the peer tutoring program?
8. How well did your peer tutor help you?
9. Besides helping you with your project, how else did peer tutoring affect you?
    a. Engaged in science?
    b. Confidence to complete a project?
10. Hos would you improve communication with your tutor?
11. Do you think you should get a grade based on communicating with your tutor?

Section 2: Student Experience with Open Inquiry

Now, I’d like to ask some questions related to your research project.

1. How was your research project different from other science projects you completed in the past?
    a. Easier? Harder? More work?
2. What did you like about doing an original research project?
    a. Coming up with an idea
    b. Writing research
    c. Getting materials
    d. Creating a procedure
    e. Answering the questions
    f. Making a poster
3. What was the most difficult part of your research project? The easiest?
    a. Coming up with an idea
    b. Writing research
    c. Getting materials
    d. Creating a procedure
    e. Answering the questions
    f. Making a poster

4. Describe your experience conducting your research project as if you were talking to a 7th grader who is thinking about taking the class.
    a. What do you think they would like about it?
    b. What do you think they would not like?
5. If you were to take this type of class again, do you think it would be easier?
6. How important is it to have a teacher to help you
7. What is it like to complete a project that no one knows the outcome to, including the teacher?
8. What are some other supports that would have helped you with your project?
    a. Peer tutor?
9. How did it feel to complete your research project?
10. Engineering group: Was this your first engineering project? What did you like and not like about it?
11. How has this class affected your confidence to do well in science?
12. What was it like to work with a group?
    Challenges?
    Benefits?

Section 3: Future Considerations

1. How likely are you to take the science research class at the high school?
    a. Why?
2. How do you feel about studying science moving forward?
    a. How has this experience changed your view of science class?
3. Have you developed any skills in science so far that may help you out of class?
4. Is there anything you would like to share that we didn't talk about?

Appendix B
Student Questionnaires

Group Name

1. How would you rate the help your received from your peer tutor?

1	2	3	4	5
very bad	bad	neutral	good	very good

2. Describe how your peer tutor helped you.

5. In what ways did the peer not help you?

6. Do you feel that you could have completed this scientific process as successfully without the

help of the peer tutor? Circle on: Yes No

7. How would your work have been different without a peer tutor

Chapter 3: Practitioner Article for Science Scope (NSTA) Submission

Reinventing Student Research for Middle School Science Competitions

Jennifer Johnson

Rutgers University

January 2018

Content Area: STEM, Science Research
Grade Level: 6-8
Big Idea/Unit: Research Projects for Science Competitions
Essential Pre-existing Knowledge: Students should be familiar with the scientific practices.
Time Required: 3-4 months
Cost: Varies

"I think doing research definitely gave us more of an idea of what scientists and engineers do, because it's kind of as if we were in their footsteps. Nobody gave us set instructions on how to do certain things. We did things based on our research."
-Middle School Student

Middle school science fairs often showcase projects that replicate research conducted online or that has been published in books. While there is value to this approach, because students learn the scientific method, the projects lack the originality, complexity, dynamics, and meaningfulness, of authentic scientific research. To remedy this, we need to give students more autonomy and challenge them to design innovative projects that help solve real-world problems of their choosing. With the technology and resources available today, students have the ability to think beyond conventional experiments and design inventive and advanced research projects. Doing so will elevate science competitions and better engage students with the NGSS science and engineering practices. Plus, making projects more rigorous can introduce students to scientific research that can have practical implications and make them more marketable to colleges.

To help provide students more authentic research opportunities, teachers can use an instructional method called "open inquiry." Open inquiry uses a student-centered approach that lets students design experiments from start to finish. Appendix A describes how open inquiry compares to other inquiry levels (Colburn, 2000). This means that they get to decide on what topic they want to explore, design the methods, conduct their experiment, analyze their results, and share their findings, all under teacher guidance. As one student states, "It was fun actually learning about something we wanted to learn about and not just follow[ing] directions from a teacher. We got to go out and explore and learn [for] ourselves." Open inquiry turns students' curiosity into real-world research. This approach enables students to view science as a dynamic process, rather than a linear one. Furthermore, with open inquiry, students are exposed to more NGSS practices than traditional "cookbook" labs. However, this process needs to occur in a guided learning environment, where the teacher provides a balance of guidance, supervision, and scaffolding that accompanies such independent learning. Also, open inquiry is a lengthy process that complements science elective classes, such as a STEM class, or afterschool science clubs that primarily focus on research projects.

The benefits of open inquiry reach far beyond academics. They include affective gains, such as increased engagement (Hubber, Darby, & Tytler, 2010) and interest in science (Mumba, Mejia, Chabalengula, & Mbewe, 2010). Plus, students develop 21st century skills for the workplace, such as creativity and imagination, critical thinking, problem-solving, collaboration, and leadership. Since students decide on their own strategies, measures, and processes for investigating their question, open inquiry even eliminates the age-old lab question, "What do I do next?"

In this article, I use the 5e-learning cycle (Liu, Peng, Wu, & Lin, 2009) and provide an example of a student research project from my STEM elective class to describe how open inquiry can be applied to middle school research. I also share tips and resources to walk you and your students through the necessary steps to conduct original scientific research. I focus special attention on explaining how you can help students choose a research problem and design their research project—the two most challenging components of middle school research that I have encountered in my 15 years of practice. If you are new to open inquiry, you will find this particularly helpful. Along the way, I also point out when NGSS practices occur.

Engage

To begin, I use an online STEM competition called ecybermission (ecybermission.com) to structure parts of my open inquiry STEM class. This website provides helpful resources that frame class activities and offers considerable student supports in the form of expert videos, past student examples, worksheets, and rubrics. When I first introduce science research to my students, I let them know that they will become scientists working in groups of three or four and they will investigate a science or engineering problem of their choosing. Then, I tell them that they are to follow the scientific method or engineering design process to address a problem and enter their findings in the ecybermission competition and our district science symposium.

Next, I familiarize the students with the research process and competition they are about to embark on by showing previous student work (examples are available at ecybermission.com) and discuss past student accomplishments in science competitions. This usually inspires students to begin their research project and shows them the task is achievable. I also remind the students that conducting research involves solving purposeful problems that will benefit local or global communities, not merely entering competitions. Following this, I introduce the science categories that their research can fall under. These include: alternative energy sources, the environment, food, health and fitness, forces and motion, national security and safety, robotics, and technology. My students usually spend a week choosing one. For purposes of the example used in this article, the student group decided to investigate national security and safety.

Explore

Defining a problem within a science area can be difficult for students, because they are accustomed to teacher direction. With open inquiry, middle school students may feel overwhelmed with having freedom of choice and they may not understand the limitations of experimentation in a middle-school classroom. To help, I encourage the students to ask family and friends if they have a problem that needs a solution. Most likely, someone will say, "You know, I always wished someone could come up with a way to…" Next, I share articles from science magazines like *Scholastic Science World*, online science articles, or the news, because problems noted in these sources might translate into workable experiments. I also ask my students to look at solutions that already exist for problems and try to improve upon one. Lastly, I jot down problems or project ideas as I come across them. This way, I have a reserve of possible ideas to share with struggling students.

After preliminary online searches and conversations with family and friends, the students in this example decided to focus on car safety, because they all knew of someone who was affected by car accidents. The students also decided that they wanted to use engineering practices, rather than the scientific method, to design and test a solution. Next, the group performed the science practice of asking questions and researched additional information online to build on their scientific knowledge of car accidents (at least 10 total sources from journals, websites, and expert interviews). For example, the students researched how often car accidents occur, the most common ways passengers get injured, and what innovations currently exist to help prevent accidents. They learned that certain factors, such a false sense of invincibility, peer pressure, or embarrassment, make teen drivers less likely to wear seat belts and more likely to get hurt in car accidents. This motivated the group to focus on the problem of a lack of seat belt safety. Next, they wrote a summary explaining what they learned in their research and established a need for this problem to be addressed (this takes students about two weeks to identify, research, and write the problem).

