AN IN-DEPTH ANALYSIS OF THE TEACHER TALK THAT OCCURS DURING INTEGRATED STEM UNITS

by

Valarie L. Bogan

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THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Dr. S. Selcen Guzey , Chair

Department of Curriculum & Instruction

Dr. Paul A. Asunda

Department of Technology, Leadership and Innovation

Dr. Lynn Bryan

Department of Curriculum & Instruction

Dr. David Eichinger

Department of Curriculum & Instruction

Approved by:

Dr. Janet Alsup

Dedicated to:

Carlee the best roommate to ever exist. You listened when I needed to talk and only occasionally judged me. You kept me sane during grad school and were my saving grace during the COVID lock-down. I will always love you, my beautiful fur-baby—the best cat in the world.

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ABSTRACT

Teacher talk is a powerful pedagogical tool in the science classroom. Educators use their talk to provide information, guide discussions, check for understanding, and develop students' scientific identities. However, few researchers have investigated how teachers use their talk during an integrated science, technology, engineering, and math (STEM) unit. This three-study dissertation investigates how teachers use their talk to introduce a new discipline to students and how their talk affects student learning and engagement during an integrated STEM unit. I designed these research studies to answer the overall question: What talk moves do teachers use during an integrated STEM unit, and how does the teacher talk affect student engagement and learning? Study 1 is a multiple case study investigating how teachers guide classroom discussions and how that teacher talk affects student learning during the integrated STEM unit. Results demonstrate the importance of teachers carefully balancing dialogic discussions and providing information during these instructional units. Study 2 is an interpretative qualitative study that investigates how a teacher's autonomy-supportive and/or suppressive talk affects student engagement during the integrated unit. Results show that each student responded differently to the teacher talk that occurred in the classroom. While some became more engaged when the teacher used autonomy-supportive talk, others became disengaged during the same type of talk. Study 3 is a multiple case study investigating the talk moves teachers use when integrating engineering concepts in the curriculum. Results show that the two teachers requested student participation in the conversation about engineering more during the first lesson of the unit than the last. In addition, only one of the two teachers in this study incorporated talk about engineering into the science lessons. The last chapter of this dissertation synthesizes the data from all three studies. This chapter identifies some common themes across the studies, including the complex nature of teacher talk, the influence of non-talk factors, and the importance of dialogic discussion. This chapter also identifies some implications for teaching, including the need to restructure the curriculum units and to coach teachers during their first implementation of an integrated STEM unit.

INTRODUCTION

A key topic in many recent discussions in education is students' lack of interest in science, technology, engineering, and math (STEM) careers. Policy documents highlight that a continuous decrease in student engagement in STEM learning will cause a shortage of workers in these fields, which could lead to economic decline (President's Council of Advisors on Science and Technology, 2010; U.S. National Science & Technology Council, 2018). Researchers and educators have suggested that to build interest and get students engaged in STEM learning, educators must integrate the disciplines in lessons that offer authentic connections to the work of STEM professionals (NGSS Lead States, 2013; U.S. National Science & Technology Council, 2018). Research has shown that integrating science and engineering can increase student learning, engagement, and interest in STEM (Cunningham et al., 2020; Wendell & Rogers, 2013). However, there has been little research on effective integrated science and engineering education. It is critical to investigate the methods or approaches teachers use in the classroom and their effects on student achievement and motivation to learn STEM subjects.

My three-study dissertation investigates the teacher talk during integrated STEM units and the effect of that talk on student learning and engagement. I conducted this research to determine the improvements needed to curriculum units and professional development programs. I designed this dissertation to answer the overall question:

> What talk moves do teachers use during an integrated STEM unit, and how does the teacher talk affect student engagement and learning?

The three studies in this dissertation focus on the teacher talk that occurs during an integrated STEM unit. Study one is a multiple case study framed by the sociocultural learning perspective (Cobb, 1994; Duschl, 2008; Vygotsky, 1962). This study investigates the productive talk moves of three 8th grade science teachers and the effect of their talk on student learning. I designed study one to answer the following questions:

- How do teachers facilitate classroom discussions during an integrated STEM unit?
- Does academically productive teacher talk support learning outcomes?

Study two is an interpretative qualitative study that investigates how the autonomy-supportive or suppressive teacher talk affects how students experience the integrated STEM unit. The participants in this study include two 8th grade teachers and a target group of four students from each class. I framed the study with the Self Determination Theory (Ryan & Deci, 2002) to answer the question:

- How does teacher talk affect student engagement during an integrated STEM unit

Study three is a multiple case study investigating the talk moves two 8th grade teachers used when discussing engineering concepts during integrated STEM units. I framed by the sociocultural learning perspective (Cobb, 1994; Duschl, 2008; Vygotsky, 1962) and designed it to answer the following questions:

- What engineering concepts do teachers talk about during the engineering-focused lessons of an integrated STEM unit?
- What talk moves do they use when speaking about those concepts?

Teacher Talk Research in Science Education

Researchers have been interested in the talk that occurs within a classroom for many decades (Mercer & Dawes, 2014). The earliest studies were observational and allowed researchers to make generalizations about classroom talk. For example, researchers determined that the most common questioning style involved a teacher asking a question, a student responding, and the teacher evaluating the answer (Sinclair & Coulthard, 1975). Later, researchers realized that a teacher's talk influenced student learning and began developing models of how teachers should communicate with their students (Mercer & Dawes, 2014). The two earliest talk models were Dialogic Teaching (Alexander, 2004) and Exploratory Talk (Mercer & Wegerif, 2004). These models encouraged teachers to provide opportunities for students to share ideas that they supported with reasoning. Later, Michaels and colleagues (2008) developed Accountable Talk or Productive Talk, which instructed teachers to encourage students to challenge their peers' answers. Lastly, Gillies (2013) created Academic Productive Talk, which encouraged teachers to request reasoning from students and allow them to request reasoning from their peers. Although there are subtle differences between these talk programs or models, there are many similarities. Each of them was developed for use in any classroom and depend on the teacher's ability to ask quality questions at the right time to guide student understanding of the content.

While it is crucial to investigate the teacher talk in a variety of classrooms, as done in the studies above, it is essential to investigate the teacher talk within specific disciplines. Learning the language of science is particularly challenging for many students, with some researchers referring to learning science as learning another language (Lemke, 1990). Due to the challenges associated with science dialog, many researchers have focused on the teacher talk in a science classroom. One group of researchers has focused on the teacher talk associated with one branch of science (Bleicher et al., 2003; Jurik et al., 2014; Thörne & Gericke, 2014). At the same time, other researchers have taken a more detailed approach investigating the teacher talk that occurs during a specific science activity (Alozie et al., 2010; Chin, 2007; Oliveira et al., 2012; Oliveria, 2010; Pimentel & McNeill, 2013; Ryder & Leach, 2008; Zeidler & Lederman, 1989). There is also interest in the social nature of teacher talk in the science classroom. These researchers understand that while a teacher can convey content information with their talk, it is also possible to affect the inclusiveness of a classroom through the words chosen by a teacher. These researchers investigate how teachers create learning environments that are inviting to all their students (Brown & Spang, 2008; Moje et al., 2001; Moje, 1995; Sheth, 2016). Lastly, two researchers have taken the idea of a talk model from the general teacher talk research and created a talk program especially for use in science classrooms (Michaels & O'Connor, 2012).

Several researchers have focused on the teacher talk related to a specific science discipline (Bleicher et al., 2003; Jurik et al., 2014; Thörne & Gericke, 2014). For example, Thörne & Gericke (2014) investigated the teacher talk in biology classrooms, specifically focusing on how teachers spoke about proteins. By investigating the teacher talk and the student understanding of proteins, the researchers determined what teachers needed to include in their talk to increase student learning. Alternatively, Bleicher and colleagues (2003) focused on the teacher talk in a chemistry classroom. The researchers determined that the teacher's controlling language prevented students from participating in authentic scientific inquiry. It is helpful to investigate the type of language that occurs during a specific activity, like scientific inquiry, because researchers can identify ways to improve the teacher's talk. However, this type of study includes all the types of teacher talk, making it difficult to suggest improvements to specific talk moves. Other researchers have focused on a specific talk move during a science lesson. For example, Jurik and colleagues (2014) investigated the effect of questioning and feedback on student learning and motivation to learn in a physics classroom. The researchers found that if questions were open-ended and required reasoning, students were more motivated to participate in class and learned more than if questions were close-ended. By carrying out detailed investigations on teacher talk in specific disciplines, these researchers have found out what types of talk are working well and the improvements needed.

The next common focus of teacher talk research in science classrooms is creating a welcoming environment for all students. Several researchers have investigated how science teachers use their talk to create an inclusive environment for their students (Brown & Spang, 2008; Moje, 1995; Sheth, 2016). The earliest studies in this category investigated how teachers used their talk to create classroom and discipline communities for all students (Moje, 1995). However, more recent studies have focused on how teachers create inclusive environments for minority students. A few researchers have investigated how teachers connect the personal lives of minority students to the science content (e.g., Sheth, 2016). While other researchers investigate how teachers help minority students learn science vocabulary. For example, Brown & Spang (2008) investigated how an elementary teacher connected science vocabulary to the vernacular of students by using Double Talk. This talk style involved the teacher using both the science vocabulary word and the vernacular in the same sentence. All of the studies in this section found that teachers can create a welcoming environment for their students with the right words.

Most of the researchers interested in science-based teacher talk focus on a specific pedagogy. Several researchers are interested in how teachers explain the nature of science to students. By investigating the teacher talk, researchers have determined that the words teachers use to talk about science affect student understanding of the subject. For example, if teachers tell students that they must conduct science activities a certain way, students understand that science is a concrete discipline with many rules (Oliveira et al., 2012; Zeidler & Lederman, 1989). Another pedagogy often investigated is class discussions. Some researchers investigate the effectiveness of a professional development program in altering how teachers conduct class discussions (Oliveria, 2010). While others analyze the questions, the teachers asked and the student responses to determine the most compelling questions for increasing student knowledge (Chin, 2007; Pimentel & McNeill, 2013). Lastly, there is a small amount of research on the teacher talk that occurs during project-based learning. Alozie and colleagues (2010) investigated how teachers used the student-centered prompts included in the curriculum. They found that teachers often reverted to their usual ways of talking instead of using the provided prompts. Therefore, the researchers determined that teachers need more support to change their teacher talk during a new pedagogy.

Recently, researchers have investigated the teacher talk that occurs during STEM curriculum units in science classes. A few researchers have investigated how teachers talk about engineering during these integrated units (Guzey et al., 2019; Johnston et al., 2019). Guzey and colleagues (2019) found that the way a teacher spoke about engineering improved the longer he participated in a professional development workshop. This finding is not unexpected given that integrated STEM units are relatively new pedagogies and most teachers have no experience teaching engineering. Other researchers have moved beyond just investigating engineering talk and are researching how teachers integrate science and engineering talk during the unit (Aranda et al., 2020; Guzey & Ring-Whalen, 2018). In this small set of studies, there are different results some teachers have difficulties integrating the disciplines in their talk and tend to favor science over engineering (Guzey & Ring-Whalen, 2018), while other teachers cannot only integrate the disciplines in their talk but also guide their students to do the same (Aranda et al., 2020). Finally, a small number of studies have investigated how teacher talk during the integrated unit affects student learning (Aranda et al., 2018; Guzey et al., 2019). One of the studies focused on how the teacher integrated engineering into their science talk. Guzey and colleagues (2019) found that the more explicit the connections between engineering and the science content, the higher the learning gains. Alternatively, Aranda and colleagues (2018) investigated how the teacher's talk style affected student learning. One teacher used controlling talk moves while the other had a dialogic talk style. Despite the significant differences in talk style, the researchers only found a slight difference in student learning gains between the controlling and dialogic classrooms.

Theoretical Frameworks for Learning and Engagement

Learning is a complex endeavor often influenced by social interactions. Several theorists have incorporated social interactions into theories on how people learn (Bandura, 1977; Piaget, 1995,1965; Vygotsky, 1978). I framed studies 1 and 3 of this dissertation under the sociocultural learning perspective (Cobb, 1994; Duschl, 2008; Vygotsky, 1962). The learning under this perspective is situated both socially and culturally. In classrooms where the sociocultural learning perspective influences learning, teachers and students are part of a community of practice where everyone contributes to the conversation and builds knowledge together (Cobb, 1994). The community operates under rules which were selected to emulate the actions of professional scientists. These rules require the class to participate in reflective classroom discourse where everyone provides evidence for their claims and evaluates the evidence provided by peers (Duschl, 2008). Learning under this perspective is typically active, emphasizing using the authentic practices of scientists. As students participate in these cultural practices, they not only learn scientific concepts but also develop an understanding of how scientific inquiry is accomplished (Duschl, 2008).

Study two focuses on how a teacher's talk affects motivation, drawing upon the self-determination theory. Researchers based the self-determination theory on the belief that "all individuals have natural, innate, and constructive tendencies to develop an ever more elaborated and unified sense of self" (Ryan & Deci, 2002, p.5). The theory's creators specified that individuals continue to develop as they better understand themselves and their connections to others. According to the theory, some factors can support or thwart this development, and all socially based environments, such as classrooms, have the potential to contain both types of factors.

Self-determination theory is not a single theory but rather a collection of several mini-theories: basic needs theory, cognitive evaluation theory, organismic integration theory, and the causality orientations theory. I based study two on the basic need’s theory. This theory states that there are three basic psychological needs: competence, relatedness, and autonomy. The need for competence is satisfied when you feel able to accomplish a task and are comfortable in the belief that you will have a chance to demonstrate your skill. The need for relatedness refers to the feeling of being accepted and supported by a group and accepting and supporting other members of the group in return. The need for autonomy pertains to actions that an individual takes part in because of personal value or interest. Ryan and Deci (2002) stress that this need is not the same as independence because the need for autonomy is affected by others, which is not true for independence. All these needs can be affected by contextual factors that can result in a healthy individual if the environment is supportive of these needs or an individual who is having difficulty thriving due to a need thwarting environment (Ryan & Deci, 2002). I designed study two to study the effect teachers have on students' need for autonomy.

Overview of Research Design

Teacher talk is a complex construct. To investigate as many aspects of teacher talk as possible, this three-study dissertation uses both multiple case studies (Yin, 2018) and interpretative qualitative research design (Merriam, 2002). These approaches allowed me to non-intrusively investigate the teacher talk and student outcomes in a naturalistic setting while attempting to answer the research question: What talk moves do teachers use during an integrated STEM unit, and how does the teacher talk affect student engagement and learning?

Although each study used a different set of participants (Table 1) to investigate aspects of teacher talk, all studies took place in an 8th-grade classroom during an integrated STEM unit focused on genetics. Three participants, Mrs. Anderson, Mr. Winchester, and Mr. Hale were selected for study one. These individuals were selected because they participated in the same summer professional development workshop and taught the same integrated STEM unit in their classrooms. By including three participants from two schools, I considered differences both between schools and within a school. I selected two participants, Mr. Winchester and Mr. Hale for study two. I chose these teachers because they taught at the same school and used the same integrated STEM unit. Therefore, I could ignore factors related to the setting and focus on how the talk of each teacher impacted the experience of students during the unit. Lastly, I selected two participants, Mrs. Evans and Mrs. Anderson for study three. While these teachers were using different integrated STEM units, the unit's topic was similar, and the teachers participated in similar professional development workshops. By investigating the talk moves they used to discuss engineering components, I was able to identify needed improvements to future workshops. Together these studies give us a complete view of the teacher talk that occurs during integrated STEM units.

Table 1 *The Teachers and Schools Included in Each Dissertation Study*

Teacher	School	Demographics	Study 1	Study 2	Study 3
Mrs. Evans	X	Suburban; 460 students enrolled in 6-8, 22 % students of color, 41% economically disadvantaged			X
Mrs. Anderson	Y	Urban; 1074 students in 7-8, 51% students of color, 72 % economically disadvantaged	X		X
Mr. Winchester	Z	Rural; 842 students in grades 7-12, 10% students of color, 42% economy disadvantaged	X	X	
Mr. Hale	Z	Rural; 842 students in grades 7-12, 10% students of color, 42% economy disadvantaged	X	X	

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STUDY 1: DO ACADEMIC PRODUCTIVE DISCUSSIONS DURING AN INTEGRATED STEM UNIT HELP STUDENTS BETTER UNDERSTAND THE CONTENT?

Abstract

National educational reform documents indicate that it is essential for students to engage in discourse practices in science classes. Prior research has shown that when students talk about science or discuss the topics taught in class, they develop a deeper understanding. With the recent emphasis on science and engineering integration, it has become critical for students to participate in dialogic instruction since they engage in disciplinary content and discourses from science and engineering. However, there is little research on dialogic instruction during integrated science and engineering units and its effects on student learning. This study examined how teachers facilitate classroom discussion during an integrated STEM unit and the influence of academically productive teacher talk on student learning outcomes. Three middle school teachers and 38 students participated in the study. Findings showed that students who engaged in more content-focused classroom discussions and elaborated, reasoned, and connected information had higher learning gains than students who engaged in less productive classroom discussions. This finding indicates the importance of dialogic instruction and balancing academically productive talk and disciplinary content information to help students learn the content.

Key words: student learning, talk moves, STEM curriculum, teacher talk, integrated instruction

Introduction

The Next Generation Science Standards (NGSS) calls for students to construct explanations, engage in argument, and communicate information (NGSS Lead States, 2013). To accomplish these goals, teachers must take an active role in guiding student participation in classroom discussions. In addition to reflecting the practices of professional scientists and engineers, classroom discussions also help students develop a deeper understanding of the content (Lemke, 1990). Over the last few decades, many researchers have investigated the talk that occurs in science classrooms. Several researchers have investigated the teacher talk used to inform students about the characteristics of science and the creation of scientific laws and principles (Ryder & Leach, 2008; Zeidler & Lederman, 1989). Other researchers have focused on the classroom talk that occurred about a specific discipline such as biology (LeBlanc et al., 2017), chemistry (Bleicher et al., 2003), and physics (Jurik et al., 2014). While some researchers focused on how teacher-guided whole class discussions (Lehesvuori et al., 2013; Pimentel & McNeill, 2013), others focused on teachers' use of questions to guide student understanding (Chin, 2007; Eliasson et al., 2017; Newton & Newton, 2001; Smart & Marshall, 2013). Lastly, some researchers investigated how teacher talk could make students feel included in both the classroom and scientific communities (Brown & Spang, 2008; Moje, 1995). These studies show that teacher talk is a powerful tool for teaching content and procedures when teachers use it effectively.

While several studies focused on how teachers talk during science class, there have been relatively few that investigated teacher talk during integrated STEM units (Aranda et al., 2018; Guzey & Ring-Whalen, 2018). Researchers and educators design integrated STEM units to teach science and/or mathematics through engineering or technology design in a socially and culturally relevant context (Bryan & Guzey, 2020). Some researchers have focused on the way teachers talk about just one of the disciplines during the integrated STEM unit (Johnston et al., 2019). Alternatively, some have focused on how teachers integrate their science and engineering talk during the unit (Guzey et al., 2019). Lastly, researchers have investigated how the teacher talk during an integrated unit influenced the students' use of science and math concepts in an engineering design (Valtorta & Berland, 2015). While these limited studies have highlighted the importance of dialogic instruction in integrated STEM education, it is necessary to investigate how teachers can successfully guide student discussions while navigating the integrated STEM units and the impact of those practices on student learning. Considering the fact that teaching techniques and knowledge associated with these integrated units are new to many teachers, it is critical to investigate successful and effective instruction for the widespread implementation of integrated science and engineering education.

Building on the research areas of productive talk in science classrooms and discipline-specific talk, we need to determine how teachers talk and which types of talk or talk moves help students integrate content and understand the concepts included in integrated STEM units. Once we have a comprehensive understanding of effective dialogic instruction during integrated units, then professional development programs can be created to help teachers use academic and productive discussions during integrated STEM instruction. This study contributes to the efforts for successful science and engineering instruction and adds to the previous literature by investigating how teachers use the talk moves identified as productive in a classroom during integrated STEM units and how such practices influence student learning.

The following research questions guided the study:

- How do teachers facilitate classroom discussions during an integrated STEM unit?
- Does academically productive teacher talk support student learning outcomes?

Theoretical Framework

This study is framed under the sociocultural learning perspective (Cobb, 1994; Duschl, 2008; Vygotsky, 1962). This perspective allows researchers to focus on both the social and cultural elements within a classroom. The social component of instruction focuses on how the teacher and students work together within a community of practice to create a body of knowledge (Cobb, 1994). Within this community of practice, everyone is expected to follow the communication guidelines of professional scientists by providing evidence for their claims and challenging the claims of others (Duschl, 2008). The cultural portion of instruction focuses on using the authentic practices of STEM professionals in the curriculum. Students learn about science concepts as they practice scientific techniques during hands-on learning activities (Duschl, 2008).