Next, the group devised a design plan (I allot about 5 weeks for this NGSS practice), which included identifying their goal, design criteria, and constraints. Using open-ended questions can help students begin designing their plan. You can find excellent open-ended questions at https://journeynorth.org/tm/inquiry/inquiry_guide.pdf. The students decided their goal would be to create a device that prevents car motors from starting until a buckled seat belt is detected. However, coming up with a design that could achieve their goal was difficult. I find that students encounter common “pitfalls” or obstacles during the design process, especially those without much Level 3 or 4 inquiry experience. Pitfalls include developing a design that is unsafe to test, too large of a scale, too timely to test, too advanced for the middle school level, or they want to design a prototype that looks professionally built. Appendix B includes a table with descriptions of the pitfalls this group faced and how we moved past them.

To visualize possible design solutions, the students performed the engineering practice of modeling by creating diagrams. They drew a diagram showing how seat belts work and started labeling the parts that could be manipulated to send a signal to the motor to start after a seat belt was buckled. Then, the students generated potential designs and discussed them with the class, myself, cross-age student groups, and other teachers. The more feedback the better! Asking open-ended, probing questions helped the students think about the benefits and challenges of each design and helped them decide which path to take. Sample questions included: What is it about your first design that would help you solve the problem better than your second design? How did you decide on your final seatbelt design? How does your design motivate someone to wear a seat belt? Appendix C shows the design they chose for their prototype. Their design included a light sensor that detects when the light intensity in the buckle falls below a determined threshold (this occurs when the tongue clicks into the buckle and blocks the light from entering), and then signals the motor to start. Having a self-chosen, testable design excited the students to continue the research process.

Their design statement was: Our seat belt safety device is designed to prevent a motor from starting until a light sensor system detects that a driver is buckled up. It will help prevent people from driving without wearing a seat belt and decrease the number of injuries from car accidents. Their criteria included: The motor does not turn on until the light intensity in the buckle goes below a determined threshold. The light sensor does not interfere with the connection of the seat belt buckle and tongue. The light sensor can detect a light source from any angle. Their constraints were: The design is not wireless and is bulky. The design cannot be tested with an actual motor. There is limited time to design, build, and test this concept.

After choosing a design, the students wrote the procedure needed to build the prototype. I had students write multiple drafts of their methods and provided them with timely feedback to help improve their directions. Often, I needed to remind the students to be specific with their directions (How many? What size? How frequently?). The students also needed to understand that they would refine and develop their methods as they built their prototype. Usually, my students write 2-3 drafts of their method before building their design. An experimental design checklist and rubric found on ecybermission.com can remind students of important procedural components.

Once their procedure was written, the students gathered the necessary materials and began building their prototype. For this project, I taught them how to use a digital control unit, data logger system, and light sensor, so they could test their device autonomously. Keep in mind that open inquiry activities may require additional time and teacher guidance to explain how to use equipment, because each group’s methods may involve a different technology. Plus, teachers may need time to teach themselves how equipment works. After the prototype was built, the students tested, evaluated, and revised their design. The group developed many solutions during testing trials to address design problems that they encountered. Aspects, such as the angle of the light sensor, wiring, and determining a suitable light threshold to program into the data logger, were modified during performance trials.

Explain

Upon completing the experimental phase, the students analyzed and interpreted their data. This engineering practice could take 1-2 weeks. Scripted labs that accompany Level 2 inquiry usually provide pre-made charts and graphs for students to complete, but with open inquiry, students have to construct every aspect of their data visuals. My students struggled with choosing and creating these, so I reviewed the basics of making graphs, tables, and charts, and discussed which format best communicated their findings. I also modeled how to make tables and graphs and had the students practice doing the same with sample data. Watching short YouTube videos can help students construct data visuals. A short video that can help them create bar graphs can be found at: https://www.youtube.com/watch?v=aBV2vvTFI84.

Extend and Elaborate

Lastly, the students wrote their conclusion (suggested time 1-2 weeks). Unlike traditional labs, where students answer straight-forward conclusion questions, conclusions to open inquiry activities required them to reflect on their study design, evaluate the success of their design using evidence, relate their findings to the literature, recommend future studies/designs, and make connections to their original real-world problem. Again, open-ended questions can help students consider evidence when evaluating their design. In this case, sample questions included: What patterns do you see in your data? How does your data support/refute your design statement?

What evidence supports your explanation? What were the strengths and weaknesses of your design? How can you improve your design?

Based on testing results, the students decided that their design did not meet their criteria. First, their design was only effective when the light source was directly over the opening of the buckle. Second, a person could take any object, like a blanket, and cover the opening of the buckle to block the light, which would then signal the motor to start. These flaws led the group to think of future design solutions that included a sensor that could detect seat belt tension or putting a magnetic sensor inside the buckle to detect when the seatbelt is clicked together. Learning that a design solution does not work perfectly can happen and it is ok. Very rarely do designs work the first time around. What matters is that the students learn how to improve their design. Students sometimes worry that an unsuccessful design means they failed. This is not the case. I tell them that they have the chance to explain what happened, as well as future designs in their conclusion.

Evaluate

For a summative assessment, the students created a research poster to communicate their investigation and submitted it in the ecybermission competition and our district’s Science, Engineering and Technology Symposium. Each poster used a single PowerPoint slide template found under the resource tab on my website (https://jenhutchinson2.wixsite.com/peertutor). The finished product looked professional and was an artifact the students could take pride in. I used a rubric to evaluate each poster (Appendix D). Once the posters were printed, the students needed time to practice presenting their research. My students presented their findings to the 6th grade science classes, which made them more comfortable communicating their investigation in front of an audience and excited the younger students to take STEM in 8th grade. This group did very well in their science competitions. They earned first place in engineering in the district symposium, were nominated for a national science competition, and placed in the highest scoring range for the ecybermission competition.

Conclusion

While the students' work shown here is not without mistakes, it represents higher-level middle school research that can be entered in science competitions. Yes, there were flaws with the design, but that is ok. What is important is that the students experienced science as a dynamic process and gained knowledge to improve their design. I hope that sharing my open inquiry example helps teachers better understand the student research process and invokes confidence incorporating this method into their science elective classes or clubs. After all, as educators, we strive to shift from students learning about science to students *doing* science.

References

Colburn, A. (2000). An inquiry primer. *Science Scope 23*(6), 42-44.

Hubber, P., Darby, L., & Tytler, R. (2010). Student outcomes from engaging in open science investigations. *Teaching Science*, *56*(4), 8-12.

Liu, T., Peng, H., Wu, W., & Lin, M. (2009). The effects of mobile natural-science learning based on the 5E learning cycle: A case study. *Educational Technology and Society*, *12*(4), 344-358.

Mumba, F., Mejia, W.F., Chabalengula, V.M. & Mbewe, S. (2010). Resident scientists' instructional practice and their perceived benefits and difficulties of inquiry in schools. *Journal of Baltic Science Education, 9*(3), 187-195.

National Science Teachers Association. (2008). The many levels of inquiry. Retrieved from http://www.nsta.org/publications/news/story.aspx?id=5098

Segala, Laura. (2018). Observe, describe, wonder. Teacher Guide. Building Inquiry into Instruction. Retrieved from: https://journeynorth.org/tm/inquiry/inquiry_guide.pdf

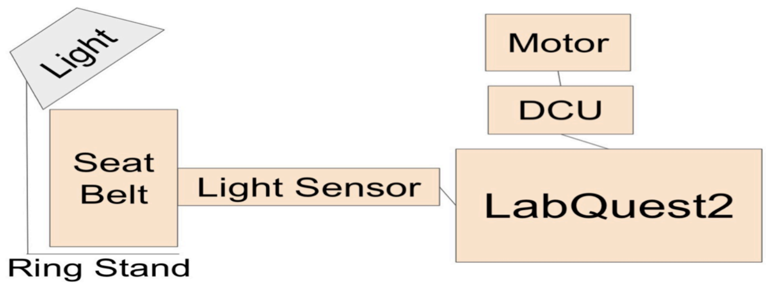
Appendix A
Descriptions of Inquiry Levels (NSTA, 2008)

Inquiry Level	Question	Procedure	Solution
1-Confirmation Inquiry Students confirm a principle through an activity when the results are known in advance.	x	x	x
2-Structured Inquiry Students investigate a teacher-presented question through a prescribed procedure.	x	x	
3-Guided Inquiry Students investigate a teacher-presented question using student-designed/selected procedures.	x		
4-Open Inquiry Students investigate questions formulated through student-designed/selected procedures.			

Appendix B
Challenges Designing and Conducting Experiments

Potential Pitfalls	Example	The Rescue
Students choose a design that risks someone's safety.	A device that shocks a person if he doesn't wear a seat belt before starting a car.	We thought of other ways to motivate people to put on a seat belt besides ones that already exist (sounds and pictures). This led students to develop the light sensor for the seat belt, which is presented in this article.
Students want to test their solution on a real-life scale.	The students wanted to manipulate a seat belt and motor in a real car.	I explained that scientists usually experiment on a small scale before they test in the field. I also explained that we didn't have the means to a car that could be potentially destroyed, or access to a light sensor that could connect to a real a car motor. I reassured students' that testing on a small scale did not weaken their experimental design.
The students' design requires too much time to test.	The students wanted to build a seat belt that had a light sensor built into the design instead of attaching a bulky one as they did in this experiment.	It probably is possible to 3D print most if the parts of a seat belt and figure out how to incorporate the light sensor into the seatbelt design. However, this goes beyond the time period of a one-semester class. Instead, the group bought a seat belt for $15 on Amazon. The students could refine the design of their seat belt safety device in high school if they chose to and discuss future designs in their discussion.
Students choose a problem that is too advanced or grandiose for the middle-school level.	The students wanted to design a camera that could recognize if a seat belt is buckled, and then allow a car to start.	We thought of other ways we could know the seat belt was buckled that were within the constraints of a middle school classroom. The students thought of a magnet that could be in the buckle and on the tongue. When the magnetic field reached a threshold the car could start.

Appendix C
Student Model of Car Safety Device



Appendix D
Research Poster Rubric

Research Poster Rubric - Science Research
Student:________________________________
Scoring: 0 – missing or completely erroneous 1 – poor 2 – adequate 3 – good 4 – outstanding
Title _____Font size appropriate
Introduction _____Labeled _____Clearly defines a problem _____Includes sufficient background information/claims that justify the problem _____Discusses at least one/two previous research findings from the literature _____Includes proper citations: For example: (Smith, 2008) _____Information is accurate _____Figures enhance understanding _____Figures properly labeled (on bottom as Fig. 1, Fig. 2, etc. and includes a caption)
Design Statement _____States what the problem is _____States who has the problem _____Explains why it is important to solve the problem
Materials and Methods _____Labeled _____Steps in logical order, whether written or visual _____Includes specific concentrations/voltages/amounts, etc. _____Describes specifics of equipment _____Steps sufficient to understand procedure _____Includes diagrams, figures to enhance understanding of design and procedure _____Figures properly labeled
Results _____Labeled _____Includes sufficient data to draw conclusions _____Data organized and presented in appropriate form (graphs/tables/photographs)

______Figures properly labeled, including units (graphs are labeled as figures) ______Appropriate units are utilized ______Sufficient quantity of data to draw a reasonable conclusion
Discussion ______Labeled ______Explains trends seen in data ______Analyzes data with appropriate statistical/mathematical references ______Uses evidence to evaluate the success of a design ______Uses evidence to suggest future design solutions ______Relates data to conclusions drawn by at least one form of previous research ______Discusses future direction for research ______Discusses limitation of conclusions
General Poster Elements ______Title is of sufficient size ______Color scheme does not distract ______Text boxes are neat and legible and of sufficient size ______Figures are of sufficient quality ______Figures are of sufficient size ______No excessive empty space ______Demonstrates general planning and thoroughness of construction
______Point total

Chapter 4: Open Inquiry Professional Development Plan

Jennifer Johnson

Rutgers University

January 2018

Title: Open Inquiry Professional Development Proposal
School District: Valley Township School District
Suggested Dates: Summer 2019, Hourly monthly meetings throughout the 2019-2020 school year
Submitted By: Jennifer Johnson
School/Position: Riverside Middle School/8th Grade Science and STEM Teacher
Email:
Intended Grade Level/ Audience: 8th Grade STEM Teachers and STEM Club Advisors
Minimum/Maximum Number of Participants: Max: 25

Introduction

Background Information

Following the adoption of the Next Generation Science Standards (NGSS), 8th grade science teachers in Valley Township School District (VTSD) were tasked with exposing students to science and engineering practices. This meant that teachers would help their students conduct student-led research. In addition, teachers and administrators created a Science, Engineering, and Technology Symposium (SETS) to showcase the students' projects. The symposium has grown over the last five years and is now affiliated with the Broadcom MASTERS program, a national science and engineering competition for middle-school students.

Problem

Although the symposium highlights student research, the originality, complexity, and meaningfulness of student work, along with the degree of NGSS alignment, varies greatly. Often, student work represents projects that have been frequently performed, fails to target a real-world problem, or overlooks NGSS practices. To create more uniformity and enhance the quality of student work, teachers can use an approach called "open inquiry." Open inquiry entails student-directed research, which involves students proposing research questions and designing procedures that address a problem with unknown results. During open inquiry, teachers relinquish most of their control and provide scaffolded support, when needed, as students complete a research project. Using open inquiry will help to align student projects with NGSS more so than "cookbook" projects, which are sometimes found in the symposium. In addition, open inquiry provides opportunities for students to model the work of professional scientists.

There are numerous benefits associated with open inquiry. First, it can improve students' understanding of scientific practices, because the students design every aspect of their experiment (Berg, Bergendhal, & Lundberg, 2003). Second, the students strengthen their problem-solving skills as they resolve unexpected difficulties that accompany the open inquiry (Sadeh & Zion, 2011). In addition, the students develop 21st century skills for the workplace, including creativity and imagination, critical thinking, collaboration, and leadership, all of which will prepare them for future success. Third, open inquiry can increase students' engagement and interest in science (Crawford, Krajcik, Marx, 1999; Lesseig, Nelson, Slavit, & Seidel, 2016; Mumba, Mejia, Chabalengula, & Mbewe, 2010). This is because students feel excited with the concept of modeling the work of scientists to discover something new. Having ownership in the experimental design and investing many hours in exploring a student-directed research question can amplify the students' desire to participate in scientific research. Overall, open inquiry results in the formation of new knowledge and helps the students view science as a dynamic process, more so than lower forms of inquiry or traditional science activities (Minner, Levy, & Century, 2010; Sadeh & Zion, 2009; Zion & Slezak, 2005). Incorporating open inquiry into STEM classes or afterschool science clubs will elevate the quality of student work and can inspire a student's passion for science.

However, teachers in VTSD have not had many opportunities to learn about open inquiry. For this reason, they may not be aware of the different teacher roles and strategies that accompany this teaching approach. For instance, teachers may feel uncomfortable relinquishing control and letting students formulate designs, maneuver through obstacles, and make decisions. Likewise, teachers may not be aware of the roles they need to fulfill as students direct their learning; this includes their serving in the role of guide, mediator, co-explorer, and coach (Crawford, 2000). Making the shift from teacher-directed to student-directed instruction can be challenging, and without proper training, teachers may unknowingly teach open inquiry activities incorrectly (Nadelson et al., 2013). Also, teachers who are primarily familiar with Level 2 inquiry may struggle when helping students choose a problem/phenomena to study, develop an original research question, and design a procedure, because they are accustomed to them being provided in curriculums. Plus, they may not be aware of the questioning and feedback strategies that create the meaningful dialogue needed to help students progress through the research process. Having a repertoire of questioning probes and feedback prompts is key to fostering the critical thinking and decision-making skills required with open inquiry (Krajcik et al., 1998). Similarly, teachers who are unfamiliar with open inquiry may overlook the value of modeling certain scientific practices, especially to students who are new to open inquiry. In summary, using open inquiry can be an adjustment for teachers. However, with proper training and support, teachers will engage students in meaningful, authentic learning experiences that model the work of professional scientists.