Many integrated STEM investigations have been framed by sociocultural learning perspectives (Barton et al., 2017; Cunningham et al., 2020; Guzey & Aranda, 2017; Wieselmann et al., 2019). For example, Guzey and Aranda (2017) investigated how student discussions in small groups affected their engineering design decisions. They found that students could share ideas with their peers to develop a design plan. They also found that the teacher could be an influential presence in the decision-making process. When the teacher interacted with the small groups he was able to guide the group discussion away from minor points like cost to more important considerations such as the heat conduction properties of building materials. Other researchers have investigated the effect working in small groups on engineering projects has on student learning. Cunningham and colleagues (2020) compared the amount of learning that occurred after students participated in an engineering project or an alternative activity. The researchers found that the students who completed engineering projects in small groups learned more than the students who completed the alternate activity.

In the following section, I discuss the relevant literature for this study. The section begins by describing several models of teacher talk. The four common themes from those models are discussed: questioning, elaborating on answers, providing reasoning, and making connections. The section ends by discussing the types of teacher talk that occur during integrated STEM units.

Characteristics of Classroom Talk

The type of talk that occurs in a classroom has gotten much attention, with many researchers identifying the forms of dialogic teaching that support student learning. Michaels and colleagues (2008) showed how Accountable Talk or Productive Talk helps teachers orchestrate carefully structured productive discussions. The authors stated that all classroom talk should build on the things previously said by others, everyone should use evidence to back up what they say, and that the evidence should come from sources that are available to everyone in the learning community. Mercer and Wegerif (2004) offered a different but complementary model of dialogic instruction, Exploratory Talk, which emphasizes the importance of everyone having an opportunity to share their insight with the class. This model of teacher talk is similar to Accountable Talk in that it requires students to support their answers with reason. However, Mercer and Wegerif also suggested that teachers encourage students to challenge their classmates' claims and continue a discussion until the class reaches a consensus. Alexander (2004) also developed a talk model referred to as Dialogic Teaching. This program is similar to the previous two programs in that it requires students to support their claims with evidence and encourages them to build on their classmates' speech. This talk program emphasizes the need for a teacher to create quality open-ended questions to begin the discussion and as follow-up inquiries that guide the discussion toward the learning goal. Based on his findings, Alexander (2018) showed that in classrooms where teachers used dialogic teaching, students were engaged in the discussions and had more significant learning gains than in classrooms where the teacher used traditional pedagogies. Gillies (2013) called her talk program Academic Productive Talk. This talk program also encourages students to support their claims with reasons and challenge others' claims. She provided evidence that when students challenge their peers’ answers and ask questions, they develop a deeper understanding of the content. Throughout these talk models, there is a focus on asking questions, pushing students for longer, more detailed answers, requesting the reasons for student answers, and requiring students to combine the answers offered by many individuals to come up with the best answer for a question.

Teacher Questioning

The most researched component of productive talk is teacher questioning. Some recent studies in science classrooms have focused on the type of questions asked and the impact on student learning. For example, Smart and Marshall (2013) used a mixed-methods design to investigate the impact of question type on middle school science students' engagement. They discovered that open-ended questions caused students to become cognitively engaged with the science content. Other researchers have found similar results with older students who are studying a specific type of science. For example, Jurik and colleagues (2014) investigated the use of questions in a high school physics classroom. In addition to finding that open-ended questions lead to student engagement, the researchers also found that asking open-ended questions allowed students to develop their understanding of the content. This result indicated that open-ended questions lead to greater understanding than closed questions. However, not all studies of teacher questioning have found the same impact on student achievement. Hmelo-Silver and colleagues (2015) investigated the teacher talk during a computer-based inquiry activity. One of the teachers used the initiation, response, evaluation (IRE) questioning technique. This type of questioning begins with a close-ended question to which one student responds, and then the teacher evaluates the answer (Cazden, 2001). The other teacher had a dialogic style, asking open-ended questions and leading whole-class discussions. However, the researchers found no differences in the student's learning gains. This discrepancy between studies suggests that more investigation on this topic is necessary to determine the effects of teacher questioning style on student achievement.

Other researchers have been interested in how teachers use questions during specific parts of a lesson. Kawalkar and Vijapurkar (2013) were interested in how a teacher's questioning during an inquiry activity was different from questioning during a regular science lesson. The researchers discovered that the teacher used questions as a scaffolding device during inquiry activities but not during regular class activities. Alternatively, Harris and colleagues (2012) were interested in how teachers used questioning to develop student conversations. They found that the most successful teachers used open-ended questions to start the discussion and then followed those up with a series of open-ended questions intended to keep the conversation going. Van Booven (2015) combined these research interests by investigating how teachers could lead discussions after an inquiry activity. The researcher found that it was important for the teacher not to evaluate a student's incorrect answer, or the conversation would end. Instead, a successful teacher used a series of questions to guide incorrect answers toward the correct interpretation of the content.

Lastly, some researchers have investigated the types of questions that are predominant in subject classrooms. A group of researchers investigated the types of discourse in the math and science classrooms in designated STEM schools. They found that science teachers were more likely to ask open-ended questions that required reasoning than math teachers (Tofel-Grehl et al., 2017). A study by Andersson-Bakken and Klette (2016) does not agree with the previous study. These researchers compared the use of questioning by language arts and science teachers. They found that science teachers often asked closed-ended questions, which required students to recall information, while language arts teachers used open-ended questions to guide class discussions. These differing results are why it is essential to continue studying questioning techniques in science classes. The need to study questioning is especially critical during integrated units, which are relatively new pedagogies to science teachers.

Elaborating on Answers

Productive discussions not only involve asking quality, open-ended questions but also having students elaborate on answers given by themselves or others. During these discussions, teachers use a series of open-ended questions to guide students as they construct knowledge (Reznitskaya & Gregory, 2013). Students often give short answers to teacher questions, so teachers must use a series of follow-up questions that require students to elaborate on their initial responses. By using a series of open-ended and follow-up questions, teachers can guide students to the desired learning outcome (Alexander, 2004; Michaels et al., 2008). Researchers have discovered that the follow-up questions used can affect the success of this strategy. Harris and colleagues (2012) investigated how teachers led whole class discussions during an ecology unit. While all the teachers who participated in the study asked students to elaborate on their answers, the techniques varied from one participant to the next. Some teachers were repetitive in their requests for elaboration, while others used a variety of phrases to get students to elaborate. The students of teachers who asked different kinds of elaboration questions had more substantial learning gains than the students who had teachers that continually asked for elaboration in the same manner. While the previous study demonstrated the importance of using variety within teacher talk, it is more important that teachers request students to elaborate on their answers even if they use similar prompts each time. Alozie and colleagues (2010) found that many teachers do not ask students to elaborate on their answers because of a lack of time.

Providing Reasoning

Productive talk also involves students providing reasoning for their comments during a whole-class discussion. The investigation of a student's ability to apply reasoning to a science topic is most often associated with argumentation studies. That is because reasoning is part of the commonly used framework for structuring arguments in a science classroom: claim, evidence, and reasoning (McNeill & Krajcik, 2011). There is a large body of research that focuses on the use of argumentation in the science classroom. Often these studies investigate how an intervention affects students' abilities to create an argument. For example, in a study of 13 elementary teachers and their students, researchers found teachers could guide their students in creating arguments following a professional development workshop. Researchers also found that through the process of creating arguments, students increased their understanding of the science content (Wilkinson et al., 2017).

There are studies not focused on argumentation that coincide with the finding that reasoning improves students' science knowledge. In a recent review of collaborative learning studies, researchers found that when teachers requested students provide reasoning during the learning activities, they developed a deeper understanding of the content (van Leeuwen & Janssen, 2019). Practitioners, as well as researchers, support the assertion that providing reasoning improves student knowledge. Following a five-year professional development project that guided teachers in creating productive classroom discussions, researchers found that students involved in the project had higher scores on content tests than their peers who were not involved in the project. When the researchers asked teachers why they thought the project was successful, most responded that it was because students understood the content better. They accredited this to the fact that students had to provide reasoning for their responses (O'Connor et al., 2015).

Making Connections

Of the components of productive classroom talk, the one least researched is connecting knowledge. Although Michaels et al (2008) identified this as a vital component of dialogic talk, few researchers have focused on this classroom talk component. Mercer and colleagues (2009) conducted a study to determine if elementary teachers used their talk to help students connect information learned in one science lesson to subsequent lessons. They found that teachers rarely made these connections; they often taught each lesson as a stand-alone activity. Alternatively, other researchers have investigated if teachers connect what happens outside the classroom with the content taught in class. In a study of the dialogue in a third-grade class, researchers found that the teacher required students to connect what they saw during field trips and what they were learning in class. While the teacher guided students through the process, they rarely made connections for them (Kumpulainen & Lipponen, 2010). Regardless if the teacher or the students are providing the connections, it is clear that this type of talk is rare. For example, in a study of Accountable Talk during reading lessons in elementary and middle schools, researchers found that both teachers and students rarely made comments that linked one body of knowledge to another (Wolf et al., 2006).

Discourse during Integrated STEM Units

While there have been several investigations on the teacher talk during an integrated STEM activity (e.g., Aranda et al., 2018; Guzey & Ring-Whalen, 2018; Johnston et al., 2019), little research has focused on teacher's questions or methods of leading student discussions. The research on teacher talk during integrated STEM units has mainly focused on exploring the characteristics and quality of teacher talk in engineering (Aranda et al., 2020; Guzey & Ring-Whalen, 2018; Guzey et al., 2019; Johnston et al., 2019). There has also been a small amount of research on how teachers interact with students during the design process (Guzey & Aranda, 2017; Valtorta & Berland, 2015).

Due to the nature of science and engineering, when science teachers use an integrated STEM unit in their classroom, they need to alter how they talk to students during learning activities (Hynes, 2012). While the fields of science and engineering both include similar practices such as asking questions and planning and carrying out investigations, the way professionals address those practices is different in each discipline (NRC, 2012). For example, when teachers guide students in scientific inquiry, they discuss identifying a scientific question and a hypothesis and then developing an experiment to test it. At the end of the investigation, the students report if their hypothesis was supported or not, and then the class moves on to the next topic. On the other hand, when teachers guide students in engineering design, they talk about asking questions to identify a problem and developing a solution that meets the client's needs. Teachers guide students through the development of a product, which then goes through several cycles of refinement until a final product that meets the criteria and constraints of the project is developed (Cunningham & Carlsen, 2014).

Despite the differences between the two disciplines, one of the expectations of integrated units is that educators will teach the subjects in a manner that allows students to identify the connections between disciplines. It seems to be a reasonable expectation that teachers use discipline-specific talk in their integrated instruction. However, researchers have found mixed results when investigating this component of teacher talk in STEM units. Guzey and colleagues (2019) conducted a three-year longitudinal study on how one teacher taught an integrated unit. Each year the teacher integrated engineering discourse into the unit in a different way. Researchers determined that the students had higher learning gains when the teacher explicitly discussed engineering during the science lessons. This study demonstrates the importance of discussing engineering during lessons on each of the STEM concepts students need to complete the engineering challenge.

One of the qualities attributed to a unit that contains a STEM challenge is that it is student-centered. Several studies determined that teachers design student-centered units by using open-ended questions and having students elaborate on their answers (Aranda et al., 2018; Guzey & Aranda, 2017; Mathis et al., 2018). However, this type of talk varies among teachers, as seen in a study by Aranda and colleagues (2018). The researchers conducted a multi-case study on the ways two teachers talked during an integrated STEM unit. Despite having co-created the unit, the teachers had very different talk styles. One teacher used the IRE questioning technique while the other teacher used primarily dialogic discussions. Researchers have also found that the type of questions asked depends on the discipline. Tofel-Grehl and colleagues (2017) investigated the teacher talk at six self-identified "STEM" schools. The researchers determined that math teachers were more likely to use open-ended questions than science teachers. The mixed results from these studies indicate that it is vital to continue investigating how teachers use their talk to include students in the learning activities during an integrated STEM unit.

Methods

This study employs a multiple case study design (Yin, 2018). The integrated STEM curriculum unit serves as the case. This methodology allows for an in-depth understanding of each case, and then through cross-case analysis, the cases can be compared to one another, allowing for a more thorough understanding of how teacher talk affects student achievement during an integrated unit.

I used qualitative methods to examine the first research question about teacher talk in STEM units. The second question is quantitative, and the data were analyzed to determine if students in classrooms where teachers use dialogic discussion techniques including open-ended questions, requesting reasoning, requiring student elaboration, and consolidation of information had higher learning gains than students in classrooms with initiation, response, evaluation (IRE) interactions.

Participants and Setting

The participants were identified based on a convenience sample from a larger research study. The participants, three middle school science teachers, were selected because they taught 8th-grade science in the same geographic area and taught the same integrated STEM unit. Two of the participants, Mr. Hale and Mr. Winchester, taught at a rural Jr. Sr. High School. At the time of the data collection, the school had 842 students enrolled in grades 7-12 with 10% students of color, 21% had disabilities, and 42% were economically disadvantaged. The third participant, Mrs. Anderson, taught 8th-grade science at an urban middle school less than thirty miles from the other school. At the time of the data collection, the school had 1,074 students enrolled in seventh and eighth grade, with 51% students of color, 19% had disabilities, and 72% were economically disadvantaged.

In addition to teaching in the same area, all three participants also attended a professional development workshop the summer before implementing the integrated STEM unit in their classrooms. The workshop provided the teachers with the curriculum and pedagogical techniques necessary for implementing the integrated unit in their classrooms. This unit contained lessons on genetics and concluded with an engineering design challenge that required students to use the scientific knowledge gained in the unit to create a process that would limit cross-contamination between GMO and non-GMO corn (Table 2).

Table 2 *Overview of the Integrated STEM Unit*

Lesson	Days Needed	Objectives
1: Introduction to the Engineering Challenge	4-5	Students will be able to identify the engineering challenge, constraints and criteria that will affect the solution, and understand why the problem is important.
2: Introduction to DNA Structure and Function	2 - 3	Students will understand where DNA is located and will be able to describe it after extracting it from a cell.
3: Genes and Trait Expressions	2 - 3	Students will be able to define several inheritance associated vocabulary words and will be able to describe how a gene is related to a trait.
4: Introduction to Heredity	1 - 2	Students will be able to describe how traits are inherited, the difference between sexual and asexual reproduction, and how corn reproduces.
5: Applied Heredity	3 - 4	Students will use Mendelian genetics to determine the traits of offspring after a parental cross.
6: Genetic Modification	1 - 2	Students will understand how a GMO is created.
7: Engineering Challenge	5 - 7	Students will create a solution, revise the solution based on feedback, and present their final design.

Data Collection

This study's primary data was video recordings taken during the integrated STEM unit in each of the three classrooms. Each of the participants spent approximately the same amount of time teaching the unit to their students (~22 days). Researchers attended each class during the integrated STEM unit to place the video camera at the back of each classroom and to take field notes. The camera allowed researchers to view most of the students in the room and the teaching activity at the front of the room. Each teacher wore a microphone, which allowed their talk to be recorded clearly on the video.

To assess student understanding of each lesson, researchers provided each student with an engineering notebook. At the end of the unit, researchers took pictures of each page of a student's notebook then compiled those pictures in the correct order to create an electronic version of the notebook. Teachers gave the students printouts of all student activity pages, which they either glued or taped into their engineering notebook. The research team created the questions on these pages to align with the lesson's learning objective. The students answered the questions in their notebooks during each of the lessons. Since Lesson 6 did not contain any printed student pages, I omitted this lesson when assessing how teacher talk affected student learning.

Data Analysis

Over 60 hours of video recordings from the three classrooms were transcribed verbatim. I coded the whole class instruction portions of these transcripts using talk turns as the unit of analysis. A talk turn was considered all the dialogue uttered by a single individual until another person was allowed to speak. Because this study was framed under the sociocultural learning perspective I focused on the teacher talk that could influence how students participated in the conversation. Researchers coded each of the teacher's talk turns using a slightly modified version of the coding scheme found in Howe and colleagues (2019) (Table 3). It is important to note that a single talk turn could be double-coded if the teacher's talk had different purposes in that turn. Two researchers coded approximately 10% of the data separately and then met to discuss discrepancies in the codes applied to the talk turns. During that discussion, researchers modified the definitions of codes to reflect the data in the current study. For example, we added the codes for *providing information* and *classroom management* because all the teachers spent a significant amount of time explaining concepts to students and giving procedural instructions. Also, *invite reasoning* was divided into two separate codes to examine the degree of dialogue between students in a class. Researchers used the new code *invites students to question others* when a teacher invited students to question each other during whole-class discussions. Once we agreed upon the refined code definitions, we used those codes to code another portion of the data separately. Afterward, the researchers met to discuss discrepancies in the data and refine the coding definitions. This process continued until the two researchers reached an agreement of 91%. The author coded the remainder of the data.

Table 3 *Teacher Talk Coding Scheme*

Code	Definition	Example
Provides information	The teacher shares information with students through lectures.	If you have a dominant allele for a trait that will be expressed.
Classroom management	The teacher gives directives, manages behavior, or deals with classroom logistics.	Everybody grab your notebook on the way to your table.
Invite elaboration	The teacher invites a student to elaborate on what they said	Tell me more about that.
Teacher elaboration	The teacher clarifies something a student said.	So, let me see if I can make what you are saying clearer. Heredity involves passing traits from parents to offspring. And those traits make up your appearance, or as Claire said, it makes you, you.
Inviting reasoning	The teacher invites a student to explain a statement either made by themselves or on a written document by connecting it to science or engineering.	What do you think that means?
Invites students to question others	The teacher invites students to seek reasoning from others.	Who has a question for them?
Teacher reasoning	The teacher explains a statement make by themselves or others by connecting it to science or engineering principals.	That is talking about the DNA and how it controls what organisms look like, or their phenotype.

Table 3 *continued*

Invites connecting	The teacher invites students to summarize, evaluate or compare two or more statements. Includes referring back to information shared in previous lessons.	Who can summarize what everyone has been saying?
Teacher connecting	The teacher summarizes, evaluates or compares two or more statements. Includes referring back to information shared in previous lessons.	To sum up what everyone has been saying.
Table 3 continued		
Querying	Doubting, full/partial disagreement, challenging an idea.	Are you sure that that pairing would give you all heterozygous offspring?
Close ended questions	The teacher asks a question that only has a select number of acceptable answers.	What is heredity?
Open ended questions	The teacher asks a question that does not have an expected answer.	How could we keep pollen from moving across fields?
Positive feedback	The teacher expresses acceptance of a student answer.	Excellent
Negative feedback	The teacher rejects a student's answer.	Nope

I reduced the data by applying the codes to four of the themes identified by Howe and colleagues (2019). The theme of questioning included the codes for open and close-ended questions and positive and negative feedback. To determine if a teacher's questioning strategy favored student interaction, I added the number of times a teacher used open-ended questions to the teacher's positive feedback. I divided this number by the total number of questioning utterances used within that time frame and converted it to a percentage. The theme for elaboration included the codes for teacher elaboration and invites elaboration. To determine the percentage of those utterances that focused on student participation in the discussion, I divided the number of invites elaboration utterances by the total number of elaboration utterances and converted it to a percentage. The reasoning theme included the codes for invites reasoning, invites students to question others, and teacher reasoning. To determine the percentage of time that the reasoning utterances were student-centered, I added the invites reasoning and invites students to question others utterances together and divided by all of the reasoning utterances and converted it to a percentage. The theme for connecting information included the codes for inviting connection and teacher connection. To determine the percentage of those utterances that encouraging student participation, I divided the invite connection utterances by the total number of connection utterances and converted it to a percentage.

To evaluate student learning during the unit, I created a rubric for lessons one, two, three, four, five, and seven in the engineering notebook (Table 4). Questions from each lesson were selected so that the point total for each lesson was 12. Two researchers independently used the rubric to score a notebook. Afterward, the researchers met to discuss discrepancies in their grading and to refine the rubric. Then the researchers independently scored another notebook and met to compare grades and discuss discrepancies. This process continued until they reached acceptable levels of inter-rater reliability for each lesson. The reliabilities ranged from 0.87 to 1. After that point, the author completed the remaining grading independently.

Table 4 *Sample Questions from the Engineering Notebook*

Lesson	Objective	Question
1	Students will be able to identify the engineering challenge, constraints and criteria that will affect the solution, and understand why the problem is important.	What will make the solution effective (criteria)?
2	Students will understand where DNA is located and will be able to describe it after extracting it from a cell.	What did you have to do to see the genetic material in the cell?
3	Students will be able to define several inheritance associated vocabulary words and will be able to describe how a gene is related to a trait.	What is a phenotype?
4	Students will be able to describe how traits are inherited, the differences between sexual and asexual reproduction, and how corn reproduces.	How does a corn plant pollinate?