Solution

I propose a summer professional development (PD) training, together with ongoing support throughout the school year, to help teachers incorporate open inquiry into their STEM classes. This training will support VTSD’s vision of student achievement in the science and engineering practices. First, I will provide VTSD middle school science teachers with a rich, eight-day experience-based PD in the summer of 2019, coupled with implementation of a professional learning community (PLC) that will meet monthly throughout the 2019-2020 school year. The summer training will help teachers understand what open inquiry looks like from a student’s and teacher’s viewpoint and provide teachers with questioning, feedback, and modeling strategies recommended for inquiry use (Krajcik et al., 1998). Activities will include analyzing student work, modeling teaching strategies, watching expert videos, discussing the relationship between open inquiry and NGSS, collective dialogues, and experiencing open inquiry first-hand. Teachers will take home helpful handouts of the strategies they learned in PD for use in the classroom. Subsequent to the summer training, PLCs will be formed to strengthen teachers’ knowledge of open inquiry and NGSS, provide them time to problem-solve, and offer opportunities for teachers to reflect upon and share their experiences as they enact the new practices.

Setting

The teachers will meet in a vacant classroom at Riverside Middle School on June 24-27, and July 8-14, 2019 from 9:00 am-12:30 pm for an intensive, experience-based, open-inquiry summer training. Following the training, each middle school will establish mandatory PLCs during the 2019-2020 school year, which will help teachers develop knowledge and skills, provide feedback, and troubleshoot, as they design and perform open inquiry activities. Monthly PLCs will occur in each of the teachers’ respective schools. Administrators will need to provide release time for teachers to participate in PLC or it can be held after school.

Participants

PD will be available to all middle school science teachers in VTSD; however, target participants are 8th grade science teachers who teach STEM-elective classes, lead STEM clubs, guide student research projects, or are interested in learning about open inquiry. The teachers’ professional experience ranges from approximately 2 to 20 years, and their educational backgrounds mostly include the biological sciences. Until two years ago, almost all middle school teachers have been using Level 2 inquiry-based curriculums throughout their entire career.

Professional Development Design

Goals and Objectives

The goals for this open inquiry PD include: 1) Teachers will understand the differences between confirmation, structured, guided, and open inquiry instruction, and understand the benefits of each. 2) Teachers will implement effective open-questioning practices and feedback strategies during open inquiry instruction. 3) Teachers will learn how to use modeling during open-inquiry instruction to scaffold student learning. 4) Teachers will understand how open inquiry aligns with NGSS practices.

The objectives that will help teachers meet the overarching goals during the summer PD are: 1) Teachers will summarize the different inquiry levels. 2) They will evaluate, develop, and enact examples of effective questioning and feedback. 3) Teachers will be able to design and enact modeling activities that can be incorporated into open-inquiry lessons.

Open Inquiry Professional Development Plan

Overview

This professional development plan describes a cohesive two-step plan that includes an experience-based summer training and a yearlong PLC. First, I will describe how the summer training will familiarize teachers with open inquiry and the teaching strategies specific to this approach. See Appendix A for a detailed table of activities, formats, materials, and objectives.

Second, I will explain how a yearlong PLC will help to sustain the change initiative by providing ongoing teacher training and support as teachers implement open-inquiry activities. In total, the PD and PLCS will consist of approximately 38 hours over the course of the 2019-2020 school year. Lastly, I'll share how the evaluative procedures will uncover strengths and weakness of the training, changes in teacher practice, and the trainings' effect on student success with open inquiry.

Summer PD Description

On the first day, norms will be collectively developed and teachers' past experience and knowledge of inquiry will be shared. The theory of andragogy states that teachers need to see the value in learning and the reasons why they should learn about it (Bookfield, 1986). Therefore, teachers will learn why open inquiry is useful in science and how it will benefit their practice. Teachers will also become familiar with the different levels of inquiry by way of inquiry videos, vignettes, and lesson plans. After they can differentiate from among the four levels and comprehend the benefits and challenges of each, teachers will spend three days learning how open inquiry can be used in science elective classes and understand specific teaching strategies that are useful in open inquiry. Specifically, they will learn questioning, feedback, and modeling techniques that can help students develop successful research projects. Teachers will have opportunities to observe, discuss, and perform these strategies during the PD. Along the way, they will receive feedback on their performance. Next, teachers will spend three days participating in and leading open-inquiry activities to better help them understand how teachers and students perceive open inquiry. Lastly, teachers will spend a day designing an open-inquiry lesson plan that they can use in the classroom. The following details some of the activities that show how I will enact the PD design.

Many PD activities will adhere to the second and third objectives, so that teachers will develop the questioning, feedback, and modeling skills needed to effectively lead open-inquiry activities. The following includes sample activities designed to help teachers learn and perform different questioning techniques. However, similar activities will be done to help teachers learn about modeling and how to provide feedback. First, the exploratorium.edu website will be used to familiarize teachers with open- and closed-ended questions. Specifically, documents found on the website will be used to provide examples of deeper-level questions that teachers can refer to during the school year. Once they are familiar with open- and closed-ended questions, teachers will be able to observe me model how to use open-ended answers in conjunction with student work. The teachers will then have time to practice asking open-ended questions with sample student work. I will provide teacher feedback and, together, we will discuss the challenges and benefits that came up as they asked open-ended questions. Next, teachers will look at documents from the website that describe how phrasing questions differently can help students predict, design, analyze, and explain their findings. We will also discuss how to best phrase questions to help students reflect on their work, explain their ideas, and form answers. Teachers will watch videos of experts demonstrating the questioning strategies, practice them, and receive feedback. This cycle will be followed for each practice, so that teachers are not merely observing, but also enacting these teaching practices.

Hands-on activities will also be part of the PD design, so that teachers can actively learn about valuable strategies used in open inquiry. For example, teachers will learn how questioning can be categorized as subject-centered, person-centered, process-centered, and "other" by participating in the Floating Egg and Hinged Mirror activities found on the exploratorium.edu website. As they engage in the activities, teachers will each write one question that would help students explain the phenomenon they would witness if they were to perform the activities in class. Together, we will then discuss how their questions can be categorized into the four groups and learn why person-centered questions are best at helping students express their thought processes and rationales. Activities like these will help teachers practice performing exemplary questioning practices and construct new knowledge specific to open inquiry. Similar hands-on activities will be used to learn and practice feedback and modeling strategies.

Most importantly, this PD includes opportunities for teachers to authentically experience open inquiry from the student’s perspective and practice leading open-inquiry activities. Based on experiential learning theory, which is thought to meet the needs of adult learners (Burke, 2013), teachers will be given the chance to actively engage in authentic open-inquiry activity. This opportunity is known to help change teachers’ beliefs and deepen their understanding of open inquiry (Svinicki & Dixon, 1987). Groups of teachers will experience open-inquiry activities in the same way that students do by collaboratively conducting a research project, while other teachers will lead the open-inquiry activities. While stepping into the student role, teachers will better understand how questioning, feedback, and modeling strategies influence student learning. While performing in the teacher role, teachers will receive feedback as they practice using the strategies. The groups will switch roles throughout days 5 and 6 of the PD. Extensive time will be set aside for teachers to collaboratively reflect on how the newly taught strategies can influence students’ success with open inquiry. These authentic experiences will also let teachers witness the effects group dynamics can have on student achievement and help them appreciate how important teamwork is in open-ended projects (Lesseig et al., 2016). Likewise, teachers will discuss NGSS science and engineering practices that were performed and recognize how open inquiry adheres to the three dimensions of NGSS. In summary, this experienced-based learning opportunity will foster self-construction of knowledge.

Each day during the PD, time will be allotted for teachers to ask questions, receive feedback, and brainstorm. The dialogue will challenge their assumptions and shape their future practice using open inquiry. The inquiry-driven discussions and collaborative reflection will liken the chance that teachers will gain new perspectives, develop their practices, and, in some instances, even reverse teacher beliefs that may have hindered their use of open inquiry to this point. In other words, inquiry-based discussions will help uncover teachers' thoughts and perspectives about open inquiry that would otherwise go unnoticed and help them collectively construct new knowledge. By critically reflecting on their experiences, teachers will discover solutions, gain support, and learn new ways of using open inquiry. Furthermore, dialogue and reflection will help me assess the teachers' level of understanding and target areas that need more or less attention. Also, the teachers will have ample opportunities to process their understanding of how open inquiry incorporates NGSS practices while reflecting and discussing learning activities.

Lastly, teachers will apply their new knowledge by designing and teaching open-inquiry lessons. Using open inquiry with students will give teachers the opportunity to practice their newfound knowledge and share their progress with peers. This step can involve risk-taking and uncertainty; as a result, teachers will be given support throughout this phase within a PLC that follows this training program.

Year-long PLC Description

Following the summer training program, these 8th grade science teachers will participate in a year-long monthly PLC. The goal of the PLC is to offer continuous support that develops and sustains effective open-inquiry practice. The PLC will also ensure that the objectives are being met as teachers discuss new strategies they use in the classroom. I will facilitate the inquiry-based PLC, because I have the knowledge to help process the successes and obstacles teachers will experience with open inquiry. Eventually, 8th grade science teachers will be chosen as teacher leaders when they feel comfortable doing so. Monthly PLC meetings will include inquiry-based, collaborative discussion, and reflection, because research shows that this can help teachers develop and sustain the knowledge gained in the PD and encourage the use of new pedagogical approaches.

To break down privatization norms associated with educators, I will collaboratively develop new norms to create trusting and collegial relationships among teachers. This will help teachers feel safe sharing their open-inquiry experience with others and transform a potential pseudo-community into an authentic community. In addition, protocols will be used to help stimulate meaningful discussion, reflection, and participation, as teachers collaboratively form new knowledge.

The PLC will provide time to delve into teacher experiences using open inquiry. Since learning is often a social project consisting of collective dialogue, the teachers will be asked to discuss their practice and collaboratively reflect upon their experiences with the group. Teachers will be asked to bring examples of the questioning, feedback, and modeling they used in the classroom. These artifacts will be shared with the group so that teachers can discuss, reflect, and receive feedback regarding their open-inquiry performance. Together, we will revisit practices from the summer PD and evaluate how the artifacts are similar and different from what was learned. This will help teachers develop and improve their practice. Moreover, PLC will provide opportunities for teachers to revisit and troubleshoot obstacles as they encounter them. Receiving constructive feedback will help them maneuver through problems and help to reduce any stress they may feel as they implement new teaching strategies.

After trust has been established, peer observations can be performed, collaboratively discussed, and reflected upon to help teachers develop their practice using open inquiry. Peer observations can be initially intimidating, but this rich data source will help to improve everyone’s practice as teachers identify their strengths and weaknesses. In addition, data, such as student work and lesson plans, will be used to spark questioning, dialogue, and reflection. Also, district administrators can help foster research-based discussions by providing a Science Scope subscription to help teachers stay up-to-date with the latest inquiry approaches. Action research such as this has been shown to provide new perspectives that can lead to teacher change. In sum, routinely engaging in data analysis will help guide teacher practice with open inquiry

Lastly, middle school administrators must see the value of offering this PLC to teachers, because they have the authority to make structural allowances, such as meeting times, access to journals, and observation times, which are needed to make teacher learning possible. Administrators must encourage teachers to use open inquiry and invest in teacher learning by offering support. Along these lines, parents must be made aware of the teaching approach their child will encounter, so they can offer support, when needed.

Evaluation

Evaluations will be used to assess how well PD improved teachers’ use of open inquiry and determine the level of influence the training had on student achievement. Evaluation data will be analyzed to make strong connections between PD and its outcomes, determine the worth of PD, and identify where changes are needed and what should remain. First, teachers’ performance of the three strategies and their lesson plans will be measured during the PD. Second, the level of teacher learning will be evaluated. To accomplish this, student work brought to the PLC can be used to assess teachers, as well as any artifacts that show their questioning, feedback, and modeling. Also, the science supervisor, teacher coach, or facilitator can conduct observations (video optional), interviews, or journal reflections twice a year (mid- and year-end) to evaluate the teachers’ use of the three teaching strategies. Third, the level of school support must be evaluated to ensure that teachers’ needs and efforts were supported. Measuring school support can be done using questionnaires and interviews in mid-year and upon conclusion of the training program and PLC. Equally important is the evaluation of student learning after the teachers have participated in the training. This can be achieved by using a rubric to assess the students’ final research poster.

In conclusion, incorporating open inquiry will benefit the students by familiarizing them with science practices and give them the chance to conduct higher-level research. This will elevate quality of the district’s symposium and make it an event that other districts will strive to replicate. The key to this success is giving teachers the knowledge and skills needed to incorporate this teaching method in their classes. Providing teachers with the PD plan described above can achieve this. It is my hope that we can work together to strengthen the science education students receive in Valley Township.

References

Berg, C. A. R., Bergendhal, C. B., & Lundberg, B. (2003). Benefiting from an open-ended experiment? A comparison of attitudes, and outcomes of, and expository versus an open-inquiry version of the same experiment. *International Journal of Science Education, 25*(3), 351-372.

Bookfield, S.D. (1986). Understanding and facilitating Adult Learning. San Francisco: Jossey Bass.

Burke, B. (2013). Experiential professional development: A model for meaningful and long-lasting change in classrooms. *Journal of Experiential Education*, *36*(3), 247–263.

Crawford, B. A., Krajcik, J. S., & Marx, R. W. (1999). Elements of a community of learners in a middle school science classroom. *Science Education*, *83*(6), 701-23.

Lesseig, K., Nelson, T. H., Slavit, D., & Seidel, R. A. (2016). Supporting middle school teachers' implementation of STEM design challenges. *School Science and Mathematics*, *116*(4), 177-188.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction--what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474-496.

Mumba, F., Mejia, W. F., Chabalengula, V. M. & Mbewe, S. (2010). Resident scientists' instructional practice and their perceived benefits and difficulties of inquiry in schools. *Journal of Baltic Science Education, 9*(3), 187-195.

Nadelson, L. S. Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: Inquiry-based stem professional development for elementary teachers. *Journal of Educational Research*, *106*(2), 157-168.

Sadeh, I., & Zion, M. (2009). The development of dynamic inquiry performances within an open inquiry setting: A comparison to guided inquiry setting. *Journal of Research in Science Teaching, 46*(10), 1137-1160.

Sadeh, I., & Zion, M. (2011). Which type of inquiry project do high school biology students prefer: Open or guided? *Research in Science Education, 42*, 831-848.

Svinicki, M. D., & Dixon, N. M. (1987). The Kolb Model modified for classroom activities. *College Teaching*, *35*(4), 141-146.

Zion, M., & Slezak, M. (2005). It takes two to tango: In dynamic inquiry, the self-directed student acts in association with the facilitating teacher. *Teaching and Teacher Education, 21*, 875-894.