Table 4 *continued*

5	Students will use Mendelian genetics to determine the traits of offspring after a parental cross.	Cross Tt X Tt and write the resulting offspring. What is the probability that the offspring will express the dominant trait?
7	Students will create a solution, revise the solution based on feedback, and present their final design.	In what ways does your solution meet the criteria and constraints of the problem?

Results

Mr. Hale's Teacher Talk and Student Learning

Mr. Hale used most of his talk turns throughout the unit to manage the classroom (27%) (Table 5). The second most frequently used type of talk was questioning. The majority of those questions were asked in an IRE manner: question, student answer, teacher evaluation. The third most frequent talk was providing information. Inversely, Mr. Hale rarely invited students to connect information from different sources. He also seldom connected information from different sources or different days for the students. Students were infrequently allowed to ask questions of either Mr. Hale or other students. Lesson 4 had less teacher talk compared to most lessons due to the learning activity. Students were participating in activity stations around the room that allowed students to discover knowledge for themselves. Lesson 6 had a limited amount of teacher talk due to time constraints and the activity's complexity.

Table 5 *Mr. Hale's Talk Turns*

	Lesson							Unit	Percentage
Code	1	2	3	4	5	6	7	Totals	of Turns
Provides information	17	18	12	3	24	3	9	86	10.5
Invites Elaboration	9	10	3	3	3	0	1	29	3.5
Teacher Elaboration	2	18	5	1	3	1	6	36	4.4
Invite Reasoning	4	8	2	2	5	0	2	23	2.8
Invites Students to Question	0	1	0	0	0	0	1	2	0.2
Teacher Reasoning	3	13	10	0	10	2	4	40	4.9
Invites Connecting	1	0	3	0	0	0	3	7	0.9
Teacher Connecting	1	0	7	0	0	0	4	12	1.5
Querying	0	4	0	0	2	0	1	7	0.9
Close-Ended Questions	14	48	17	3	49	3	22	156	19.1
Open-Ended Questions	21	33	4	6	19	1	8	92	11.2

Table 5 *continued*

Positive Feedback	22	26	8	2	14	0	8	80	9.8
Negative Feedback	0	8	3	2	8	5	1	27	3.3
Classroom Management	37	56	27	13	36	18	34	221	27

I orientated the themes in Mr. Hale's talk toward the percentage of time his talk encouraged student participation (Table 6). For example, 75% of his questioning in lesson 1 was open-ended or resulted in positive feedback. The degree that his talk invited student participation varied from lesson to lesson. Lessons one and four contained more talk that encouraged student participation in the discussion than any other lesson. Across the entire unit, Mr. Hale's talk provided reasoning and elaboration more than asking students to provide those elements during whole-class discussions. For example, the following discussion during lesson 2 included teacher elaboration:

Mr. Hale: What does a plant cell have that an animal cell doesn't?
Student: A cell wall.
Mr. Hale: Perfect, a cell wall. A plant cell has a cell wall, chloroplasts, and a large vacuole which is different from an animal cell.

His use of open-ended questions and positive feedback was slightly less than his use of close-ended questions and negative feedback. Some examples of his open-ended questions are below:

- What do you guys think engineers do? (Lesson 1)
- What are some examples of acquired traits? (Lesson 3)
- Do you understand what I did? (Lesson 5)
- What could you use as an artificial barrier? (Lesson 7)

Mr. Hale only invited or connected information during lessons 1, 3, and 7. He more frequently invited students to connect information during the engineering-based lessons 1 and 7 than during the science-centered lesson, lesson 3. Overall, Mr. Hale connected information more for his students than he requested them to make those connections.

Table 6 *Themes in Mr. Hale's Teacher Talk*

	Lesson							
Theme	1	2	3	4	5	6	7	Unit Totals
Questioning	75	51	38	62	37	11	41	49
Elaboration	82	36	38	75	50	0	14	45
Reasoning	57	41	17	100	33	0	43	39
Connecting	50	N/A	30	N/A	N/A	N/A	57	37

Note. The numbers in this table represent the percentage of time the teacher invited student participation on the discussion.

Figure 1 shows the average notebook grade and the degree that Mr. Hale invited students to participate in the classroom dialogue for each day of the unit. It appears that frequent invitations for students to participate in the conversation during lesson 1 led to the unit's lowest notebook score. However, a close examination of the assessment and the teacher talk show that Mr. Hale did not present some of the information included in the assessment, which resulted in students getting low scores. The assessment focused on the engineering project's criteria and constraints, but Mr. Hale never spoke of those things during class. The lessons with the highest student scores (two, three, five, and seven) also had the least invitations for students to participate in the discussion. Alternatively, the lesson with the lowest score, except for lesson 1, had the greatest percentage of student opportunities to speak. Again, there were no student sheets for lesson 6, thus, students did not receive grade for that lesson.

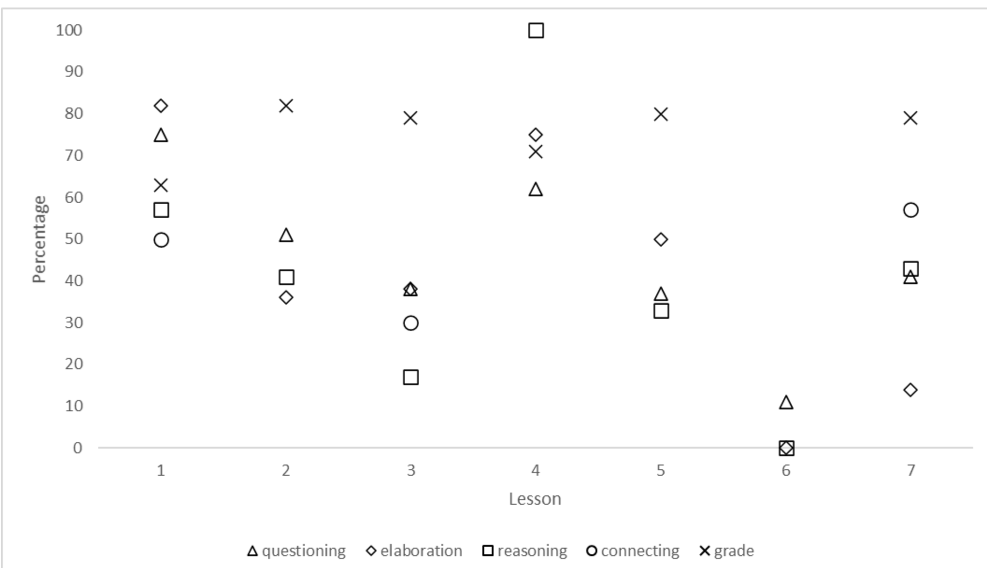

Figure 1 *The Effect of Mr. Hale's Teacher Talk on Student Achievement*

Mr. Winchester's Teacher Talk and Student Learning

Mr. Winchester used most of his talk turns (38%) to ask questions (Table 7). The majority of the questions were close-ended. Mr. Winchester asked the most questions during lesson 5, applied genetics. For example, he often asked, "Which version is dominant?" or "What are the offspring from that cross?" while students worked on practice Punnett Square problems.

While Mr. Winchester did provide information about the content to his students and addressed classroom management issues, those two components made up less of the talk turns than asking questions. He infrequently asked the students to make connections or connected information himself. The only lesson that contained frequent requests or teacher utterances of elaboration or reasoning was lesson 1. Mr. Winchester invited students to provide more explanations than he provided them himself:

> Mr. Winchester: Who knows what DNA is used for?
> Student A: It tells you who you are4.
> Mr. Winchester: What do you mean by that?
> Student A: You get it from your mom and your dad.
> Mr. Winchester: So, give me more.
> Student A: Your parents give you copies of their DNA. You combine those copies and come out looking like you but also kind of like them.

Table 7 *Mr. Winchester's Talk Turns*

	Lesson							Unit	Percentage
Code	1	2	3	4	5	6	7	Totals	of Turns
Provides information	16	13	26	6	23	7	10	101	11.7
Invites Elaboration	11	10	2	0	8	0	0	31	3.6
Teacher Elaboration	13	3	0	0	2	0	2	20	2.3
Invite Reasoning	17	8	3	0	3	0	3	34	3.9
Invites Students to Question	11	0	1	0	7	0	2	21	2.4
Teacher Reasoning	18	10	3	0	3	1	2	37	4.3
Invites Connecting	4	0	0	0	0	0	2	6	0.7
Teacher Connecting	3	1	0	0	1	0	1	6	0.7
Querying	6	1	4	0	4	0	0	15	1.7
Close-Ended Questions	25	41	18	0	95	6	12	198	23
Open-Ended Questions	56	24	21	5	23	2	2	133	15.4
Positive Feedback	25	18	9	0	31	1	2	86	10
Negative Feedback	4	2	1	0	5	2	0	14	1.6
Classroom Management	48	36	20	2	40	0	14	160	18.6

I calculated the percentages for each theme to reflect the teacher inviting students to participate in the conversation (Table 8). The degree to which Mr. Winchester invited students to participate in the class discussion varied from one day to the next. For example, during lesson 1, elaboration was the only theme that depended more on Mr. Winchester's contribution than the students. However, during lesson 2, that same theme was the only one that depended more on student contributions than those of the teacher. There was minimal teacher talk due to lesson 4's learning activity, which resulted in questioning being the only theme present in that lesson's discourse. During the entire unit, Mr. Winchester made more invitations for students to participate than he provided the information himself.

Table 8 *Themes in Mr. Winchester's Teacher Talk*

	Lesson							
Theme	1	2	3	4	5	6	7	Unit Totals
Questioning	74	49	61	100	35	27	25	51
Elaboration	46	77	100	N/A	80	N/A	0	61
Reasoning	61	44	57	N/A	77	0	71	60
Connecting	57	0	N/A	N/A	0	N/A	67	50

Note. The numbers in this table represent the percentage of time the teacher invited student participation on the discussion.

Figure 2 plots the student learning and teacher talk themes for each lesson. Due to the reasonably consistent average achievement and the fluctuating levels of invitations for students to elaborate from one lesson to another, it does not appear there is a clear connection between these elements. The same is true for reasoning and coordination. It appears that the high number of open-ended questions during lesson 4 led to the lowest level of achievement for the unit. However, none of those questions corresponded to the content that was assessed for lesson 4. Therefore, it is unlikely that Mr. Winchester's questioning in lesson 4 affected student achievement.

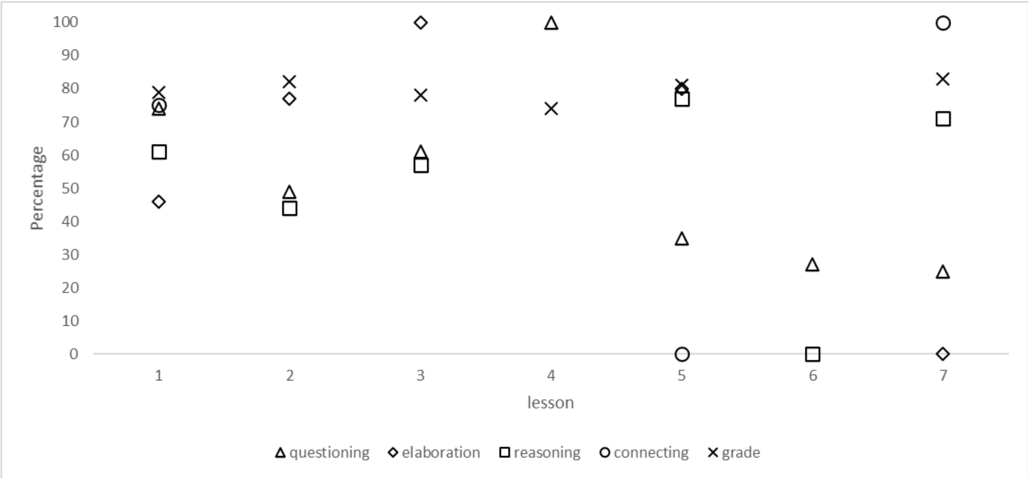

Figure 2 *The Effect of Mr. Winchester's Talk on Student Achievement*

Mrs. Anderson's Teacher Talk and Student Learning

Mrs. Anderson most frequently used her talk turns to ask questions (33%). She tended to ask more close-ended questions than open-ended questions (Table 9). The second most frequent talk category was classroom management, which she used to direct student actions and address behavior issues. For example, "Okay gents, let's put that away for now and get busy on this activity." She rarely invited students to connect information or did it herself outside of the engineering-based lessons, one and seven. For instance, in lesson 7:

> **Mrs. Anderson**: Who can explain how the DNA extraction we did is connected to our engineering project?
> **Student A**: We can use to test our corn.
> **Mrs. Anderson**: To test our corn for what? Can somebody help him out? How is testing the corn going to help us with the engineering project?
> **Student B**: We can use the DNA extraction like from the lab and then test the DNA of the corn to see if it has the DNA from the GMO pollen. That would let us know if the corn was contaminated.

She also frequently asked students to elaborate on their answers, or she elaborated on her own or a student's response. She never responded to a student's answer or idea in a negative manner.

Table 9 *Mrs. Anderson's Talk Turns*

Code	Lesson 1	2	3	4	5	6	7	Unit Totals	Percentage of Turns
Provides information	8	14	6	1	18	7	10	64	6.6
Invites Elaboration	9	8	8	4	7	2	5	43	4.5
Teacher Elaboration	11	5	5	3	6	5	8	43	4.5
Invite Reasoning	8	0	12	2	3	2	1	28	2.9
Invites Students to Question	12	0	6	0	0	0	0	18	1.9
Teacher Reasoning	5	5	6	2	11	1	3	33	3.4
Invites Connecting	5	0	0	0	0	0	3	8	0.8
Teacher Connecting	4	1	1	1	0	0	0	7	0.7
Querying	5	0	1	0	7	1	2	16	1.6
Close-Ended Questions	36	38	23	9	54	14	22	196	22.3
Open-Ended Questions	40	13	27	11	11	7	0	109	11.3
Positive Feedback	26	33	30	11	29	7	13	149	15.5
Negative Feedback	0	0	0	0	0	0	0	0	0
Classroom Management	62	51	46	18	41	10	22	250	26.0

The percentages for each theme in Mrs. Anderson's teacher talk reflect invitations for students to participate in the conversation (Table 10). Mrs. Anderson invited student participation in the classroom discussion more at the beginning of the unit than during lessons five and seven. During the first four lessons in the unit, she used more open-ended questions than close-ended questions. This trend did not continue in lessons five and seven. Throughout the unit, Mrs. Anderson made more invitations for students to participate when questioning and reasoning. The teacher and students had equal opportunities to elaborate on answers. Lastly, Mrs. Anderson and the students had equal opportunities to connect information during lesson one. Mrs. Anderson rarely connected information during lessons 2, 3, and 4, while students did not connect information again until lesson 7.

Table 10 *Themes in Mrs. Anderson's Teacher Talk*

Theme	Lesson 1	2	3	4	5	6	7	Unit Totals
Questioning	65	55	71	71	43	50	37	57
Elaboration	45	62	62	57	54	29	39	50
Reasoning	80	0	75	50	21	67	25	58
Connecting	44	100	100	100	N/A	N/A	0	47

The achievement and teacher talk were very similar for the first four lessons, so it is difficult to determine the effect of teacher talk on student achievement (Figure 3). However, the average achievement decreases slightly in lessons five and seven. For lesson 5, this decrease could be due to Mrs. Anderson changing her teacher talk to provide more reasoning in lesson 5 instead of asking students to provide it during whole-class discussions.

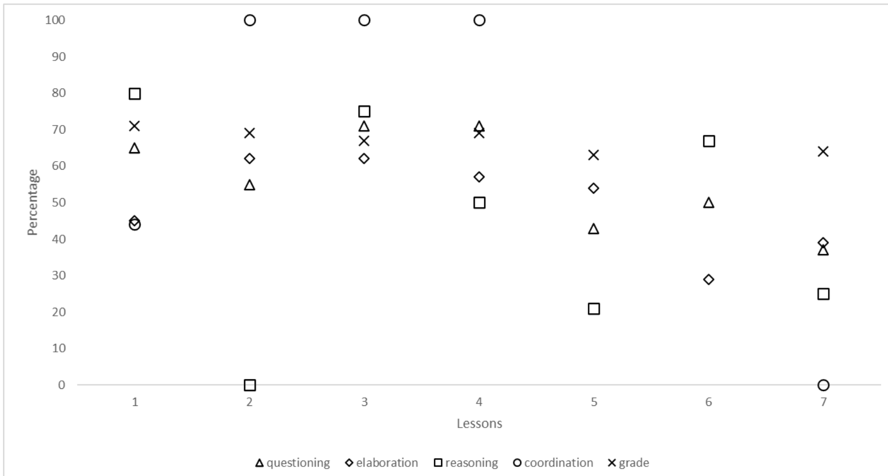

Figure 3 *The Effect of Mrs. Anderson's Talk on Student Achievement*

Comparison between Teachers

When comparing the use of open-ended questioning and positive feedback for the unit's duration, there is little difference between the three participants (Figure 4). Mrs. Anderson's use of these types of talk was slightly higher than the other two participants. This difference may be affected by Mrs. Anderson not using any negative feedback during the unit, while the other two participants occasionally reacted negatively to student answers. The differences in the use of elaboration were more pronounced than those for questioning. Mr. Winchester more often required students to elaborate on their answers than either of the other two participants. Mrs. Anderson equally asked her students to elaborate and provided the elaboration herself, while Mr. Hale was more likely to elaborate on student's answers than to ask them to do it. Mr. Winchester and Mrs. Anderson both more often asked students to explain a statement instead of explaining it themselves. While Mr. Hale rarely allowed students to explain things, choosing to provide explanations himself most of the time. While none of the participants frequently used connecting information, it was incorporated in their discourse more than once during the entire unit. Mr. Winchester was equally likely to ask students to connect information or to do it for them. In comparison, Mrs. Anderson was slightly more likely to connect information for the class. Mr. Hale was much more likely to provide the connections than to ask students to provide the connections.

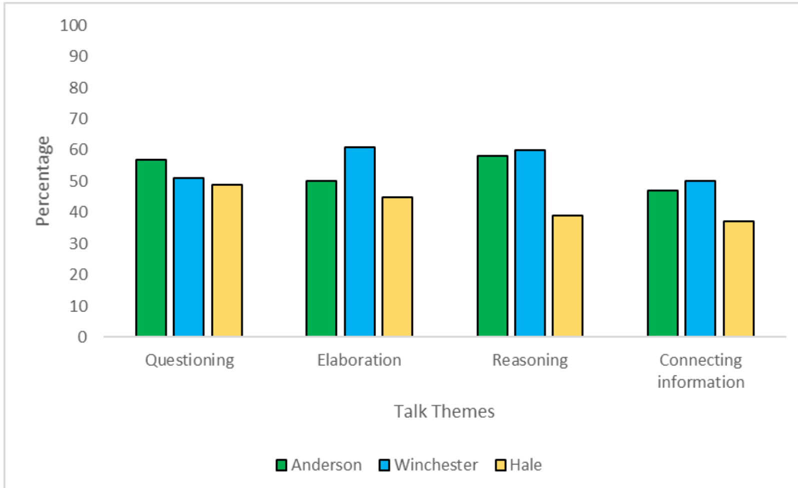

Figure 4 *Comparison of Talk Themes between Participants*

The average score on engineering notebooks in Mr. Winchester and Mr. Hale's classes was very similar (Figure 5). In contrast, the average score in Mrs. Anderson's class was measurably lower. None of the talk themes from Figure 4 have a similar configuration. That is, Mr. Winchester and Mr. Hale never had a similar use of any talk theme, while Mrs. Anderson's use of that theme was measurably lower. However, there was a teacher talk component that did not fit into the themes presented in Figure 4. All three of the teachers presented information to their students during the unit (Figure 6). Mr. Hale and Mr. Winchester presented slightly more information to their students than Mrs. Anderson did during the unit. The amount of information presented by the teachers appears to be reflected in the notebook scores.