Appendix A

Schedule of 8 Day Open Inquiry Summer Training

Table 1

Schedule of 8 Day Open Inquiry Summer Training by Day

Topic	Format	Activities	Objectives Addressed
Day 1 Norms/goals Lower Resistance/Create Buy In Sharing Knowledge and Experience The Dif Inquiry Levels	Discussion Vignettes Journal Articles Reflection	1. Setting norms/goals 2. Pair communication protocols to discuss prior knowledge and experience with open inquiry 3. Vignettes to show the dif levels of inquiry 4. Journal articles to show the benefits and challenges of open inquiry 5. Discuss their PD goals	Objectives 1,4
Day 2 Effective Questioning	Discussion Lecture Videos Modeling Enacting Strategies Reflection	1. Intro: Goals/discuss teacher knowledge of questioning strategies 2. PowerPoint/Handouts of effective questioning strategies 3. Watch videos to examine questioning in practice 4. Model questioning techniques 5. Practice enacting questioning strategies with vignettes/student work/Hinged Mirrors and Floating Egg Experiment 6. Protocols for discussion/reflection	Objectives 2,4
Day 3 Effective Feedback	Discussion Lecture Observation Modeling Enacting Strategies Reflection	1. Intro: Goals/discuss teacher knowledge of feedback strategies 2. PowerPoint/Handouts of effective feedback strategies 3. Use student work samples to enact feedback strategies 4. Discuss how to make feedback manageable 5. Introduce rubrics w/ PowerPoint/Handouts 6. Use rubrics to assess student work 7. Create a rubric to assess student work 8. Protocols for discussion/reflection	Objectives 2,4
Day 4 Effective Modeling	Discussion Videos Lecture Modeling Enacting Strategies Reflection	1. Intro: Goals/discuss teacher knowledge of modeling strategies 2. Watch videos of teachers modeling 3. PowerPoint with modeling strategies 4. Handouts 5. Use student samples from Students and Research book to enact modeling strategies	Objectives 3,4

		6. Protocols for discussion/reflection	
Day 5 Participating & Leading Open Inquiry Activity	Reflection Feedback Discussion Stream Table Activity	1. Goals 2. Stream Table Activity for teachers to experience inquiry from student perspective 3. I will model the roles a teacher fulfills in open inquiry activity 4. Synthesize group findings 5. Discussions to reflect, make meaning, and discuss inquiry experience	Objectives 1,2,3,4
Day 6 Participating & Leading Open Inquiry Activity	Group Activity Modeling Feedback Reflection Discussion	1. Goals 2. Half of the teachers will lead open activity and half will step into the student role 3. Use protocols for discussion/reflection	Objectives 1,2,3,4
Day 7 Participating & Leading Open Inquiry Activity	Group Activity Modeling Feedback Reflection Discussion	1. Goals 2. Teachers switch roles from yesterday to gain a new perspective of inquiry 3. Use protocols for discussion/reflection	Objectives 1,2,3,4
Day 8 Creating Open Inquiry Lessons	Modeling Feedback Reflection Discussion	1. Goals 2. Examine my open inquiry lesson plans 3. Teachers design 1-2 weeks of open inquiry lesson plans 4. Analyze teacher plans and provide feedback 5. Discuss and reflect how teachers' beliefs of open inquiry have changed from when they began PD	Objectives 1,2,3,4

CONCLUSION

Open inquiry allows students to model the work of professional scientists while exploring a self-chosen interest. Instead of following scripted labs with known outcomes, students are given autonomy to develop a research project and experience science as a dynamic process, all with teacher guidance. The student benefits of open inquiry are well documented in the research, yet so are the difficulties students face when they initially perform open inquiry. Being that open inquiry is the highest level of inquiry, students often face more challenges with open inquiry compared to lower inquiry activities. One result of these difficulties can be decreased self-efficacy in science (Gormally, Brickman, Hallar, & Armstrong, 2009). This is noteworthy, because if students’ self-efficacy lowers, the likelihood that they will pursue advanced science classes decreases (Gormally et al., 2009). Therefore, educators can consider offering supports to students using open inquiry.

To counter these difficulties, this study incorporated an online cross-age peer tutoring program to support students as they used open inquiry. Online cross-age peer tutoring was found to increase the self-efficacy of students using open inquiry. This is meaningful, because it suggests that students cannot only succeed with open inquiry, but they can actually feel better about their science capabilities afterwards. Thus making online cross-age peer tutoring a viable support in middle schools. Another student benefit of an online tutoring program that connects middle school and high school students in the same district is that it can help build relationships. Knowing that the tutors have completed the same research class and have additional years of research experience can make them relatable and trustworthy to middle school students. However, it is not just students who can benefit from online cross age peer tutoring; the teachers can too.

First, an online cross-age peer tutoring program can provide teacher support as students gain proficiency in open inquiry. Having an additional outlet for students to discuss their ideas and difficulties can reduce the teacher workload, which is known to stress teachers (Costenson & Lawson, 1986; Dennis & O'Hair, 2010; Sadeh & Zion, 2011). Of course, the teacher has to monitor the tutor feedback, but the extra help is invaluable when managing multiple, diverse research projects. Tutors may be able to solve problems or redirect tutees, allowing the teacher to provide feedback to other students. Second, this type of tutoring program connects classroom teachers who are teaching the same material and using the same approach. Open inquiry pairs very well with STEM elective classes and afterschool science programs and will likely become more widespread with the push for STEM, but currently it is not common to have students at the middle school level choose a research topic from a broad array of science categories and then design and complete the project. Therefore, having access to another open inquiry teacher can be a great support for both the teacher's workload and emotional well-being. This relationship can be especially helpful for teachers new to open inquiry. In addition to teacher benefits, the online format has its advantages.

The online format can be desirable when considering how to integrate cross-age peer tutoring programs into schools. First, the online format is a low-cost intervention that eliminates the difficulty of scheduling meeting times and transportation of students who attend different schools. Instead students can communicate any time the technology is accessible. Second, the online format allows for students to correspond in a way that they are very comfortable with: technology. Students are becoming increasingly comfortable with technology and most have a device to communicate with. Plus, there are numerous platforms that the students can use to communicate with each other. These include, Google Docs, Facetime, Skype, and texting.

However, as noted above, teachers need to monitor online communication to ensure that it is respectful and helpful.

While student support, such as online peer tutoring, can benefit students with open inquiry, it is important to remember that in order to achieve these benefits, teachers must be given the skills to work through obstacles associated with such student-driven work and learn to effectively enact this teaching method. Offering training and support in the form of professional development (PD) and professional learning communities (PLC) can help reduce the obstacles that teachers face when beginning to use open inquiry and help ensure that they are teaching open inquiry effectively. All of which will increase the likelihood that the students achieve success and feel confident in STEM.

Although there are many benefits to an online cross-age peer tutoring program, there are some drawbacks. Designing the program takes time and cooperation between teachers. Figuring out which students to pair together, deciding how to grade student participation, providing tutor feedback, and training the tutors, requires time. Along with this, once the program is established, teachers must spend time maintaining the program. Teachers need to monitor the communication between students to confirm that the tutor help is accurate and of quality. This is especially important because high school students are not expert tutors or expert researchers and will likely need continuous feedback. Also, there needs to be a working relationship between the teachers because they will need to discuss the students' performance and the program's development frequently. All of this considered, I find that the support I receive from the peer tutors outweighs the time it takes to design and run the program.

The online format also has disadvantages. Students may not develop close relationships to their tutors online as they would in person. Thus, it may be harder to build trust and a sense of community if the students are not meeting in person. Perhaps video conferencing can alleviate this problem by allowing the students to hear each other's voices and see each other's faces, however, that would mean that students have to plan common meeting times, which can be difficult to do with afterschool commitments. Communicating online can also mean that there is a lag time between communications. This can make it harder to communicate ideas and receive feedback, thus slowing progress.

Peer tutoring is one support that can help students' self-efficacy in science, but there may be others that can have the same or greater effect. In this study, peer tutoring did not have a significant effect on students' self-efficacy in engineering, technology, or math, which indicates the need for other supports to accompany open inquiry science in STEM classes. Perhaps future studies can see if supports like visits from professional scientists or college student mentors positively influence self-efficacy. Future studies can also determine how an online tutoring program affects the tutors' self-efficacy because there is little research regarding this topic. It may be possible that helping students strengthens their confidence to learn science even with an online format. Also, it would be helpful to know how exposure to lower-levels of inquiry before using open inquiry can influence students' self-efficacy in science. The students in this study had very little experience with Level 3 inquiry (guided inquiry), before they were exposed to open inquiry. Being familiar designing methods, analyzing results, and writing conclusions may help students become even more confident using open inquiry in science. Lastly, exploring how PD and PLCs affect teacher confidence using open inquiry can be beneficial, especially if open inquiry is a method teachers adopt to teach their STEM classes.

In conclusion, teachers are encouraged to use supports, such as peer tutoring, when using open inquiry to teach STEM elective clubs or lead science clubs. The result can lead to higher self-efficacy in science, which may benefit students academically and inspire them to pursue future science studies. Open inquiry does come with teacher challenges, but providing training to teachers can increase the likelihood that this approach is performed properly. Setting aside time in the form of a PLC can help teachers process their experiences with this approach and improve their practice. The trend in science education is to give students more autonomy and exposure to science practices, which means that higher-level inquiry may become more common in science programs. Learning how to best support teachers and students as they initially learn to use open inquiry will help make this transition successful. It is my hope that this dissertation provides some of the necessary strategies and supports to achieve this.

References

Akinoglu, O. (2008). Assessment of the inquiry-based project application in science education upon Turkish science teachers' perspectives. *Education*, *129*(2), 202-215.

Avery, Z. K., & Reeve, E. M. (2013). Developing effective STEM professional development programs. *Journal of Technology Education*, *25*(1), 55-69.

Barron, B. (2003). When smart groups fail. *Journal of the Learning Sciences, 12*(3), 307–59.

Berg, C. A. R., Bergendhal, C. B., & Lundberg, B. (2003). Benefiting from an open-ended experiment? A comparison of attitudes, and outcomes of, and expository versus an open-inquiry version of the same experiment. *International Journal of Science Education, 25*(3), 351-372.

Berghmans, I., Michiels, L., Salmon, S., Dochy, F., & Struyven, K. (2014). Directive versus facilitative peer tutoring? A view on students' appraisal, reported learning gains and experiences within two differently-tutored learning environments. *Learning Environments Research, 17*(3), 437-459.

Berghmans, I., Neckebroeck, F., Dochy, F., & Struyven, K. (2013). A typology of approaches to peer tutoring: Unraveling peer tutors' behavioural strategies. *European Journal of Psychology of Education, 28*(3), 703-723.

Bevins, S., & Price, G. (2016). Reconceptualising inquiry in science education. *International Journal of Science Education, 38I(*1), 17-29.

Bookfield, S.D. (1986). Understanding and facilitating Adult Learning. San Francisco: Jossey Bass.

Bowman-Perrott, L., Burke, M. D., Zhang, N., & Zaini, S. (2014). Direct and collateral effects of peer tutoring on social and behavioral outcomes: A meta-analysis of single-case research. *School Psychology Review, 43*(3), 260-285.

Brown, P., Concannon, J., Marx, D., Donaldson, C., & Black, A. (2016). An examination of middle school students' STEM self-efficacy with relation to interest and perceptions of STEM. *Journal of STEM Education: Innovations and Research*, *17*(3), 27–38.

Britner, S. L., & Pajares, F. (2006). Sources of science self-efficacy beliefs of middle school students. *Journal of Research in Science Teaching, 43*(5), 485-499.

Burgess, A., Dornan, T., Clarke, A. J., Menezes, A. & Mellis, C. (2016). Peer tutoring in a medical school: Perceptions of tutors and tutees. *BMC Medical Education*, *16*(85), 1-7.

Burke, B. (2013). Experiential professional development: A model for meaningful and long-lasting change in classrooms. *Journal of Experiential Education*, *36*(3), 247–263.

Chow, R. (2016). A pilot project of an online cross-age tutoring program: Crescent school virtual learning (vLearning). *International Journal of Adolescent Medicine and Health, 28*(4), 451-453.

Cohen, P. A., Kulik, J. A., & Kulik, C. C. (1982). Educational outcomes of tutoring: A meta-analysis of findings. *American Educational Research Journal, 19*(2), 237-248.

Colburn, A. (2000). An inquiry primer. *Science Scope 23*(6), 42-44.

Costenson, K., & Lawson, A. E. (1986). Why isn't inquiry used in more classrooms? *American Biology Teacher 48*(3), 150-158.

Crawford, B., A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching, 37*(9), 916-937.

Crawford, B. A., Krajcik, J. S., & Marx, R. W. (1999). Elements of a community of learners in a middle school science classroom. *Science Education*, *83*(6), 701-723.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative and mixed methods* *approaches* (4th ed.). Thousand Oaks, CA: Sage.

De Smet. M., Van Keer H., & Valcke, M. (2008). Blending asynchronous discussion groups and peer tutoring in higher education: An exploratory study of online peer tutoring 94ehavior. *Computers and Education, 50*(1), 207-223.

De Smet, M. D., Van Keer, H. V., Wever, B. D., & Valcke, M. (2010). Cross-age peer tutors in asynchronous discussion groups: Exploring the impact of three types of tutor training on patterns in tutor support and on tutor characteristics. *Computers and Education, 54*(4), 1167-1181.

De Wever. B., Van Keer. H., Schellens, T., & Valcke, M. (2010). Structuring asynchronous discussion groups: Comparing scripting by assigning roles with regulation by cross-age peer tutors. *Learning and Instruction, 20*(5), 349-360.

Dejarnette, N. K. (2012). America's children: Providing early exposure to STEM (science, technology, engineering and math) initiatives. *Education*, *133*(1), 77-84.

Dennis, J., & O'hair, M. J. (2010). Overcoming obstacles in using authentic instruction: A comparative case study of high school math & science teachers. *American Secondary Education*, *38*(2), 4-22.

Friday Institute for Educational Innovation (2012). *Middle and High School STEM- Student Survey*. Raleigh, NC: Author.

Germann, P. J., Haskins, S., & Auls, S. (1996). Analysis of nine high school biology laboratory manuals: Promoting scientific inquiry. *Journal of Research in Science Teaching, 33*(5) 475-499.

Ginsburg-Block, M. D., Rohrbeck, C. A., & Fantuzzo, J. W. (2006). A meta-analytic review of social, self-concept, and behavioral outcomes of peer-assisted learning. *Journal of*

Educational Psychology, 98(4), 732-749.

Gormally, C., Brickman, P., Hallar, B., & Armstrong, N. (July 01, 2009). Effects of inquiry-based learning on students’ science literacy skills and confidence. *International Journal for the Scholarship of Teaching and Learning, 3*(2), 1-22.

Harwell, M., Moreno, M., Phillips, A., Guzey, S. S., Moore, T. J., & Roehrig, G. H. (2015). A study of STEM assessments in engineering, science, and mathematics for elementary and middle school students. *School Science and Mathematics*, *115*(2), 66-74.

Hsiao, A., Brouns, F., Van, Bruggen, J., & Sloep, P. B. (2015). Effects of training peer tutors in content knowledge versus tutoring skills on giving feedback to help tutees’ complex tasks. *Educational Studies, 41*(5), 499-512.Hubber, P., Darby, L., & Tytler, R. (2010). Student outcomes from engaging in open science investigations. *Teaching Science*, *56*(4), 8-12.

Isabelle, A. (2017). STEM is elementary: Challenges faced by elementary teachers in the era of the Next Generation Science Standards. *Educational Forum*, *81*(1), 83-91.

Iwata, K., & Furmedge, D. S. (2016). Are all peer tutors and their tutoring really effective? Considering quality assurance. *Medical Education,* 50(4), 393-395.

Johnson, D. W., & Johnson, R. T. (1989). *Cooperation and competition: Theory and research.* Edina, MN: Interaction Book.

Kirschner, P. A. (2001). Using integrated electronic environments for collaborative teaching/learning. *Learning and Instruction: Supplement 1*(10)*,* 1-9.