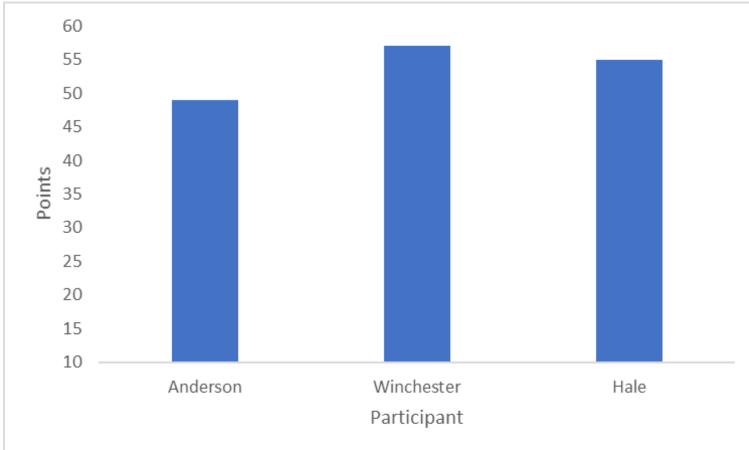

Figure 5 *Average Score on the Notebooks for the Unit*

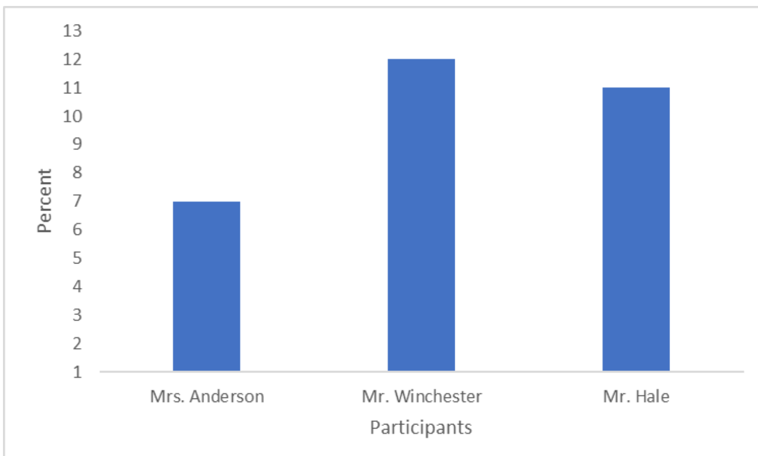

Figure 6 *Percentage of Talk Moves used to Present Information*

Discussion

The present multiple case study investigated how teachers facilitated academically productive classroom discussions during an integrated STEM unit and the impact of the discourse-rich practices on student learning. The results of this study were analyzed through the sociocultural prospective to determine the effect of teacher talk on the classroom conversation. The findings showed that the types of talk a teacher used varied from lesson to lesson in response to the learning activities used in that lesson. After analyzing the teacher talk across the unit, researchers determined that Mr. Winchester invited students to participate in class verbally more than any other participant. For each of the four themes, questioning, reasoning, elaboration, and connection, he more often requested students to participate than he provided information. Mrs. Anderson also encouraged student participation with her open-ended questioning, positive feedback, invitations to elaborate and to reason. However, she was more likely to connect information for the students than invite them to make the connections. Alternatively, Mr. Hale used a more teacher-centered approach to whole-class discussions. He depended on himself to provide information on all four themes. The differences in how the teachers used their talk to guide the whole class discussion resulted in student learning differences. The analysis of the student notebooks showed that students in Mr. Winchester's classroom learned slightly more than the students in Mrs. Anderson and Mr. Hale's classroom. This finding supports previous research suggesting that when students participate in quality class discussions, they better understand the content (Alexander, 2018; O'Connor et al., 2015).

In-depth analysis of teacher talk showed that all three participants asked more questions than they used any other type of teacher talk moves. Most of those questions were close-ended, and the participants used them within the IRE format of class discussion. However, for lesson 1, all three participants used more open-ended questions than closed. The type of question asked may be due to the topic of lesson 1. This lesson introduced students to engineering, a new topic for the students and the participants, and had students engage in small group and whole-class discussions to understand the engineering problem (i.e., scope, criteria, constraints). It is possible that a lack of familiarity with the topic caused the participants to teach this lesson with an inquiry focus. Thus, they used questioning techniques that would allow them to draw out the knowledge students gained from the activities. Since all three participants were veteran science teachers, they were familiar with the unit's remaining topics and were comfortable leading fact-finding conversations. These results align with the findings of Kawalkar and Vijapurkar (2013), who determined that middle school teachers were more likely to use open-ended questions during inquiry activities than during traditional science lessons. Alternatively, it could be that engineering lessons are well-suited for open-ended questions. Several researchers have found that the type of question asked can be connected to the discipline (Andersson-Bakken & Klette, 2016; Tofel-Grehl et al., 2017). This study found a difference in the types of questions asked during the introduction to engineering lesson – Lesson 1 and the science lessons – Lessons 2 to 6. It is impossible to determine if this difference extended to lesson 7, the engineering challenge, because most conversations were between a small group and the teacher, and only the whole class discussions were the focus of the current study.

While prior research has shown that teachers must request students to elaborate on their answers (Alexander, 2004; Michaels et al., 2008), it is apparent that not all the participants in this study allowed students to elaborate. Mrs. Anderson incorporated inviting elaborations into her talk during every lesson. She attempted to guide students to the lesson's knowledge, but she filled it in for them if they could not identify the correct information. Her approach to elaboration reflects the belief expressed by Michaels and colleagues (2008) that students learn more when they are allowed to build a body of knowledge together by elaborating on peers' answers. Mr. Winchester's use of this talk move occasionally coincided with Mrs. Anderson’s but was often affected by outside factors. For example, in lesson 1, he elaborated on students' answers instead of requesting students to elaborate. Mr. Winchester had a background in engineering. Therefore, it is possible he considered himself to be an expert in the field and preferred to provide information rather than request it from students. During lessons 4 and 6, Mr. Winchester did not ask students to elaborate on their answers. During those lessons, he behaved as if there was not enough time to complete the activity. Mr. Hale's use of this talk move also seems connected to the availability of time. During the first two lessons of the unit, he often requested or provided elaborations on student answers. However, as the unit progressed, Mr. Hale seemed in a hurry to complete the activities from each lesson. This sense of urgency may have affected his use of this talk move. This observation aligns with a finding in a study by Alozie and colleagues (2010), which found that teachers often do not incite elaborations because they run out of time.

Providing or requesting reasoning was used sporadically throughout the curriculum unit by the teachers. Mr. Winchester and Mrs. Anderson frequently invited student reasoning, but only in specific lessons. For example, both teachers invited reasoning in lessons one and five. It is possible that the teachers identified those lessons as either challenging or essential for the unit and therefore wanted to make sure the students had a good understanding of the content. This action aligns with current research, which has found that asking students for explanations of their answers leads to increased performance on standardized tests (O'Connor et al., 2015). Mr. Hale, on the other hand, rarely invited students to provide reasoning, instead choosing to do it himself. Similar to the other participants, he only provided reasoning during selected lessons, perhaps because he thought the information was challenging or essential for the unit. Unfortunately, researchers have found that providing explanations for students instead of allowing them to explain is an ineffective strategy for increasing student understanding (van Leeuwen & Janssen, 2019).

Connecting information between different sources or topics was the least used type of teacher talk for all three participants. This finding aligns with a study of Accountable Talk in elementary and middle school classrooms, which found that teachers rarely made connections or requested students to make connections between topics (Wolf et al., 2006). The lack of connecting information in this study was surprising, given the integrated nature of the STEM unit. Since students had to use their science knowledge to complete the engineering design challenge, it was reasonable to expect teachers to make connections or request students make them. Mr. Winchester and Mrs. Anderson both occasionally linked the content from another lesson back to the engineering challenge. In contrast, Mr. Hale did not invite or make connections between the engineering challenge and the other lessons until the unit's end, when students were working on their engineering projects. The hesitance to connect the disciplines could be because all three teachers were teaching an integrated STEM unit for the first time. Guzey and colleagues (2019) found that teachers develop the skill to integrate multiple disciplines in one unit over several years. It is possible that the participants would utilize this type of teacher talk more as they taught this unit in subsequent years.

This study's results indicate that the effect of dialogic teaching on student learning is complex and cannot be attributed to one type of teacher talk. Mr. Winchester, who had students with higher notebook scores, asked students to elaborate, reason, and connect information more than had students respond to his open-ended questions. Also, he provided more content-specific information to students than the other two teachers. It appears that Mr. Hale was able to compensate for his lack of dialogic teaching with the amount of information he provided students since his students obtained nearly the same level of learning as those in Mr. Winchester's class. It also appears that Mrs. Anderson's lack of providing information may have been the reason her students had smaller learning gains than the students in the other two classes, given that her use of dialogic teaching was similar to that of Mr. Winchester.

However, when considering student learning and dialogic instruction, I believe that it is also critical to focus on the quality of classroom talk. Besides quality, other factors affect the impact of dialogic teaching, such as the number of students involved in the conversation and the teacher's classroom management style. Therefore, teachers must carefully consider the factors impacting structure and coordination and classroom discussions and create a balance between providing information and the dialogic discussion talk moves.

Limitations

This study has several limitations. First, the sample size is small, with only three teacher participants and two geographic locations. Despite the small number of participants, the individuals selected for this study represent very different ways of talking during the integrated unit. However, the findings from this study only apply to the three classrooms from which I collected data. Second, the number of students in each class was small. This small sample size of the students did not allow for additional statistical analysis for correlational analysis. Third, this study did not focus on the quality of the information provided to the students (e.g., clarity, correctness), and it is possible this affected student learning. Lastly, this study did not investigate students' prior knowledge of the concepts included in the unit. Snell and Lefstein (2018) found that high achieving students exhibited enhanced learning due to the classroom talk's dialogic nature, but that low-achieving students' performance was not affected by this talk. Therefore, a student's pre-existing knowledge may have affected the notebook scores.

Implications and Suggestions for Future Research

Science teachers should use dialogic pedagogy and provide necessary disciplinary content information when teaching integrated units. By encouraging students to provide rationales for their answers, challenge others' answers, provide an extended answer, make connections between topics, and answer open-ended questions, teachers give students control of the learning environment. Student-centered units are critical in the STEM disciplines because these learning activities allow students to develop the 21st-century skills, such as critical thinking, creativity, collaboration, and communication, that they will need if they pursue a job in a STEM field. There was limited evidence of teachers connecting the science and engineering topics within this unit. As demonstrated by Valtorta and Berland (2015), teachers need to make sure students understand all discipline-specific content and how to apply it to the engineering project in order for them to integrate the knowledge from the unit into the design challenge. Teachers must be explicit in their talk and encourage students to connect the science content they are learning and the engineering project throughout the unit. In addition to teachers, this study revealed some implications for curriculum developers. When creating integrated STEM units, it is essential to include guidance for how teachers should lead student discussions. Curriculum developers should stress that students must provide as much information as possible through a series of open-ended questions and calls for elaboration and explanations.

This study is part of a small body of research on teacher talk and student achievement during integrated STEM units. This study provides an in-depth look at teacher talk and student achievement by lesson. Future studies need to continue investigating the effect of dialogic teaching during integrated STEM units to further our understanding of dialogic classroom cultures. For example, studies need to focus on large schools with high numbers of minority students. Research conducted in these environments would complement the current study and build on the body of knowledge on the effect of student background and dialogic teaching on student learning during integrated units. Future studies should also focus on the quality of teachers' content presentation. It is crucial to determine if the way a teacher presents the content during an integrated unit affects student learning. Additional learning data needs to be used to clearly show the relationship between dialogic discussions and student learning. For example, pre and post-content tests could be included in a research study to bring more insight on student understanding of the content.

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STUDY 2: DO TEACHERS WITH MORE AUTONOMY SUPPORTIVE TALK HAVE MORE ENGAGED STUDENTS DURING AN INTEGRATED STEM UNIT?

Abstract

According to the national education reports in the U.S., students' interest in pursuing STEM careers has decreased in recent years. Many teachers have integrated the STEM disciplines into curriculum units to ensure student engagement and motivate students to pursue STEM fields. Although the use of these innovative curriculum units has become widespread, there is still little known about the quality of instruction in STEM units and how it is associated with students' interest and engagement in STEM. Building on the Self Determination Theory, this study investigated teachers' autonomy-supportive/suppressive talk and how it affects students' engagement during an integrated STEM unit. The data for this study were whole class and target group video recordings from two 8th grade science classrooms. Researchers coded the whole class video recordings to determine each teacher's autonomy-supportive/suppressive talk. Video recordings of two target groups of four students each, one group from each teacher's class, were transcribed and coded to determine how each student's engagement was affected by the teacher talk. The findings showed that each student responded differently to the teacher’s autonomy-supportive/suppressive talk. While some students’ engagement increased with more autonomy-supportive talk, other students' engagement decreased under those conditions. These findings make it clear that while various internal and external factors influence student engagement, teachers need to be observant of their students and use the type of talk that effectively engages all students in the STEM curriculum.

Key words: autonomy supportive talk, student engagement, STEM curriculum, teacher talk, integrated instruction

Introduction

There has been much interest recently in better educating students in science, technology, engineering, and math (STEM). This attention follows reports that youth are not interested in pursuing careers in the sciences or engineering (U.S. National Science & Technology Council, 2018). This lack of interest has led to the fear that the U.S. could have a shortage of workers in these fields, which could start a period of economic decline (President's Council of Advisors on Science and Technology, 2010; U.S. National Science & Technology Council, 2018). When students are not interested in a subject, they struggle to learn the content, which affects their learning and achievement (Jansen et al., 2016). Student scores on national assessments of science, technology, engineering, and math have marginally increased in recent years. However, most students are scoring below the proficiency level on those exams (U.S. Department of Education, National Center for Educational Statistics, 2015, 2018, 2019). This lack of achievement and interest has led to the recommendation that teachers integrate the STEM disciplines in instruction and curriculum that offer authentic connections to the practices of STEM professionals (NGSS Lead States, 2013; U.S. National Science & Technology Council, 2018). Those instructional activities also fulfill the recommendation from *A Framework for K-12 Science Education* (National Research Council [NRC], 2012) that students "actively engage" in science and engineering practices.

Many educators alter existing curriculum materials to incorporate the knowledge from one or more additional disciplines to meet the national reform documents' recommendations. While the integration of disciplines can occur in various ways, teachers most often use the content and practices of one anchor STEM discipline that defines the unit's primary learning goals. They then integrate components of at least one other STEM discipline into the curriculum. Alternatively, using a team-teaching approach, a group of STEM teachers can collaborate on a curriculum unit, and each teacher teaches a portion of the unit in their classroom. As long as at least two STEM disciplines are combined in a project or curriculum unit in a single class or multiple classrooms, it is considered STEM integration (Bybee, 2013). In addition, using engineering as an integrator to bring STEM disciplines together and having students apply science and mathematics concepts to justify design decisions, solve real-world in culturally and socially relevant contexts, and engage in 21st-century skills such as collaboration and teamwork are critical elements of quality STEM integration (Bryan & Guzey, 2020.)

Recent research has shown the benefits of integrated STEM education and the effects of student engagement in curricular materials for STEM instruction (NRC, 2014). For example, Barrett and colleagues (2014) integrated meteorology and engineering in a unit that ended with students having to build a model house that could withstand the sheering motion of a tornado. The researchers found that students were engaged in the project and gained knowledge of meteorology and engineering by participating in the STEM project. Similarly, English and King (2019) found that middle school students became engaged during an engineering challenge that required them to use math and science knowledge to design a paper bridge that could support a load. Researchers have found an increase in interest and engagement in various settings, including schools whose populations are predominantly students of color. In another study, Sinatra and colleagues (2017) found that elementary students developed an interest in physics and math as they applied the disciplines to modeling collisions with toy cars. These and similar other studies (e.g., Cunningham et al., 2020; Guzey et al., 2019; Lottero-Perdue & Lachapelle, 2020) show the positive impact of integrated STEM education on student learning and engagement at the K-12 level.

While researchers have studied the effect of the curriculum units on STEM integration, there is little research on the factors that influence the implementation of integrated STEM units and student engagement. In this study, I drew from studies of teacher talk and from the field of self-determination theory to investigate the role of teacher talk on student engagement during an integrated STEM unit. The following research question guided the study:

- How does autonomy-supportive teacher talk affect student engagement during an integrated STEM unit?

Theoretical Framework

"Integrated STEM education occupies a multidimensional space" (NRC, 2014, p.31), and this study investigates a complex learning environment in which students engaged in STEM concepts and practices. Given the inherent complexities of integrated STEM education, the study builds on several research areas: dialogic instruction, student outcomes, autonomy-supportive teaching, and the Self-Determination Theory (Ryan & Deci, 2000). All these research areas provide data and insights for improving integrated STEM education.

Teacher Talk

Teacher talk is a social activity with multiple purposes, such as sharing content-rich information with students, providing instructions, and leading discussions. Students learn to talk science by listening to the teacher talk science and engaging in science talk. Once students have learned to talk science, they begin to learn science (Lemke, 1990). Therefore, teacher talk is a powerful instructional tool in the science classroom. Research has shown that teachers often use their talk to guide students in discussions (Pimentel & McNeill, 2013), build understanding (Thörne & Gericke, 2014), evaluate understanding (Smart & Marshall, 2013), and create a sense of identity (Moje, 1995).

Teacher talk research has a long history in science education (Michaels & O'Connor, 2012; NRC, 2008; Scott, 1998; Soysal, 2021). However, researchers have recently started investigating the types of teacher talk that occur during integrated STEM units (e.g., Guzey & Ring-Whalen, 2018; Johnston et al., 2019; Valtorta & Berland, 2015). For example, Aranda and colleagues (2018) compared how two science teachers talked or orchestrated academic discussions during an integrated STEM unit. Other researchers have investigated how teachers talk about another STEM discipline during the integrated units. Specifically, researchers have investigated if a teacher could change how they talk to include engineering in their science lessons (Guzey et al., 2019; Guzey & Ring-Whalen., 2018). The researchers found that the first time a science teacher uses an integrated unit in their classroom, the talk is generally more science-focused (Guzey & Ring-Whalen, 2018); however, if a teacher continues using integrated units for several years, their talk changes to include more references to engineering (Guzey et al., 2019). A study by Johnston and colleagues (2019) supported the results of the previous studies. They also found that by addressing the students as engineers during the unit, as a tool for student motivation, this teacher increased student interest in engineering. This study builds on and complements these previous studies by investigating the relationship between teacher talk and student engagement in the context of integrated STEM education.

Autonomy-Supportive Teacher Talk

Researchers have suggested that autonomy-supportive instructional interactions support the autonomy of students (Reeve et al., 2004). When students have autonomy, they can control their learning environment. This control then makes students more motivated to engage in learning activities (Reeve, 2006). The most suggested method is for teachers to provide a rationale for all learning activities. Researchers suggest that teachers explain why students are doing activities and how the information will benefit students in the future (Reeve, 2006; Reeve & Halusic, 2009; Stroet et al., 2013). Sansone and colleagues (1999) demonstrated the importance of rationales in a study investigating the conditions that would cause students to work on a tiresome task. They found that a group of college students were more engaged with a tedious task if instructors gave them a reason the task was beneficial.

Another way to support student autonomy is by offering them choices concerning the work they will do to achieve the learning objectives of the class. The effect of choice on a student's engagement is a common topic in studies interested in autonomy-supportive teaching (Jang et al., 2016; Patall et al., 2010). One such study compared the achievement of students who could choose their homework to students who received a standard homework assignment. At the end of the unit, researchers found that the students who chose the style of their homework were more engaged with the work and scored higher on the unit test than those who did not (Patall et al., 2010).

Teachers can also support student autonomy by inviting students to participate in a discussion about the content. Researchers suggest that teachers encourage students to share their ideas and provide a classroom culture where students feel safe talking about the learning activities (Reeve, 2006; Stroet et al., 2013). To make students feel safe sharing ideas, it is essential that teachers only respond positively or neutrally to student contributions. If a teacher responds negatively to students during a class discussion, they suppress the autonomy of the student who contributed to the conversation and the rest of the class (Reeve 2006; Reeve & Halusic, 2009; Ryan & Deci, 2000).

Another way teachers can affect student autonomy is through the words and phrases they use during class. The type of language a teacher uses is either controlling or informational. Teachers often use both types of language within the same class (Jiang et al., 2019). Controlling language is rigid and demanding, telling students exactly what to do and when to do it. Conversely, informational language instructs students but is flexible, allowing them to control how the task is completed (Reeve, 2006). Researchers have found that when a teacher uses controlling language, it limits student autonomy. They also found that the lack of autonomy contributed to the students lack of conceptual learning (Vansteenkiste et al., 2005).

The last technique for supporting student autonomy is allowing students to express their displeasure with the learning activity. Researchers have found that students perceive teachers to be more autonomy supportive if teachers listen to student complaints (Reeve, 2006; Reeve & Halusic, 2009; Ryan & Deci, 2000). This finding does not mean that teachers should change a learning activity because a student does not like it, but it suggests that just acknowledging student displeasure supports autonomy. However, Jang and colleagues (2016) found that students are more likely to complete assignments if they find the activity enjoyable. The researchers suggested that instructors have an open dialogue with students to determine the best learning activities for a class. They stress that giving students some autonomy over the tasks will lead to higher student engagement and ultimately higher learning gains.

Several researchers have investigated teachers' use of autonomy support in science classes. Many of these studies used questionnaires to investigate students' perceptions of the teacher's motivating style and student engagement. For example, Kiemer and colleagues (2015) investigated ninth-grade students' perceptions of their math or science teacher's autonomy-supportive or suppressive style and its effect on their interest in the subject. They found that students were more interested in the content when they perceived the teacher's questioning and feedback as autonomy-supporting. Other researchers have found that students were affected by different aspects of teacher autonomy support. For example, Patall and colleagues (2018) found that when a teacher supported students' autonomy by offering a rationale for the learning activities, they were motivated to learn the topic and were engaged in the learning. Alternatively, Hofferber and colleagues (2016) discovered that it is not just the teacher's actions and talk that affect student autonomy. The researchers found that the students perceived the teacher to be autonomy supportive when the learning activity was enjoyable. In addition, the researchers demonstrated that students' perceptions of teacher autonomy support could be affected by factors outside the teacher's control.

One group of researchers used observational techniques to study science teachers' genuine autonomy-supportive actions (Struyf et al., 2019). This study followed high school students as they attended math, physics, and integrated STEM lessons. The researchers observed each class once and conducted a focus group interview with a selected group of students from the class. They determined that the collective engagement was higher in any class when the teacher supported student autonomy. However, the engagement was highest in integrated STEM classes where the teacher supported student autonomy (Struyf et al., 2019).

Self Determination Theory

I framed this study under the Self Determination Theory (SDT), a meta-theory about what motivates an individual (Ryan & Deci, 2000). Ryan and Deci specified that an individual's motivation continues to develop as they better understand themselves and their connections to others. Some factors can support or suppress this development, and all socially based environments, such as classrooms, have the potential to contain both types of factors. This study is framed specifically by the Basic Needs aspect of SDT. This theory states that each individual has three basic psychological needs: competence, relatedness, and autonomy. The degree to which one or all of those needs are supported or suppressed by others will affect an individual's motivation to participate in an activity (Deci & Ryan, 2002). This study focuses on an individual's need for autonomy, which is a feeling of control over their actions. Researchers have found that if teachers support student autonomy, their work is more creative, and they can develop a deeper understanding of the content (Reeve, 2006).

This study uses the concept of engagement as a way to study student motivation. It is a commonly held assertion in motivation and engagement research that engagement is a consequence of motivation (Skinner et al., 2009). While it is possible to observe student engagement while they are in the classroom, it is impossible to observe their motivation because it is a private matter that students do not share with others. Engagement is a multifaceted construct, and there has been some disagreement in the literature about which components are part of the construct. In this study, I consider engagement to have three components: behavioral, emotional, and cognitive (Fredricks et al., 2004). Behavioral engagement consists of the actions a student takes that demonstrate they are involved in the learning activity. This type of engagement includes paying attention, putting forth effort on assignments, taking part in small and large group discussions, and not giving up until an activity is complete. Emotional engagement involves a student displaying emotions such as happiness or boredom and expressing interest in an activity (Reeve et al., 2004).

Previous research highlights the complexity of productive, autonomy-supportive teacher talk for student motivation and engagement. The current study expands on teacher talk research by focusing on how different autonomy-supportive talk affects student autonomy during an integrated STEM unit. Specifically, the study investigates the effects of a teacher's autonomy-supportive talk on behavioral and emotional engagement.

Methods

Participants and Setting

This research study took place in the classrooms of two 8th grade science teachers who worked in a rural school district in the Midwest region of the United States. The school has 842 students enrolled in grades 7-12, with 10% students of color, 21% have disabilities, and 42% were economically disadvantaged. This study used a convenience sample drawn from the participants in a more extensive research study. As part of that study, the two 8th grade science teachers, Mr. Hale and Mr. Winchester attended a professional development workshop during the preceding summer. The workshop provided the teachers with the curriculum and pedagogical techniques necessary for implementing the integrated unit in their classrooms. Both of these experienced teachers taught the unit in each of their 8th-grade classes. The teachers selected a class with a suitable target student group for data collection. In Mr. Hale's class, this target group consisted of two boys, Jack and Eddie, and two girls, Lydia and Shae. While in Mr. Winchester's class, the target group consisted of one boy, Dylan, and three girls: Makayla, Jenny, and Emma. All names are pseudonyms.

Research Design

This investigation used an interpretive qualitative research design (Marriam, 2002). This approach allowed me to analyze two sources of data and interpret the effect of the teacher talk on student engagement during the integrated STEM unit. I interpreted the data in this study through my bracketed experience as an experienced middle school science teacher and an integrated STEM curriculum developer.

Curriculum Unit

The curriculum unit consisted of seven lessons and took 22 days to complete (Table 11). Lesson 1 started with teacher-led discussions about engineering, the engineering design process, and the engineering challenge. The lesson ended with a student-centered activity that required students to work in groups to research and then debate the merits of GMO crops. Lesson 2 consisted of two student-centered science activities. The modeling activity allowed students to understand the placement of DNA in the cell. In comparison, students gained an understanding of the structure of DNA during the extraction activity. The third lesson in the unit was science-focused and contained a mixture of teacher-centered and student-centered activities. The lesson began with a teacher-centered demonstration of gene placement on a chromosome. Following the demonstration, two student-centered activities allowed students to explore traits and how they are inherited. Lesson 4 consisted of a student-centered science activity. The students traveled between four stations in the classroom to learn about reproduction and how genes are inherited. Lesson 5 consisted of several teacher-centered science activities. The teachers started the lesson by instructing students on the foundations of Mendelian genetics. During the remainder of the lesson, the teacher guided the students through several Punnett Square practice exercises. Lesson 6 contained a student-centered science activity that allowed students to model the process of creating a GMO organism. Lesson 7 consisted of several student-centered activities that used engineering and science knowledge. Students worked in small groups to design a testing method to see if there was cross-contamination between GMO and non-GMO corn. The groups then redesigned their plan based on teacher feedback and presented their final plan to the class.

Table 11 *Overview of the Integrated STEM Unit*

Lesson	Days		Objectives
	Mr. Hale	Mr. Winchester	
1: Introduction to the Engineering Challenge	1-3	1-4	Students will be able to identify the engineering challenge, constraints and criteria that will affect the solution, and understand why the problem is important.
2: Introduction to DNA Structure and Function	4-5	5-6	Students will understand where DNA is located and will be able to describe it after extracting it from a cell.
3: Genes and Trait Expressions	6-8	7-8	Students will be able to define several inheritance related vocabulary words and will be able to describe how a gene is related to a trait.
4: Introduction to Heredity	9-10	9	Students will be able to describe how traits are inherited, the difference between sexual and asexual reproduction, and how corn reproduces.
5: Applied Heredity	11-14	10-13	Students will use Mendelian genetics to determine the traits of offspring after a parental cross.

Table 11 *continued*

6: Genetic Modification	15	14-15	Students will understand how a GMO is created.
7: Engineering Challenge	16-22	16-22	Students will create a solution, revise the solution based on feedback, and present their final design.

Data Collection

Researchers videotaped each teacher's class during every day of the unit. A video camera was placed at the back of each room and pointed toward the teacher. This camera allowed researchers to view most of the students in the room and the teaching activity at the front of the room. Researchers used an iPad to record the activity at the target group's table. This device was mounted on one end of the table and positioned to see all four students' work.

Data Analysis

To determine the autonomy-supportive and suppressing language used by each teacher, I transcribed the video recordings verbatim. I created a codebook for autonomy-supportive and controlling teacher talk based on the characteristics of these motivating styles found in Reeve and colleagues (2004) (Table 12). Two individuals coded a small section of the data. Afterward, we met and compared codes arriving at inter-rater reliability of 60%. We then discussed coding differences and refined the definitions of the codes. We continued the process of independently coding a section of data and meeting to discuss and refine definitions until we reached inter-rater reliability of 92%. The author coded the remainder of the data.

Table 12 *Code Book for Teacher Talk*

Code	Definition	Example
Interest building (IB)	Teacher makes activity appealing to student. They enhance interest, enjoyment, curiosity, or appeals to sense of challenge.	After you finish those questions then we are going to move on to the fun part.
Seeks compliance (SC)	Teacher persuades student into doing activity. They offer incentives, consequences, utter directives, set deadlines and give assignments.	You have five minutes to get those questions answered.
Choice (CH)	Teacher offers choices to students.	You can read these letters together as a group or you can read them by yourselves.
Positive feedback (PF)	The teacher responds to an answer from a student in a positive way.	You are doing a great job young lady.
Negative feedback (NF)	The teacher responds to an answer from a student in a negative way.	Nope.

Table 12 Continued

Code	Definition	Example
Invitation to orally participate (VP)	The teacher asks open or close ended questions or tells students to discuss in small groups.	What does an engineer do?
Informational language (IL)	Teacher uses words like can, could, may, might. Teacher is noncontrolling and flexible.	You could add a flow chart to your presentation if you think it will help you explain what you did.

Table 12 *continued*

Controlling language (CL)	Teacher uses words like should, must, got to, have to. They give directives and commands, pressuring, rigid, and no nonsense.	Pour the buffer into the test tube now.
Explanatory rationales (ER)	Teacher says because, so, the reason is. They identify the meaning, use, benefit, or importance of a task or request	As you read the letter underline the main ideas. That will help you answer the questions.
No explanatory rationale (NER)	Teacher does not say because, so, or the reason is. They do not identify the value, meaning, use, benefit, or importance of a task or request.	No example possible. This code was applied if students were told to do an activity but no explanation was provided.

I used the teacher talk codes to determine a daily rating for each of the four subscales within the teacher's autonomy support scale (Reeve et al., 2004). For example, to determine the rating for subscale 1, the frequency of the supportive codes (CH, PF, IL IB) were added together and divided by the frequency of all the codes that applied to that subscale (CH, PF, IL, CL, NF, SC, IB) and then converted into a percentage. I then used these percentages to determine the rating on the subscale. To align this study with others that have used this rating scale, I averaged all four numbers to determine a single autonomy-supportive rating for the day.

To determine daily engagement for each student in the target groups, I used the observation instrument from Reeve and colleagues (2004). Two researchers independently rated a portion of the data then met to compare ratings. We discussed the ratings that were different and refined the characteristics used to determine engagement or disengagement for each subscale. The cycle continued, independently rating and meeting to discuss and refine until we reached inter-rater reliability of 87%. After that point, the author rated all remaining student engagement.

I plotted student daily engagement ratings and teacher autonomy-supportive ratings to identify trends in each student's engagement data. To reduce this data and to determine the essence of how the teacher's motivational talk affected each student's engagement under the Self Determination Theory, I looked at the video from days when a student's engagement was similar and compared that to the coded transcripts from those days. I observed the student's facial expressions and body language and listened to their verbal responses to the different teacher talk types. I repeated this process for each of the trends in a student's data until I could explain how the teacher's motivational style affected the student's engagement for the entire unit. I completed this process for each of the students in the two target groups.

Results

Mr. Hale’s Autonomy Supportive Talk

Overall, Mr. Hale's motivational talk did not support student autonomy. His autonomy-supportive style was rated below four for the unit's duration, except for day 12 (Figure 7). A rating of four was the midpoint in the Likert scale, and anything above a four was autonomy-supportive while anything under a four was autonomy suppressing or controlling (Reeve et al., 2004). His most autonomy-supportive talk came on day 3 when the students were debating GMOs. He also had a supportive style on days 9 and 10 when students worked at stations on reproduction. Lastly, he had high levels of autonomy support on days 11 through 14 when students worked with manipulatives to solve Punnett Square problems. On these days, he used a moderate amount of autonomy-supportive talk, more informational than controlling talk, and a varied amount of rationale for activities.

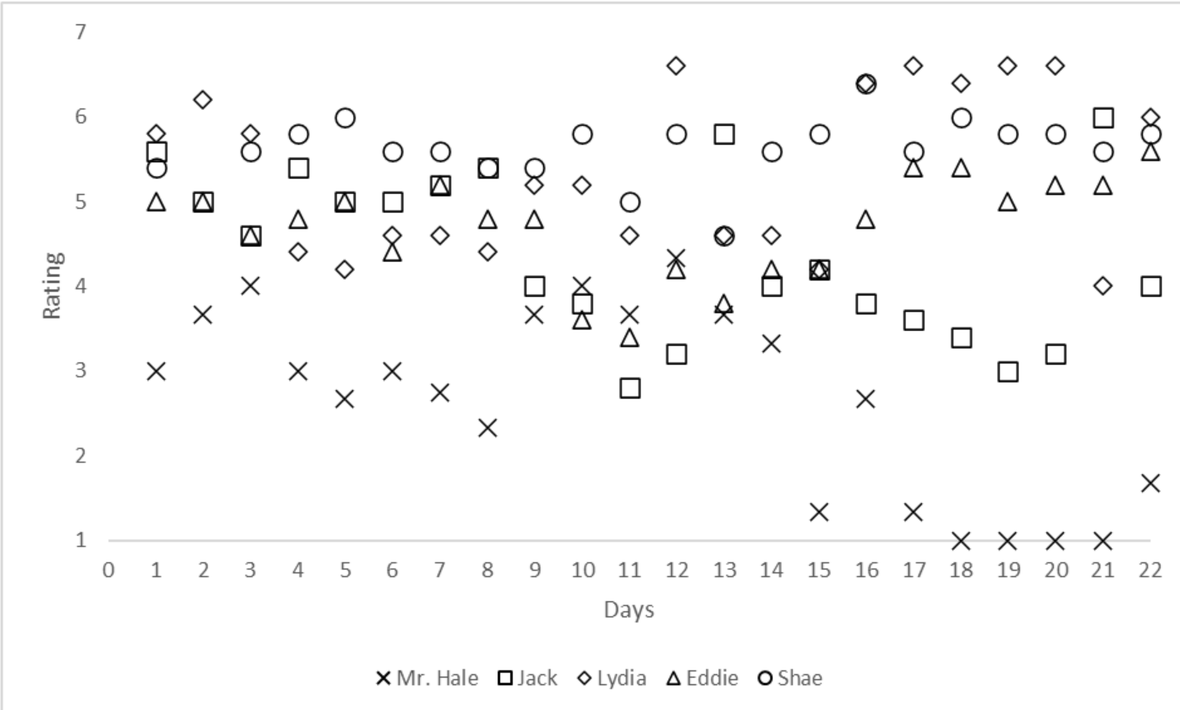

Figure 7 *Daily Autonomy Support and Engagement Ratings for Mr. Hale and Students*

In comparison, Mr. Hale used autonomy suppressive language on days 4 and 5 during the cell modeling lab and the DNA extraction activity, both of which were intended to be student-centered. He also used autonomy suppressive language on days 6 through 8 while students participated in the inheritance of traits activities. During these lessons, Mr. Hale used controlling language, often did not provide a rationale, and sought compliance, resulting in these days containing some of his least motivational talk. Day 15 was the only day for the plasmid activity. Due to a shortage of time and a great deal of student confusion, he resorted to using very controlling language, sought compliance, gave directives, and not providing any rationale. This combination of teacher talk led to that class period having low levels of autonomy-supportive talk. Mr. Hale’s lowest levels of autonomy-supportive talk came at the end of the unit during the engineering challenge. These scores were affected by the fact that most of these class meetings were devoted to small group work, and there was little whole group teacher talk. The teacher talk that did occur focused on seeking student compliance in getting the assignment finished in the given amount of time.

Mr. Hale's Students' Engagement

All four students had similar levels of engagement at the beginning of the unit (Figure 1). That trend continued until day 9, when Jack's engagement started decreasing. On days 10, 11, and 12, the differences between student engagement increased. That trend reversed on day 14, when student engagement was within a narrower range. On day 15, Jack's engagement was substantially lower than that of his groupmates. That trend continued for the rest of the unit except for day 21. All four students' engagement levels vary from day to day throughout the unit.

Jack's engagement levels fluctuated throughout the unit and stayed at or below level 4 after day 9. During the first 12 days of the unit, he became more engaged with higher levels of teacher control. It appears that when the teacher used moderate levels of autonomy support and controlling language and did not provide rationales for the activities, Jack experienced his highest engagement levels during the unit. For example, on day 5 when Mr. Hale said, "The big balloon that's where the beads go into. You should have five green and five red beads. Put the beads in the big balloon. Do that right now." Jack immediately picked up the balloon and stretched the top so Lydia could put the beads inside. Likewise, he responded well when the teacher gave students a time limit, such as on day 6, "Notice there are five questions that go along with the balloon lab. You need to answer those questions while I am doing attendance." Jack was not at his table during this announcement, but as soon Mr. Hale stopped speaking, Jack rushed back to his desk and started answering the questions. There was one autonomy-supportive talk move that Jack responded well to during the first twelve days of the unit. Whenever Mr. Hale would invite students to discuss in their groups, such as on day 7, "Okay, now take the next five minutes to answer those questions. Talk, discuss [in groups]." Jake was quick to speak with his group mates. Although he usually was not the first student to talk, he would contribute to the conversation more than once, collaborating with his group mates to understand the topic.

Jack's above-average engagement on day 13 is unexpected given Mr. Hale's moderate level of autonomy support. It is important to note that this was the first day back in class following a two-week winter break. The following days, 14-20, Mr. Hale's motivational talk did not affect Jack's engagement the same way it did at the beginning of the unit. Instead of the teacher's use of controlling language and assignments causing Jack's engagement to increase, it steadily decreased. Jack's response to Mr. Hale's motivational talk changed, for example, on day 18. Mr. Hale said, "Look at your client letter. There are some things you need to underline in there. Underline this sentence, the whole thing." Jack was not looking at his letter when this was said and waited a long time to respond to the teacher's directions. At the beginning of the unit, Jack would have responded immediately to this controlling language. Jack's response to invitations to orally participate also changed. While he would often talk to his group members about topics unrelated to class, he never contributed to conversations about the project. The unusually high engagement on day 20 was unrelated to Mr. Hale's talk. Instead, his engagement level was due to a new computer program he used to finish his project.

Lydia was moderately to highly engaged throughout the unit. Mr. Hale's level of autonomy support affected Lydia's engagement. When he used autonomy suppressive language, her engagement decreased compared to when he supported student autonomy. Lydia was particularly receptive to Mr. Hale's invitations to orally participate both at the large group and small group level. For example, on day 2, he said, "In your groups, discuss what you will need to learn to carry out the project." Lydia quickly took charge of her group and led the discussion about the science topics they needed to study before starting the project. When Mr. Hale later asked for groups to share their responses, her hand was the first one in the air, waiting to be called on to share her group's answer. Lydia did not always react to Mr. Hale's talk in the same way. Her responses to his controlling language appeared connected to the context in which the talk occurred. For example, at the beginning of class on day 17, Mr. Hale said, "Okay, ladies and gentlemen, we have a lot to do. First off, get your rings out. I also need you to get your superhero sheets out now." Lydia did not hesitate to follow the teacher's directive. However, on day 6, she had a different reaction when the directive came during a lab activity. "I need your eyes as we have got four minutes. You do not want these to mix these, so you have to tilt the cup and slowly pour from the graduated cylinder down the side of the cup." Lydia immediately sighed when he interrupted her group's work and glared in his direction. During the unit's engineering challenge, days 16 to 22, her engagement did not appear to be affected by the teacher's autonomy suppressing language. Despite his frequent reminders to complete the activity, she remained orally engaged with her group. She led the discussions which were necessary to complete the engineering project. The low engagement rating on day 21 may be unrelated to the curriculum unit or the autonomy support of Mr. Hale. At the beginning of class, she mentioned that the veterinarian was euthanizing her cat that afternoon. She then worked silently for the rest of the class period by completing her work but not orally engaging with anyone in her group.

Eddie had moderate to low engagement for most of the unit with a short period of disengagement days 10 to 13. He was often out of his seat or talking to people near him about topics that were not related to the day's topic. Due to his behavior challenges, Eddie achieved his highest engagement when Mr. Hale was using controlling language. For example, on day 1, Eddie was discussing an unrelated topic with his team when they were supposed to be working. Mr. Hale approached Eddie and said, "Worry about net neutrality later. Focus on the client letter first." Eddie immediately took charge of his group and determined that they should start reading the letter out loud. Unfortunately, he did not respond as well to informational language as observed on day 2, "You might want to make a list on your sticky notes and stick them up the big sticky note. You can use as many stickies as you want." Eddie did not engage in this activity, instead opting to write notes to his teammates on the post-its. However, he did respond well to invitations to orally participate, another type of autonomy-supportive teacher talk. His tendency to orally participate in class and the teacher's use of controlling talk to keep him on task may have led to Eddie's high engagement at the end of the unit.