Korner, M., & Hopf, M. (2015). Cross-age peer tutoring in physics: Tutors, tutees, and achievement in electricity. *International Journal of Science and Mathematics Education, 13*(5*)*, 1039-1063.

Krajcik, J., Blumenfeld, P., Marx, R., Bass, K., Fredricks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school Students. *Journal of the Learning Sciences*, *7*(3-4), 313–350.

Lent, R., Brown, S.D., & Larkin, K.C. (1986). Self-efficacy in the prediction of academic Performance and perceived career options. *Journal of Counseling Psychology*, *33*(3), 265–269.

Lesseig, K., Nelson, T. H., Slavit, D., & Seidel, R. A. (2016). Supporting middle school teachers' implementation of STEM design challenges. *School Science and Mathematics*, *116*(4), 177-188.

Liu, T., Peng, H., Wu, W., & Lin, M. (2009). The effects of mobile natural-science learning based on the 5E learning cycle: A case study. *Educational Technology and Society*, *12*(4), 344-358.

McLuckie, J., & Topping, K. J. (2004). Transferable skills for online peer learning. *Assessment and Evaluation in Higher Education, 29*(5), 563-584.

Miller, D., Topping, K., & Thurston, A. (2010). Peer tutoring in reading: The effects of role and organization on two dimensions of self-esteem. *The British Journal of Educational Psychology, 80,* 417-433.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction--what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474-496.

Moss, E., Cervato, C., Genschel, U., Ihrig, L., & Ogilvie, C. (2018). Authentic research in an introductory geology laboratory and student reflections: Impact on nature of science understanding and science self-efficacy. *Journal of Geoscience Education*, *66*(2), 131–

146.

Muhuro, P., & Kang’ethe, S. M. (2014). Exploring the importance of age factor in the delivery and implementation of tutorship programme in institutions of higher learning with empirical examples drawn from one institution of higher learning. *Mediterranean Journal of Social Sciences, 5*(27), 924-930.

Mumba, F., Mejia, W.F., Chabalengula, V.M. & Mbewe, S. (2010). Resident scientists’ instructional practice and their perceived benefits and difficulties of inquiry in schools. *Journal of Baltic Science Education, 9*(3), 187-195.

Murphy, E., & Coleman, E. (2004). Graduate students’ experiences of challenges in online asynchronous discussions. *Canadian Journal of Learning and Technology*, *30*(2), 29–46.

Nadelson, L. S. Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: Inquiry-based stem professional development for elementary teachers. *Journal of Educational Research*, *106*(2), 157-168.

National Center for Educational Statistics. (2000). *The Nation’s Report Card*. Retrieved from: http://nces.ed.gov/nationsreportcard

National Research Council (NRC). 1996. *National science education standards*. Washington, DC: National Academy Press.

National Science Teachers Association. (2008). The many levels of inquiry. Retrieved from http://www.nsta.org/publications/news/story.aspx?id=5098

National Science Teachers Association. (2015). Books and resources. Retrieved from http://www.nsta.org/publications/news/story.aspx?id=50983

Newman, J. L., Dantzler, J., & Coleman, A. N. (2015). Science in action: How middle school students are changing their world through STEM service-learning projects. *Theory into*

Practice, 54(1), 47-54.

Next Generation Science Standards. (2015). The need for new science standards. Retrieved from http://www.nextgenscience.org/overview-0

Pajares, F., Miller, M., & Hill, C. (1995). Mathematics Self-efficacy and mathematics performances: The need for specificity of assessment. *Journal of Counseling Psychology*, *42*(2), 190–198.

Pizzolato, N., Fazio, C., Sperandeo Mineo, R., & Persano Adorno, D. (2014). Open-inquiry driven overcoming of epistemological difficulties in engineering undergraduates: A case study in the context of thermal science. *Physics Education Research*, *10*(1), 010107–1–010107–25.

Rezba, R. J., Auldridge, T., & Rhea, L. (1999). Teaching & learning the basic science skills. Retrieved from www.pen.k12.va.us/ VDOE/instruction/TLBSSGuide.doc.

Robinson, D. R., Schofield, J. W., & Steers-Wentzell, K. L. (2005). Peer and cross-age tutoring in math: Outcomes and their design implications. *Educational Psychology Review, 17*(4), 327-362.

Rohrbeck, C., Ginsburg-Block, M., Fantuzzo, J., & Miller, T. (2003). Peer-assisted learning interventions with elementary school students: A meta-analytic review. *Journal of Educational Psychology*, *95*(2), 240–257.

Roscoe, R. D., & Chi, M. T. H. (2007). Understanding tutor learning: Knowledge-building and knowledge-telling in peer tutors’ explanations and questions. *Review of Educational Research, 77*(4), 534-574.

Sadeh, I., & Zion, M. (2009). The development of dynamic inquiry performances within an open inquiry setting: A comparison to guided inquiry setting. *Journal of Research in Science*

Teaching, 46(10), 1137-1160.

Sadeh, I., & Zion, M. (2011). Which type of inquiry project do high school biology students prefer: Open or guided? *Research in Science Education, 42*, 831-848.

Salmon, G. (2000). *E-moderating: The key to teaching and learning online.* London: Kogan Page.

Scruggs, T. E., Mastropieri, M. A., & Marshak, L. (2012). Peer-mediated instruction in inclusive secondary social studies learning: Direct and indirect learning effects. *Learning Disabilities Research and Practice, 27*(1), 12-20.

Segala, Laura. (2018). Observe, describe, wonder. Teacher Guide. Building Inquiry into Instruction. Retrieved from: https://journeynorth.org/tm/inquiry/inquiry_guide.pdf

Shenderovich, Y., Thurston, A., & Miller, S. (2016). Cross-age tutoring in kindergarten and elementary school settings: A systematic review and meta-analysis. *International Journal of Educational Research, 76*(1), 190-210.

Svinicki, M. D., & Dixon, N. M. (1987). The Kolb Model modified for classroom activities. *College Teaching*, *35*(4), 141-146.

Topping, K. J. (1996). Effective peer tutoring in further and higher education: A typology and review of the literature. *Higher Education, 32*(3), 321–345.

Topping, K., & Ehly, S. (2001). Peer assisted learning: a framework for consultation. *Journal of Educational and Psychological Consultation, 12*(2), 113–132.

Topping, K. J., Peter, C., Stephen, P., & Whale, M. (2004). Cross-age peer tutoring of science in the primary school: Influence on scientific language and thinking. *Educational Psychology, 24*(1), 57-75.

Tytler, R., Osborne, J., Williams, G., Tytler, K., & Cripps Clark, J. (2008). Opening up pathways: Engagement in STEM across the primary–secondary school transition. Brisbane, Queensland, Australia: Australian Department of Education, Employment and Workplace Relations.

Unfried, A., Faber, M., Stanhope, D. S., & Wiebe, E. (2015). The development and validation of a measure of student attitudes toward science, technology, engineering, and math (S-STEM). *Journal of Psychoeducational Assessment, 33*(7) 622-639.

Worley, J., & Naresh, N. (2014). Heterogeneous peer tutoring: An intervention that fosters collaborations and empowers learners. *Middle School Journal, 46*(2), 26-32.

Zambrano, V. V., & Gisbert, D. D. (2015). The coordinating role of the teacher in a peer tutoring programme. *Social and Behavioral Sciences, 191*(3), 2300-2306.

Zeneli, M., Tymms, P., & Bolden, D. (2016). The impact of interdependent cross-age peer tutoring on social and mathematics self-concepts. *International Journal of Psychology and Educational Studies, 3*(2), 1-13.

Zion, M. I., & Sadeh, I. (2007). Curiosity and open inquiry learning. *Journal of Biological Education, 41*(4), 162-169.

Zion, M., & Slezak, M. (2005). It takes two to tango: In dynamic inquiry, the self-directed student acts in association with the facilitating teacher. *Teaching and Teacher Education, 21*(7), 875-894.