Shae had consistently high engagement during the unit. She responded equally to autonomy-supportive and repressive statements. For example, "Get that packet out right now" (day 19) and "If you're done with the client letter, you could go on to the questions." (day 1) both resulted in Shae immediately following the teacher's directions. She rarely responded to Mr. Hale's invitations to speak, whether in the whole class or small group setting. She was the only person in the group who responded in any way to Mr. Hale's attempts to build interest. For example, on day 15, Mr. Hale stated, "So what we are going to look at today is we are going to look at glow in the dark cats." To which Shae expressed her excitement about the possibility of seeing such an animal. Her excitement about the unit continued throughout the engineering design project and resulted in her continued high engagement. Her unusually low engagement on day 11 did not appear to be related to the teacher's talk. Instead, she was affected by the presence of beads and chalk markers on the table. These items distracted everyone in the group and led to all members having lower engagement on that day.

Mr. Winchester's Autonomy Supportive Talk

Mr. Winchester's motivational talk supported student autonomy for most of the unit, except for days 16 and 18 (Figure 8). His talk contained the highest level of autonomy support on days 5, 9, 10, and 13. On day 5, the class discussed the modeling activity results, and Mr. Winchester provided them with multiple opportunities to participate in class orally and gave positive feedback. During lesson 4, day 9, Mr. Winchester built student interest in the stations by giving hints about the topic covered at each station. “At this station, you will learn about organisms that can reproduce by themselves. No, Steve, this isn't an option for you – you'll have to find a girl if you want to reproduce." On the first day of lesson 5, day 10, Mr. Winchester did not define the vocabulary words for the students. Instead, he invited students to share their ideas and guided the conversation until they determined each word's correct definition. On day 13, the students were completing practice Punnett Squares in small groups. There was only a small amount of whole-class discussion on that day, but when Mr. Winchester did speak, he was often using informational language. On most of the days during the unit, Mr. Winchester exhibited low levels of autonomy support. He typically encouraged students to participate through interest building and choice more than he gave directives and assignments. However, Mr. Winchester expressed autonomy suppressive talk on days 16 and 18. On day 16, he explained the engineering design project using a large amount of controlling language and suppressing student autonomy by making several assignments. On day 18, he explained the next step in the engineering project using only controlling language and continued suppressing student autonomy by giving several directives and making some assignments.

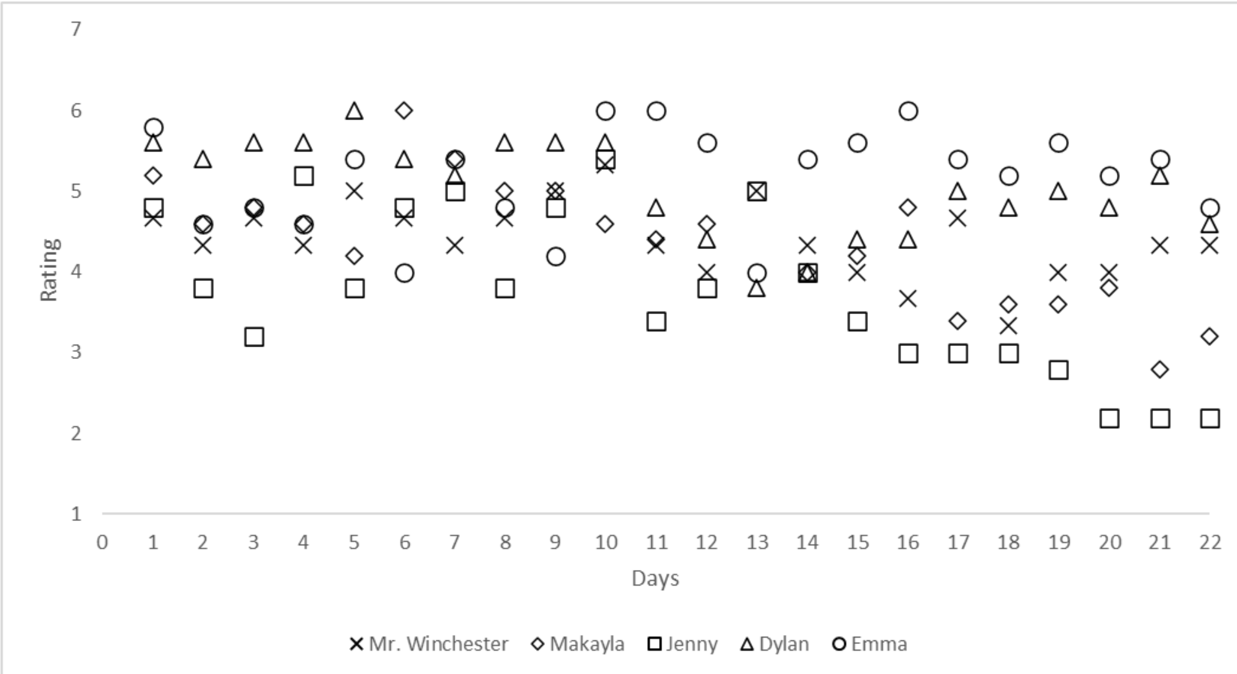

Figure 8 *Daily Autonomy Support and Engagement Ratings for Mr. Winchester and Students*

Mr. Winchester's Students' Engagement

On the unit's first day, all students were engaged in the learning activities (Figure 8). However, all of the students experienced fluctuations in their engagement levels from day to day during the unit. Jenny became disengaged on day 2 and remained disengaged throughout most of the unit. While their engagement changed slightly from day to day, Dylan and Emma maintained high engagement levels throughout the unit. On Day 17, Jenny and Makayla's engagement was much lower than that of the other two students and remained that way for the rest of the unit.

Makayla experienced moderate engagement levels for the majority of the unit, except for days 17 to 22. It appears she experienced lower engagement levels on days 5, 14, and 15 due to Mr. Winchester giving many directives and time limits for activities. As seen from this episode on day 5, these utterances caused her engagement to decrease. Mr. Winchester said:

> I want you to draw me a picture of what you see. When you do that, I need you to label these four things: cell membrane, cytoplasm, organelles, and nucleus. I need you to do that quickly, so you should be done in the next couple of minutes.

After the teacher gave this assignment, the researcher observed Makayla quickly moving papers and other materials around but not doing the requested work. On the group video, she said, "When you say things like that, it stresses me out." Her highest engagement came on day 6 following an interest-building statement by Mr. Winchester. He started the period by reviewing what the students learned from the balloon lab and attempted to intrigue them about what was coming later, "So today we're going to be doing this [breaking open the cell to see the DNA] with strawberries." Makayla became very excited and paid close attention to the teacher when he explained the lab for the day. She experienced high engagement levels on days 1, 7, 9, and 16 when Mr. Winchester used controlling language to guide her behavior when she started to disengage. Given her response to controlling language, it should follow that her engagement would be higher at the end of the unit. However, this controlling language was not directed at her behavior but rather how to complete the assignment and did not impact her engagement in the same way.

Jenny was mostly disengaged throughout the unit, with her only achieving an engagement score of four, the cutoff between engaged and disengaged, seven of the 22 days in the unit. She was often out of her seat, shouting across the room, or confused about what to do. It appears she achieved the highest engagement on the days when Mr. Winchester issued many invitations to participate in class orally or used controlling language to manage her behavior. For example, Jenny had her highest engagement rating on day 4 because Mr. Winchester invited her to participate often orally, and she got positive feedback for her first response of the day.

> Mr. Winchester: Bonus points, anybody know what DNA stands for? Jenny?
> Jenny: (pause) I know it, I know it, just give me a second.
> Mr. Winchester: I'll give you a hint. It is two words, not three.
> Jenny: I know it! Can I say it?
> Mr. Winchester: Go ahead.
> Jenny: Deoxyribonucleic acid.
> Mr. Winchester: That's exactly correct, congratulations. First-person today to know that.

This scene represents how desperate Jenny was to contribute to the class orally. She often raised her hand, but she did not have an answer when Mr. Winchester would call on her. After receiving praise from the teacher, she answered three more questions during that class period. She also responded well when Mr. Winchester used controlling language to manage her behavior, such as on days 1, 7, 9, and 13. For example, "All right, so here is what you need to do next. Shh, Jenny, put that down and be quiet; you are keeping us waiting." She immediately stopped talking and paid attention to what he was saying. She retained that level of engagement for the remainder of the class period. Unfortunately, her engagement began decreasing on day 14 and continued to do so the rest of the unit. Like Makayla, Mr. Winchester's controlling language about the assignment did not influence her engagement the same way it did when addressing her behavior. In addition, there were not many opportunities for Jenny to contribute to a whole class discussion in the last days of the unit.

Dylan experienced moderate to high engagement every day of the unit, except for days 13 and 14. It appears that when Mr. Winchester's autonomy support was high, so was Dylan's engagement. He responded well when the teacher used informational language to direct student actions, as seen on day 5, "If you want to go ahead and label your picture, you can. It doesn't have to be perfect, just a representation of what you see." Dylan was the first person at the table to start labeling his picture. He even helped Jenny get her labels in the right places. His lowest levels of engagement occurred on days 13 and 14. His engagement on day 13 did not appear related to anything the teacher said; he appeared tired and was easily distracted by the materials on the table. It is worth noting that day 13 was his first day in class after winter break. His low engagement on day 14 was due to some negative feedback he received from Mr. Winchester. The teacher had asked for volunteers to draw where the restriction enzyme would cut the plasmid. Dylan was eager for the opportunity, but after drawing the line, Mr. Winchester said, "Incorrect." and drew the correct answer. Dylan was noticeably slower in his work after that and did not volunteer to answer any of Mr. Winchester's questions later in the class period. On day 17, Dylan's engagement went up and stayed high throughout the engineering challenge.

Emma had relatively consistent engagement throughout the unit. Her highest engagement score came on day 1 in response to the explanatory rationale Mr. Winchester provided for the engineering design process. Mr. Winchester stated that,

> This is your copy of the engineering design process. So basically, what engineers use is this – the engineering design process. Since we are working as engineers during this unit, we will be using this engineering design process as a guide while we come up with the solution for our engineering problem.

Emma responded to this statement by picking up the card and looking at it carefully. No one else at her table responded in any way to the teacher's statement. During the unit, she had occasional days when her engagement was higher than usual. It appears this additional engagement was in response to Mr. Winchester's invitations to participate orally. Sometimes her verbal participation was during whole-class discussions. For example, on day 11, she answered one of the close-ended questions he asked during a whole-class discussion. At other times her verbal participation was in the small group after Mr. Winchester had given directions for verbal participation, for example, "I want you to come up with at least two ideas for your solution to the problem." She responded by leading the discussion in her small group. At times her off-topic discussions with the other people in her group caused her engagement to decrease. For example, on days 6, 9, and 13, she was distracted by the other girls in her group and spent time talking to them instead of working on the assigned task. However, she was not distracted by her groupmates during the engineering challenge and managed to maintain high engagement throughout the project.

Discussion

The present investigation used the Self Determination Theory to examine how a teacher's talk affected target group students' engagement during an integrated STEM unit. While both teachers implemented the same curriculum unit, their use of autonomy-supported talk varied throughout the unit. Mr. Hale used more autonomy suppressive than autonomy-supportive language. He often used controlling language and directives to guide students through the learning activities. Mr. Winchester, on the other hand, typically used autonomy-supportive language during the unit. He often invited students to participate in the conversation orally and provided more positive than negative feedback. Interestingly, only one of the eight students, Dylan, consistently became more engaged with increasing autonomy-supportive language levels. In contrast, Emma and Shae remained engaged throughout the unit despite changes in the teacher's motivational style. One student, Lydia, remained moderately to highly engaged throughout the unit. However, her engagement did vary due to the controlling language uttered by her teacher, Mr. Hale, when she was trying to exert her autonomy over the learning activity. Several students could only engage in the learning activities when the teachers used controlling language to manage their behavior.

The Self-determination Theory (Ryan & Deci, 2000) suggests that students need to have their psychological needs met to be engaged in the classroom. According to the theory, one of those needs, autonomy, means that students need to have some control over the learning environment. Therefore, if a teacher has a motivating style or uses language that supports autonomy, students should be more engaged in the classroom. Researchers have found this to be true in several studies, some of which used perceptions of teacher autonomy support and self-reported engagement (Furtak & Kunter, 2012; Jang et al., 2012; Tsai et al., 2008), while others rated teachers' actual autonomy support and student engagement (Struyf et al., 2019; Jang et al., 2010; Reeve et al., 2004). However, this study showed that all the students were affected by parts of the teacher's motivational talk at specific points during the integrated unit, but only one of the eight students had engagement corresponding to the teacher's motivational talk.

One explanation could be that the STEM unit was a novelty and, therefore, interesting to the students due to the disciplines' integrated nature. Hofferber and colleagues (2016) found similar findings in an experiment where 6th graders were either taught a lesson with live animals or videos on a computer. The students in the animal treatment did not respond to the teacher's autonomy-supportive teaching. The researchers determined that it was because the students found the use of live animals novel and thus interesting. Therefore, the lesson was responsible for the students' engagement, not the actions of the teacher. Alternatively, students could have been motivated to learn before the unit began and did not need teacher support to engage with the unit. Either of those explanations could explain why Shae, Emma, and for most of the unit, Lydia experienced high engagement, which seemed to be unaffected by the teacher's motivational talk.

Eddie also displayed high engagement, which did not respond to the teacher's autonomy-supportive talk during the second half of the unit. It seems probable that he was not interested in the lessons at the beginning of the unit but became interested in the second half of the unit due to its novelty or hands-on nature. Alternatively, the controlling language that Mr. Hale used to keep Eddie on task may have led to Eddie being unable or unwilling to control his behavior. Therefore, the teacher's controlling language could have ultimately led to Eddie's disengagement whenever left to his own devices (Haerens et al., 2016). This could explain his engagement levels at the beginning of the unit, while the novelty element explains why he had a higher engagement at the end of the unit.

Makayla and Jack were both moderately engaged at the beginning of the unit and experienced significantly lower engagement after returning from the holiday break. There are several reasons why these students could have experienced lower engagement after the break. Gottfried (1990) found that outside events could interfere with young children's ability to engage in school activities. Thus, it is possible that something occurred during the holiday break that prevented these students from engaging in the engineering activity. Another possibility is that the students' peers kept them from engaging in the activity. Kiefer and colleagues (2015) found that when peers help with academic tasks, they can better engage in the lesson. It stands to reason that if peers can help students engage, they can also keep students from engaging in the lesson. The researcher often observed Makayla talking to Jenny instead of working on the engineering project with the group. If Makayla was not intrinsically motivated to complete the engineering challenge, it is possible that the invitation to talk from Jenny was more potent than the teacher's autonomy-supportive talk. Jack was eager to respond to invitations to orally participate in class at the beginning of the unit. However, at the end of the unit, he did not take part in this activity. That might be due to how his peers reacted to his attempts to orally interact in the small group at the beginning of the unit. Every time he attempted to add to the conversation, his peers negatively evaluated his answers. It is possible he did not participate in the engineering activity at the end of the unit because he did not want his peers to reject his ideas again. Lastly, it is possible they just were not interested in the activity, and their disinterest led to the disengagement the researcher observed during this study.

Jenny's engagement did not respond to most of the teacher's autonomy-supportive talk. Her lack of response makes it likely that she was not interested in the curriculum unit. This interpretation aligns with what Durik and Harackiewicz (2007) found during a study with math students. The teacher attempted to motivate students to learn about a math technique by offering them a rationale. The researcher determined that the students who were not affected by the teacher's motivational style lacked interest in the activity. Jenny's behavior during the entire unit agrees with this finding. She was disengaged throughout the unit and often had to ask someone else what they were supposed to be doing because she was not listening.

It was notable that the students did not respond to either of the teachers when they used the autonomy-supportive device of providing a rationale for the activities, excluding Emma's response to the engineering design plan on day 1. Providing a rationale supports a student's autonomy by giving them a reason the task is valuable to them and worth pursuing. Sansone and colleagues (1999) found that college students were willing to continue the tiresome task of coping letters if researchers told them that they helped create jobs by completing the task. Both Mr. Winchester and Mr. Hale provided rationales for many activities throughout the unit, but none responded. Steingut and colleagues (2017) did a meta-analysis of 23 experimental studies that focused on using rationale and found that students did not respond to this device if it had a controlling tone. That was true of all of the rationales uttered by both teachers during the study. The rationales were controlling because they conveyed how students could use the information for a specific task or assessment device within the unit. The teachers did not help students understand how the information was helpful to them outside of the classroom.

None of the students in this study responded to any of the teachers' choices during the unit. Many researchers agree that choice is an essential provision of the Self Determination Theory as it directly allows students to take an active role in the learning process (Jang et al., 2016; Patall et al., 2010). While this device enables students to take control of their learning, there have been mixed results regarding this device's effectiveness in causing students to be engaged. Patall and colleagues (2010) found that college students not only had their engagement increased by the provision of choice but even connected it to increases in achievement. Alternatively, Wallace and Sung (2017) found no change in engagement when teachers gave middle school students choices. Katz and Assor (2007) conducted a literature review of studies that offered choices to students. They found that there are two types of choices; one that allows a student to express their autonomy and one that enables the student to pick between a certain number of options. The kind of choice given could be why the choices offered in this study did not affect the students. None of the choices offered during the unit allowed students to take control of their learning. For example, the teachers provided students the choice of reading letters as a group or individually and to decide which group member would be representing their position during the debate. Unsurprisingly, the student's engagement did not respond to this type of choice. This finding suggests that curriculum developers need to design units that contain choices that allow students to take control of the learning.

In conclusion, autonomy-supportive teaching is not the only factor that affected student engagement in this study. Since only one of the student’s engagement corresponded to the teacher's autonomy-supportive talk, other factors, including the nature of the activity, peer interactions, a lack of interest, and life outside of school, probably affected student engagement. However, some types of autonomy-supportive talk affected most student's engagement during the unit. For example, teachers providing opportunities for students to orally participate in the lesson increased student engagement. Like Aranda and colleagues (2018), one of the teachers in this study used more open-ended questions as invitations to participate in the conversation, while the other mainly used close-ended questions. Both studies investigated the teacher talk during an integrated STEM unit. Aranda and colleagues (2018) found that the type of questioning used did not affect student achievement at the end of the unit. As long as students were allowed to participate in the conversation, they could develop an understanding of the content. Similarly, in this study, the questioning strategy did not matter. As long as students were allowed to participate in the unit orally, their engagement increased. While Aranda and colleagues (2018) study focused on the discipline-specific talk during the integrated unit and this study focused on the autonomy-supportive teacher talk together, they allow us to understand the importance of orally participating in an integrated unit. Most of the teacher talk studies during integrated units have focused on how the teachers talk about the discipline. Many of those studies have investigated how teachers talk about engineering during an integrated unit (Guzey & Ring-Whalen, 2018; Guzey et al., 2019; Johnston et al., 2019) and allow us to understand how teachers incorporate new disciplines into their curriculum through their talk. This study adds to the literature by exploring a different dimension of teacher talk – autonomy-supportive talk and how it affects student engagement during integrated STEM units.

Limitations

This study had a few limitations. First, the study used observational data, which offers an alternative to the usual self-report studies of student engagement. This data source allowed for a closer inspection of how aspects of autonomy-supportive or suppressing talk affected students. However, there was no additional data source such as interviews to support these findings. Second, the sample size was small, although it was appropriate for the methodology. While there were only eight students in this study, the small sample size allowed for a more detailed analysis, which would have been impossible if the groups had been more extensive. Third, it is possible that the video camera and researcher in the room affected the behavior of both the teachers and the students. However, the participants did not know the purpose of the project, so it is unlikely that they changed their behavior in a way that affected this study. Lastly, this research took place during a very specialized integrated STEM unit. Due to the nature of this unit, it is possible that some of the behaviors seen from both students and teachers were different than what would be observed during a single discipline unit.

Implications and Suggestions for Future Research

This study offers several educational implications. First, the study has made it apparent that every student does not respond the same way to the teacher's autonomy support. In the current era of high-stakes testing, schools must provide evidence that every student learned the content during the school year. Teachers need to be observant of every student and adjust their autonomy support to meet each child's needs. Second, teachers need to have the autonomy to change the curriculum to meet their students' needs. The teachers in this study had to implement the unit as written. While they made small adjustments to the unit to accommodate their students' needs or interests, for the fidelity of implementation purposes they could not make large scale changes. Third, this study provided evidence that small group dynamics can affect student engagement. Therefore, teachers need to take into consideration potential social interactions before assigning students to groups. Ideally, a student group should include individuals that have different skills and that are socially compatible. Also, teachers should explicitly explain their expectations for student collaborations before the project begins. Students should understand that everyone in the group must contribute to the project and that all ideas need to be considered by the group before deciding on a solution.

This study prompts future work to shed light on the student engagement and teacher talk in integrated STEM curriculum units. Future studies could include more classrooms and target groups from diverse student populations. Such research could help us better understand if race, ethnicity, gender, and socioeconomic status affect how students respond to a teacher's autonomy-supportive talk during an integrated curriculum unit. A study with a larger number of student participants might include observational data, interviews, and self-report data from the teachers and the students. Such a large-scale study would allow for a more in-depth understanding of the teacher's autonomy support and student reactions to that teacher talk. It would also allow for the triangulation of the data, which would add additional validity to the study's findings. As the use of integrated STEM curriculum units in K-12 science classrooms increases, it is evident that teacher talk and practices that give students autonomy should be the subject of future investigations.

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STUDY 3: HOW DO MIDDLE SCHOOL TEACHERS TALK ABOUT ENGINEERING DURING AN INTEGRATED STEM UNIT?

Abstract

There has been growing emphasis on integrating engineering concepts into science curriculum and instruction. However, most science teachers do not know how to teach engineering effectively. Professional development programs play a critical role in teachers' learning and teaching practices. In this study, two teachers participated in a professional development program focused on integrated engineering and science instruction and implemented a STEM unit presented at the professional development program. Using the Social Constructivism Theory, this multiple case study examined what engineering concepts teachers talk about during an integrated STEM unit and what talk moves they use when speaking about those concepts. This study used video data collected during integrated STEM units. Transcripts of videotaped instruction were analyzed using A Framework for Quality K-12 Engineering Education, and the talk moves framework. Results showed that both teachers closely followed the curriculum units; however, there were differences in the engineering concepts taught and the talk moves used to discuss those engineering concepts. Further, only one of the teachers incorporated talk about engineering in their science lessons. These findings suggest that professional development programs should provide teachers with a variety of opportunities to engage in engineering discourse, and curriculum designers explicitly incorporate engineering concepts and practices into the science curriculum.

Key words: engineering integration, talk moves, STEM curriculum, teacher talk, integrated instruction

Introduction

Within the last decade, educational reform documents from multiple countries have suggested that science teachers integrate engineering into their curriculum (Australian Curriculum, and Assessment Authority, 2016; NGSS Lead States, 2013). Governmental agencies support this call for integrating the disciplines because studies have shown that if students experience engineering concepts and design projects, they become interested in pursuing engineering as a career (Caprile et al., 2015; Education Council, 2015; President's Council of Advisors on Science and Technology, 2010; The Royal Society Science Policy Centre, 2014). It is essential to develop student interest in STEM to stay competitive in the global economy. Furthermore, the problems we face today require multi-disciplinary approaches (U.S. National Science & Technology Council, 2018). Therefore, there is a sense of urgency to integrate engineering into science curriculum and instruction to help students engage in interdisciplinary learning and practices.

While science and engineering are similar in many ways, they are separate disciplines. Although a teacher can instruct students in science, it does not mean they can effectively teach engineering. Researchers have determined that most science teachers are unprepared to integrate engineering into their science curriculum (Trygstad, 2020). Learning to teach engineering is about learning the discourse and pedagogies of a new discipline for many teachers (Crismond & Adams, 2012). Teachers must develop new understandings of engineering constructs such as learning from failure and systems thinking. In a study of elementary teachers trying to integrate engineering into the curriculum, Lottero-Perdue and Parry (2017) found that the teachers struggled because of how they perceived learning from failure. They understood failure to be an adverse event and were reluctant to expose their young students to the concept of design failure. The researchers found that due to their previous knowledge about failure, some of the teachers were resistant to continuing with the implementation of engineering units in their classrooms. Other researchers have found that teachers are resistant to implementing engineering due to a lack of time and standardized testing constraints (Shernoff et al., 2017). Although many teachers are initially resistant to integrating engineering into their science curriculum, there are methods to overcome this challenge. If teachers are provided instruction on teaching engineering through professional development workshops, they gain confidence, allowing them to teach the discipline (Thibaut et al., 2018).

This study investigates how veteran teachers teach engineering by examining teacher talk about engineering during an integrated STEM unit. Teachers use talk as a tool to teach students about the content and to scaffold learning (Howe et al., 2019). Quality teacher talk allows teachers to guide students' knowledge creation (Alexander, 2004; Gillies, 2013; Mercer & Wegerif, 2004; Michaels et al., 2008) and use of procedures (LeBlanc et al., 2017; Lee & Kinzie, 2012; Mathis et al., 2017). It is crucial to investigate what engineering concepts teachers are talking about, and the talk moves used to integrate engineering in the science classroom to design quality professional development programs and curriculum materials. The following questions guided the study:

- What engineering concepts do teachers talk about during an integrated STEM unit?
- What talk moves do they use when speaking about those concepts?

Theoretical Framework

The sociocultural learning perspective frames this study (Cobb, 1994; Duschl, 2008; Vygotsky, 1962). This perspective permits researchers to investigate the social components of education. When this perspective guides a classroom, the teacher and students form a community of practice that collaborates to co-create a body of knowledge (Cobb, 1994). Students learn the concepts by discussing them with peers and interacting with the teacher during large and small group discussions. Teachers guide large group discussions by requesting students provide evidence for their claims and encouraging students to challenge their peers' claims (Duschl, 2008). There is also a cultural component to classrooms guided by this theory. In science classes, teachers focus on the scientific culture and teach students about scientific knowledge creation as well as allow students to participate in the authentic practices of the discipline (Duschl, 2008)

Several researchers have framed studies of integrated STEM education under the sociocultural learning perspective. These researchers have investigated the outcomes of communities of practice that complete engineering projects at the elementary (Cunningham et al., 2020; Wieselmann et al., 2019), middle school (Guzey & Aranda, 2017) and high school level (Barton et al., 2017). Wiselmann and colleagues (2019) investigated the social interactions in small groups while students were building an electromagnet for an arcade game. They found that the boys in the group were able to control the way the girls could participate in the conversation and activity. Other researchers have found that working in small groups can become a community of practice where every student has a voice and they work together to overcome challenges. Barton and colleagues (2017) found that groups of high school students were able to form cohesive communities of practice when they rallied around a problem that was plaguing their community. Still other researchers have found that the teacher can be an influential presence in small group conversations. Guzey and Aranda (2017) investigated how small group conversations affected student design decisions. They discovered that if the teacher guided a group discussion the group was likely to include scientific information in their decision process unlike other groups which focused primarily on cost. Lastly, researchers have found that participating in a community of practice while completing an engineering challenge can increase student learning. For example, Cunningham and colleagues (2020) compared engineering projects and alternative learning activities to determine which was more effective at increasing student learning. They found when students were allowed to work in small groups on an authentic engineering task they learned more than students who participated in traditional learning activities.

Engineering Integration

Moore and colleagues (2014) developed A Framework for Quality K-12 Engineering Education which outlined nine major engineering components or indicators. The researchers created this framework by conducting a thorough review of the literature to identify aspects of engineering. They designed the framework to align with the social constructivism theory (Vygotsky, 1978). The first component, *Processes of Design*, which is at the center of engineering, is broken down into three subcomponents: Problem and Background, Plan and Implement, and Test and Evaluate. Every engineering project is rooted in a problem that needs a solution. According to the researchers, during K-12 engineering units, teachers must allow students to fully understand the problem, including identifying the client, constraints, and criteria for the project. It is essential to guide students through the project's problem-scoping portion, or students will move directly to the design phase (Hsu et al., 2011). Previous research shows that a student's desire to skip the problem scoping portion is related to age. The younger the student, the more emphatic the teacher must be about including this engineering component in their curriculum (Mentzer et al., 2015). Therefore, it is essential to keep returning to the problem throughout the unit if students are young or novice designers. Researchers have found that reading memos from the client or leading a class discussion about the problem throughout the unit helps students focus on what they are trying to accomplish (Johnston et al., 2019; McFadden & Roehrig, 2019). Particular attention must be given to the project's constraints and criteria during those discussions because students often struggle with the difference between those project elements (Purzer, 2017). Some teachers have successfully helped students differentiate between those concepts by using everyday language to describe them instead of using technical engineering terminology (Aranda et al., 2020). These studies demonstrate the challenges teachers must overcome while students are exploring an engineering problem.

After students have explored the problem, they need to create a plan to design a prototype. Students should work in groups during this part of the engineering project to develop several possible solutions to the challenge. By having multiple solutions, students can evaluate their ideas' pros and cons and pick the one that best fits the project's constraints and criteria (Crismond & Adams, 2012; Moore et al., 2014). However, researchers have found that students may become invested in their first idea and have difficulty coming up with alternatives (Mentzer et al., 2015). Teachers help students avoid becoming fixated on the first design in a variety of ways. Some teachers talked their students through the planning process, urging them to spend time brainstorming and coming up with alternative plans (Aranda et al., 2020; Johnston et al., 2019). Other teachers gave students access to the materials they would be using to create the prototype and allowed them to manipulate the materials to come up with several possibilities for their final design (McFadden & Roehrig, 2019). As discussed in these studies, teachers must encourage students to create multiple plans so they can select the best solution for the engineering challenge.

After students design a prototype, teachers should guide them through the testing process. Students then use the test results to improve the design (Crismond & Adams, 2012; Moore et al., 2014). There are a variety of integrated STEM projects represented in the literature, and there are many ways these engineering projects were tested and evaluated by students. Sometimes students cannot physically test the engineering projects. Consequently, they must determine their design's effectiveness by evaluating the prototype's pros and cons. For example, Aranda and colleagues (2018) investigated the teacher talk during a unit that integrated science and engineering. At the end of the unit, students had to design a process to prevent the cross-contamination of pollen from genetically modified varieties. Since it was impossible to test such process-oriented designs, the teachers used a rubric to determine the plan's effectiveness, and students evaluated the pros and cons of their design based on that feedback. In other cases, students can test the projects, which allows them to use data to evaluate their prototype's effectiveness. For example, in an integrated meteorology and engineering unit, students designed model houses. These houses were placed in a wind tunnel to mimic the effects of a tornado. Afterward, instructors encouraged students to use the information they learned from the test to redesign their structure (Barrett et al., 2014). In both cases, the information students gained through the evaluation process was used to guide the prototype's redesign.

The second component of the framework indicates that engineers *Apply Science, Engineering, and Mathematics* knowledge to solve problems and create products. Integrated STEM units model this practice by requiring students to apply the math or science they learned to the engineering challenge (Bryan & Guzey, 2020; Moore et al., 2014). Researchers have created integrated units that apply a variety of math and science topics to engineering projects. Some examples include applying math and physics to the creation of pinhole cameras (Valtorta & Berland, 2015), applying physics to the creation of earthquake-resistant buildings (English et al., 2017), and applying Earth science concepts to the creation of a mineral sorting machine (McFadden & Roehrig, 2019). Although the projects intend students to use their content knowledge to create the engineering prototype, that does not always happen. Guzey and colleagues (2019) found that teachers sometimes add the engineering project to the end of a unit as an extra activity. While they discuss how the project is related to the unit, they do not require students to use science content knowledge in developing a solution. Therefore, teachers should design and implement STEM units that require students to use scientific or mathematical concepts through design justifications. Also, teachers must help students understand how their content knowledge applies to the project. For example, Valtorta and Berland (2015) found that the teacher had to explicitly connect physics and math concepts to the design of a pinhole camera for students to apply that knowledge to their solution. These studies found that a teacher must be explicit when connecting content to the engineering challenge for students to use this knowledge to develop a prototype.

The third component of the framework, *Engineering Thinking*, requires students to find solutions to problems, learn from failure, and identify aspects of their project which are unsafe or unreliable. To use the types of thinking that are characteristic of an engineer, students must be able to identify information that is necessary for a project. Engineering thinking also involves developing creative solutions to problems that arise during the design process (Crismond & Adams, 2012; National Academies of Engineering [NAE], 2009; Moore et al., 2014). Researchers have found that for students to express their creativity, teachers have to allow them to be in control of the design process (McFadden & Roehrig, 2019). While students require autonomy to express their creativity while designing, they may need teacher guidance to persevere through design failures. Lottero-Perdue & Parry (2017) found that students became discouraged if their design did not do well during testing. If a teacher helped students recognize their design's positive attributes, they were more willing to redesign the prototype parts that failed during testing. These studies demonstrate that engineering thinking is a component that sometimes requires a teacher's guidance and, other times, is self-regulated by the students.

The fourth component, *Conceptions of Engineers and Engineering*, involves understanding engineering and the jobs engineers do. One of the main arguments for integrating engineering into the science curriculum is increasing student interest in pursuing a career in STEM (Bybee, 2013). As part of an integrated unit, teachers should allow students to explore the profession of engineering. Students need to understand how to become an engineer and what tasks are commonly part of an engineering job (Moore et al., 2014). It is essential to discuss the profession of engineering with students because studies have found that most have misconceptions about who can be an engineer and what engineers do for a living (Copobianco, 2011; Knight & Cunningham, 2004). The literature shows that many teachers respond to this dilemma by referring to their students as engineers during STEM units. They believe students will understand what engineers do by participating in engineering activities (Johnston et al., 2019; McFadden & Roehrig, 2019; Tank et al., 2018). Alternatively, it may be that the teachers in these studies had not developed the skills necessary for talking about engineering. Guzey and colleagues (2019) found that it took three years for the teacher to develop the confidence to discuss engineering and engineers' jobs with his students effectively. One goal of integrated STEM units is that students may become interested in a STEM career (Bybee, 2013). To accomplish this goal, teachers must talk about the training an engineer needs and the skills they must develop to work in the engineering field.

The next component of the framework is *Engineering Tools* and focuses on tools, techniques, and processes used by engineers (Moore et al., 2014). Engineers use specific tools such as hammers or software packages to make their work more manageable. They also use specific techniques, which "are defined as step-by-step procedures for specific tasks (example: DNA isolation)" (Moore et al., 2014, pp. 5-6). Lastly, engineers routinely use some processes in their work. "Processes are defined as a series of actions or steps taken to achieve a particular end (examples: manufacturing, and production . . .)" (Moore et al., 2014, p. 6). During an integrated STEM unit, teachers should allow students to use some of these tools, techniques, or processes to get an accurate idea of what it is to practice engineering. Researchers have found a range of success when teachers ask students to use standard engineering tools. English and colleagues (2017) found that students had no difficulty using schematic drawings to create earthquake-resistant buildings. However, McFadden and Roehrig (2019) found that students struggled to use similar drawings to create a mineral sifting device. The difference in success may be due to the teacher's expertise with the tool or procedure. For example, Goldstein and colleagues (2018) found that middle schoolers could use the CAD design software when highly skilled individuals did the training. These studies make it clear that teachers need to be adequately trained to guide students as they use engineering tools.

The sixth component, *Issues, Solutions, and Impacts*, is composed of the social issues surrounding engineering projects and the impacts of those projects on the local and global economy. Engineering projects often affect more people than just the client. Teachers should ensure that students realize that engineering projects have local and sometimes global impacts. As part of the integrated unit, students should investigate the societal issues associated with the project (Moore et al., 2014; NAE, 2009). Unfortunately, teachers rarely include these topics in integrated units (e.g., Barrett et al., 2014; English et al., 2017). When conversations around these topics do occur, students are typically the initiators. Such as when a student brought up the issue of false advertising regarding GMO crops during an integrated genetics and engineering unit (Aranda et al., 2020). Likewise, the students in an afterschool program frequently discussed the societal issues associated with their projects while working in small groups with their peers (Wilson-Lopez et al., 2016). As evidenced from the studies above, teachers need to emphasize the issues surrounding engineering projects during the integrated STEM units.

The next component of the framework, *Ethics*, requires students to learn about how ethics affects the work of engineers. Teachers should include discussions about the ethical considerations which govern engineers' activities (Moore et al., 2014; NAE, 2009). A separate code of ethics governs each branch of engineering because they are specific to an engineer's type of work. Most of these codes are lists of things engineers should not do, such as discussing product plans with those not associated with the project (Harris et al., 2013). Teachers do not often address engineering ethics during integrated units (e.g., English et al., 2017; McFadden & Roehrig, 2019). However, they often talk to their students about the materials they can use in creating a prototype. They could introduce the concept of ethics at this point in the unit by discussing how it is not acceptable for an engineer to substitute less expensive materials for the ones included in the design plans.

The next component focuses on *Teamwork*. Integrated curriculum units should require students to work on a project in engineering teams (Bryan & Guzey, 2020; Moore et al., 2014). Teamwork is one of the most common elements of integrated STEM units (English et al., 2017; Johnston et al., 2019; McFadden & Roehrig, 2019; Wilson-Lopez et al., 2016). However, a teacher needs to tell students how to work in an engineering team for them to engage in this element of the engineering project (English et al., 2017; Johnston et al., 2019). Without instructions about working in a team, one or two students will likely take over the project in small engineering design teams (McFadden & Roehrig, 2019). These studies demonstrate the importance teachers place on teamwork within the STEM unit, but educators need to provide instructions before allowing students to work cooperatively.

The last component of the framework is *Communication related to Engineering*. Integrated STEM units should challenge students to communicate their ideas in the same manner that engineers communicate (Bryan & Guzey, 2020). The communication should include technical writing, formal presentations to the client, and presentations that use language that is understandable to everyone (Moore et al., 2014; NAE, 2009). Activities that encourage good communication should not be limited to integrated STEM units. Experts have determined that students need to communicate well in all aspects of science and engineering (NRC, 2012). The types of communication vary from one integrated unit to the next. Some units require basic communication with students creating and presenting posters (Guzey et al., 2016), while others require PowerPoint presentations in front of the whole class (Aranda et al., 2018; Johnston et al., 2019) or the entire school (Goldstein et al., 2018).

Teacher Talk

Teachers give directions, ask questions, lecture, manage behavior, and develop relationships with their students through their talk. Since teachers use their talk for many purposes, researchers have studied classroom talk for several decades (Mercer & Dawes, 2014). Some of that research has been carried out in science classrooms where they have investigated various types of teacher talk (Scott, 1998), including how teachers talk about the nature of science (Ryder & Leach, 2008; Zeidler & Lederman, 1989), inquiry (LeBlanc et al., 2017; Lee & Kinzie, 2012), and argumentation (Mathis et al., 2017). Research studies have also focused on the mundane such as how teachers use their talk to lead discussions (Pimentel & McNeill, 2013) and evaluate understanding (Smart & Marshall, 2013). Also, researchers have investigated how teachers use their talk to build content knowledge about disciplines such as biology (LeBlanc et al., 2017; Thörne & Gericke, 2014), chemistry (Bleicher et al., 2003), and physics (Jurik et al., 2014). Lastly, researchers investigated how a science teacher's talk can help students develop a sense of science identity (Moje, 1995). All these studies show that a science teacher's talk is a powerful tool for helping students understand science, develop skills and identities. Therefore, it is essential to investigate how science teachers use their talk to help students understand science and engineering in the context of integrated STEM education.

There are many ways for a teacher to present information to their students verbally. Researchers often refer to these types of teacher talk as talk moves. One of the most common approaches is presenting information through lectures. A lecture requires very little student input and allows the teacher to control the knowledge shared during a lesson (Edwards & Mercer, 2013). While this can be an effective teaching technique, many researchers have found that it is more productive to guide students in a discussion rather than provide them with information (Alexander, 2004; Gillies, 2013; Mercer & Wegerif, 2004; Michaels et al., 2008). Another talk move commonly used in classrooms is questioning. Teachers frequently ask questions in the science classroom to check for understanding (Chin, 2007) and to probe student thinking during and after inquiry activities (Windschitl et al., 2012). Some questions are close-ended because the teacher is expecting a specific response. Teachers typically use these questions as part of a series of talk moves referred to as IRE (Initiation, Reply, Evaluation). The teacher asks a question, a student responds, and the teacher evaluates the answer (Cazden, 2001). Alternatively, open-ended questions do not typically have an expected response and, if used in a series, can guide a class discussion toward the desired knowledge (Alexander, 2004). During class discussions, teachers sometimes ask students to provide reasoning to support an answer or elaborate on an answer. Several researchers have determined that if teachers use these effective talk moves consistently, then students develop a deeper understanding of the content (Michaels et al., 2008; O'Connor et al., 2015; Wilkinson et al., 2017). Finally, teachers sometimes make connections between content topics or ask the students to make those connections (Alexander, 2018). Making connections is particularly important during integrated engineering units when the goal is for students to use their content knowledge to solve an engineering challenge.

There is a small body of research on the teacher talk that occurs during an integrated STEM unit. Much of the existing research focuses on understanding how teachers communicate during whole-class instruction. For example, Guzey and Ring-Whalen (2018) investigated how a teacher talked about science during an engineering-focused unit. Alternatively, Guzey and colleagues (2019) focused on how a science teacher developed his engineering teacher talk over several years. Other researchers have conducted in-depth investigations of one aspect of a teacher's talk during a STEM unit. For example, Aranda and colleagues (2018) took an in-depth look at the talk moves teachers used during the science and engineering portions of an integrated unit and the effect of a teacher's talk style on student learning. They found that one teacher had a dialogic style while the other was controlling. The student learning gains were slightly higher in the classroom where dialogic instruction occurred. Alternatively, Johnston and colleagues (2019) did an in-depth investigation into the purpose of a teacher's engineering talk within an integrated unit. This study expands on the latter two studies' research by investigating the talk moves teachers use to incorporate the Framework for Quality K-12 Engineering Education components into an integrated unit.

Methods

This study used a multiple case study design (Yin, 2018). I chose this method because it allowed for the holistic investigation of a "how" question. In addition, a multiple case study approach also enabled me to focus on the teacher talk during the bounded confines of the integrated STEM unit. This method permits in-depth analysis of the data, which leads to a deeper understanding of what is occurring in each case (Yin, 2018). Lastly, researchers often use this method in teacher talk studies since it permits them to focus on the talk and its effect on students (e.g., Harris et al., 2012; Tofel-Grehl et al., 2017).

Participants and Setting

I purposefully selected two participants for this study from a pool of participants from two similar teacher professional development projects that focused on engineering integration in science curriculum and instruction. These teachers were both veteran educators who first experienced engineering education through the professional development workshop. The first participant, Mrs. Anderson, taught 8th-grade science at an urban middle school. At the time of the data collection, the school had 1,074 students enrolled in seventh and eighth grade, with 51% students of color and 72% were economically disadvantaged. The second participant, Mrs. Evans, taught 8th-grade science at a suburban middle school. At the time of data collection, 460 students enrolled in sixth through eighth grade, with 22% students of color and 41% were economically disadvantaged. Both schools are in the same community, approximately 11 miles apart.

Both professional development projects focused on the integration of genetics and engineering in middle school classrooms. These projects required participants to attend a two-week summer professional development workshop to learn the pedagogies necessary for implementing the integrated units in their classrooms. The two workshops' structure was similar, with participants introduced to the engineering design process during the first week of the workshop. During the second week of the workshop, teachers engaged in a genetics and engineering focused integrated STEM unit developed by the researchers. Throughout the second week of the workshops, facilitators emphasized the importance of continually connecting the engineering project to the unit's science content. The participants in both workshops received a poster showing the engineering design process that aligns with the Framework for Quality K-12 Engineering Education. Facilitators instructed them to refer to it often while teaching the unit. The workshops' facilitators guided participants through some of the science activities and the engineering project in the units.

Data Collection and Analysis

The data for this study were video recordings from every day during the two units and the two curriculum units. Researchers recorded the classes from a video camera located at the back of the classroom and pointed toward the teacher. Each participant wore a microphone to ensure the recording of all teacher utterances. To compare the teacher talk in two different units, I congregated the lessons into three categories: Introduction to the Engineering Challenge, Science Lessons, and Engineering Challenge. The Introduction to the engineering challenge was the first lesson in both units, and the engineering challenge was the last lesson in both units. The unit Mrs. Anderson taught (Table 13) contained five science content lessons, while the unit Mrs. Evans taught (Table 2) contained three science content lessons. Despite the difference in the number of lessons, the two teachers spent almost the same number of days on the unit. Mrs. Anderson spent 23 days while Mrs. Evans spent 24 days.

Table 13 *Description of the Two Integrated STEM Units*

Lessons	Activities in Mrs. Anderson's class	Days spent	Activities in Mrs. Evans' class	Days spent
Introduction to the Engineering Challenge	• Discussion about engineers and engineering • Read client letter • Discuss the engineering problem and background • Ethics of GMOs reading • Teacher provides guidance on teamwork • Discuss issues associated with GMOs • Create T-chart of content knowledge students need to know • Introduce Engineering Design Process (EDP)	5	• Review the Engineering design process (EDP) • Read the client letter • Discuss the problem and background • Research engineers and engineering • Discussion about engineering	4
Science Lessons	• Beginning of each lesson connect content knowledge to engineering project • Beginning of each lesson students identify where they are in the EDP • Build a cell model • Extract DNA • Identifying traits activity • Discussion on inherited vs acquired traits • Reproduction stations • Punnett square activity • Practice genetics problems • Gene splicing activity	12	• Beginning of each lesson connect content knowledge from previous day to engineering challenge • Beginning of each lesson students identify where they are in the EDP • Discussion about what students need to know about content knowledge for the engineering challenge • Introduction to genetics discussion	10

Table 13 *continued*

	• End of each lesson revisit T-chart and content knowledge needed for engineering project		• Genetics practice problems • Corn genetics activity • Biological engineering stations • Discussion to summarize biological engineering • Corn jigsaw research •	
Engineering project	• Review the engineering problem and background • Team planning • Design a prototype • Test prototype and evaluate results	6	• Using content knowledge to select parental genetics • Plan and design a breeding program for corn • Test and evaluate the program	10

To determine the components of engineering included in the teacher talk, I first transcribed all videos verbatim. Researchers coded the whole class discussion portions of the transcripts with a modified version of the coding scheme found in Johnston and colleagues (2019). The unit size was a sentence, and each sentence could receive as many codes as were appropriate for that statement. To become familiar with the coding scheme, two researchers coded a sample of the data. After coding a sample of data, the researchers met and discussed discrepancies in the coding and revised the code definitions. The process of separately coding samples of data, meeting to compare codes, and making slight changes to the code definitions continued until they reached an agreement of 93%. After that point, the author coded all transcripts independently. While refining the coding scheme, researchers eliminated engineering thinking and ethics because no utterances matched those codes. Although students engaged in engineering thinking, the teachers did not make explicit comments about it. The final codebook for this portion of the study had eight codes related to engineering (Table 14). I reduced the data set by calculating each code's frequency for the categories of Introduction to the Engineering Challenge, Science Lessons, and Engineering Challenge.

Table 14 *Engineering Talk Coding Scheme*

Code	Definition	Examples
Problem and Background (PB)	The teacher was helping students understand the client's problem. Included talking about the criteria, constraints, and the client.	A constraint is something that is going to limit how you solve the problem.
Plan and Design (PD)	The teacher was guiding students through the planning and design process.	Think about the pros and cons of your decisions.
Test and Evaluate (TE)	The teacher was talking about the testing process or how students should evaluate their results.	Once you have chosen the parent's genotype, go ahead and do the Punnett Square.
Content knowledge (CE)	The teacher was presenting or applying science content to the engineering challenge.	How does corn pollen move around?
Engineers and Engineering (EE)	The teacher was talking about the profession of engineering.	What does an engineer do?
Issues, solutions, and impacts (ISI)	The teacher was talking about societal issues associated with the engineering challenge.	What about poor countries who get food from rich countries. Do you think the people care if the food is GMO?
Engineering Tools, techniques, and processes	The teacher was talking about tools, techniques, or processes which were necessary for an engineer to create a product.	Today you are going to following the directions on that sheet to take out or extract DNA from a strawberry.
Teamwork	The teacher was talking about how students should combine their efforts to create a finished product.	Each of you can research one of those items and then share your knowledge with the rest of your team.
Communication	The teacher was talking about how to present their solution to an audience.	Be sure to tell us how your design meets the constraints and criteria of the project.

I coded the sentences identified above with a slightly modified version of the coding scheme found in Howe and colleagues (2019) (Table 15). This coding scheme allowed researchers to determine the extent to which each participant invited students to participate in the conversation. It was possible for each sentence to be coded with multiple codes. Two researchers coded a portion of the data separately and then met to discuss discrepancies in the sentences' codes. During that discussion, the researchers made slight changes to the code definitions to reflect the current study's focus. After our discussion, we coded another sample of the data independently then met again to compare codes and refine definitions as necessary. This process of coding independently then meeting to compare codes and refine definitions continued until we reached an agreement 89% of the time. After that point, the author coded the remaining data.

Table 15 *Productive Academic Talk Coding Scheme*

Code	Definition	Example
Provides information	The teacher shares information with students through lectures.	A constraint is a limitation, it limits what you can include in your design.
Invite elaboration	Invites a student to elaborate on what they said	You said engineers re do stuff, what did you mean by that?
Teacher elaboration	The teacher clarifies something a student said.	Did you mean that money will limit the materials you can use?
Inviting reasoning	Invites a student to explain a statement either made by themselves or on a written document	What does it mean when it says design a test plot?
Teacher reasoning	The teacher explains a statement make by themselves or others	When I said a barrier, I meant something physical – something you could touch.
Invites connecting	Invites students to connect the science and engineering elements of the unit.	How does knowing about DNA help you with the engineering challenge?
Teacher connecting	The teacher connects the science and engineering elements of the unit.	Modifying the plasmid is just how a GMO is made.
Close ended questions	Asked a question that only had a select number of acceptable answers.	What are our constraints?
Open ended questions	Asked a question that did not have an expected answer.	What does an engineer do?

The curriculum units were analyzed to determine the engineering components included in each lesson. Each activity description in the lesson was read carefully and coded according to the component of engineering present (Table 16). I described each identified activity in terms of the engineering component and included it in the unit descriptions (Table 15). This information was compared to the teacher talk during the lesson to determine if the participant included all intended engineering concepts in their talk.

Results

Mrs. Evans' Teacher Talk

Mrs. Evans included four engineering components during the introduction to engineering lesson, lesson 1 of the unit: problem and background, content knowledge, teamwork, and engineers and engineering (Figure 9). When she talked about engineering during this lesson, she mostly talked about the problem and background, which aligns with the curriculum unit. She spent much of that time talking about the engineering design process. She asked a series of close-ended questions about each phase of the plan. For example, "Design it, what happens during this phase?". She would then call on a student who read what typically happened during the phase from the poster. She elaborated on those descriptions by giving an example of redesigning a shopping cart. She also spent a substantial amount of time on the client letter. After reading the letter aloud, she asked several open-ended and close-ended questions to help students understand the problem better. For example, "The letter mentioned taking criteria and constraints into consideration as you are designing your solution. What do you think are some constraints for this project?" Interestingly, as she was helping students understand the problem, she changed a fundamental aspect of the project by identifying herself as the client instead of using the client provided in the letter. "Your client is the genetics team at sprouts seeds. Which is well me. I am your client, so you are basically going to sales pitch me." This declaration changed the project from "real-world" to a typical classroom project.

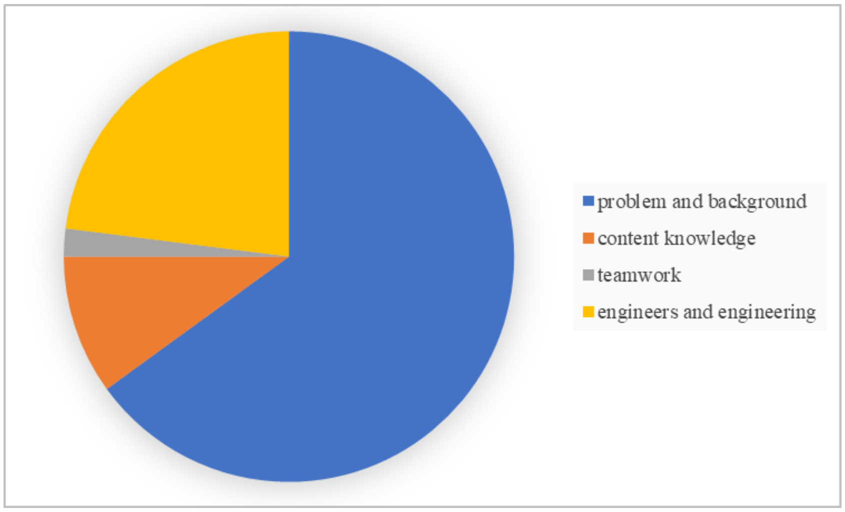

Figure 9 *Mrs. Evans' Talk About Engineering Components in the Introduction to Engineering Lesson*

After the class investigated the problem, her focus shifted to engineers and engineering, another topic included in the curriculum unit. She followed the guidance of the curriculum guide by beginning a discussion with the open-ended question, "What do engineers do?" and then allowed several students to provide answers. She ended this portion of the discussion by summing up what the students had shared, "So a lot of the times when you think of an engineer what comes to mind is redesigning a product, making something work better, or designing something large-scale like a bridge." She then provided information on the discipline of genetic engineering, which was the unit's focus. She ended her discussion on engineers and engineering by asking the open-ended question, "Does anybody think they want to be an engineer?".

The other two engineering components, connecting science to the project and teams, were not included in the curriculum unit. Mrs. Evans added these components to the lesson, although she only spoke of them briefly. Mrs. Evans led a short discussion on both days 3 and 4 about how science connected to the project. She started this discussion on day 3 by asking the open-ended question, "What do you need to learn in order to do this project?". While the students offered suggestions, she created a list of their ideas. The discussion occurred again on day 4 when she brought up the list on the whiteboard and asked if anybody could add something to the list. She briefly addressed the idea of engineering teams on day 2 following the discussion about engineers and engineering. She gave the students an assignment to research different types of engineering. She informed students that they should work as a team on the project.

> You are researching engineering, so you should act like engineers. Engineers work on teams where everybody does part of the job and then combines their efforts. So, you should each take a section and do the research, then share your findings with your team later.

Mrs. Evans used five productive talk moves during the introduction to engineering lesson (Figure 10). She primarily asked students questions as they investigated the engineering profession and the problem they had to solve at the end of the unit. During this lesson, she asked more open-ended questions that allowed students to express their opinions than close-ended questions seeking a specific answer. Also, she provided a substantial amount of information in lectures with a smaller amount of explanation. Lastly, she infrequently asked students to connect topics during this lesson.

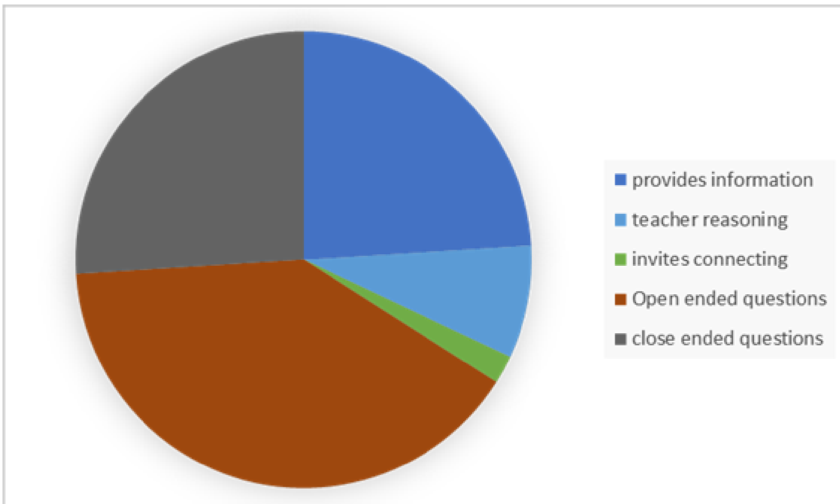

Figure 10 *Mrs. Evans' Talk Moves During the Introduction to Engineering Lesson*

Mrs. Evans did not talk about any component of engineering during the science lessons. This omission was a deviation from the curriculum unit. The curriculum designers intended for her to help students make connections between the previous day's content knowledge and the engineering challenge. In addition, she should have talked about the current stage of the EDP at the beginning of each lesson. The curriculum designers also included engineering talk during particular lessons. For example, during lesson 2, she should have led a discussion about the content knowledge students needed to complete the engineering challenge. Finally, at the end of lesson 3, she should have led a discussion on engineering after the students finished the stations.

Mrs. Evans spoke about six engineering components during the engineering challenge lesson (Figure 11). She spoke most frequently about the importance of communicating their findings and the guidelines for the presentation. She began talking about how students would share their design with the class on day 18, and that was the most common engineering topic for the remaining days in the unit. For example, “People do this all the time. They create presentations and try to win contracts." She provided all the information about engineering communication to the students through lectures and explanations of the presentation's rubric. While the curriculum designers included this engineering component in the curriculum, Mrs. Evans introduced the presentation earlier and spoke of it more frequently than instructed in the teacher’s guide.

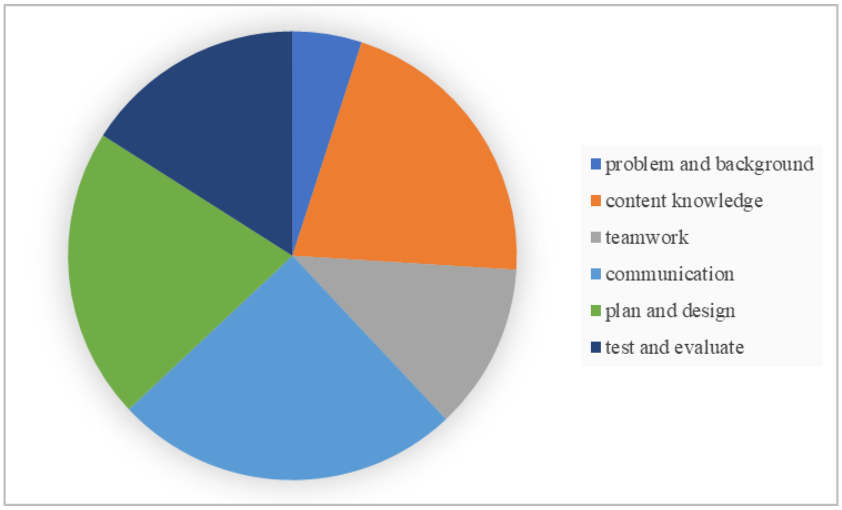

Figure 11 *Mrs. Evans Talk about Engineering Components in the Engineering Challenge Lesson*

She spoke equally about planning and designing and applying science content to the design project. She began talking about the planning and designing engineering component on day 15, the first day of the engineering challenge. She continued speaking about this component until day 18, which corresponded to the instructions in the curriculum guide. On day 15, she guided students step by step through the planning and design process. She used a combination of providing information and explaining the statements that were in the student packets. She frequently reminded them of things to consider while they were planning, such as, "Think carefully about your farm location. Remember the weather is random, so just because a spot is typically hot and dry doesn't mean it always will be." She also frequently provided information or explanations on how students should apply the science content to their design. She made these comments throughout the original design and the two subsequent redesigns. Her most common talk move was providing information, but she occasionally explained something about the science content in students' packets. For example, "You can change the genotype of the second parent if you think it will give you offspring that are better able to resist the fungus.” The curriculum unit indicated that teachers should discuss how the students’ content knowledge connected to the engineering project. However, Mrs. Evans did not follow the guidelines concerning the timing of this kind of talk. The curriculum unit indicated teachers should talk to students about using their content knowledge as soon as the engineering project started, but Mrs. Evans did not speak about information from the unit until after the first breeding programs were evaluated.

Mrs. Evans spoke of the engineering component testing and evaluating less frequently. She spoke only about testing on day 16 and about testing and evaluation on days 17, 18, and 19. She primarily provided information or explained statements in the students’ packets. For example, “You need to multiple your Punnett square results by however many you had of that parent. If you had two HH parents, then the cross with the HH parent? Those results are multiplied by two." On days 17, 18, and 19, when most students had finished testing, she would poll the class with a close-ended question such as “Who had a genotype that is missing? You didn’t have any plants with a genotype survive?” She spoke less about evaluating the results than she did testing while they were used equally in the curriculum unit. Occasionally she would offer a reminder to students, “Don’t forget to think about your results when choosing the genotype for the parent in the next generation.”

Mrs. Evans spoke briefly about teamwork in engineering every day of the engineering challenge lesson, although curriculum developers did not include it in the curriculum unit. Her comments were limited to directives she uttered at the beginning of each class. For example, "Talk to your team" or "We are working in teams." The most she ever spoke about teams was in reference to the presentation. She made it clear to students that every team member should participate in the presentation.

Mrs. Evans very briefly spoke about the design problem on the first day of the engineering challenge lesson (day 15), and when telling students about the presentation they would have to create (day 19). She presented the information about the problem the students were supposed to be solving. For example, "Remember you are supposed to design a breeding program that gives you corn which is not affected by the Northern corn leaf blight" She did not ask students to provide any information about the problem or background. She never spoke about the constraints or criteria for the project during this lesson. However, she often referred to herself as the client and emphasized that the presentation was for a grade and she expected quality work from the students. This engineering component was an addition to the ones included in the curriculum unit. The curriculum designers did not ask teachers to discuss the problem with students during the last lesson of the unit.

Mrs. Evans used four talk moves during the engineering challenge lesson, lesson 5 (Figure 12). She primarily provided information in the form of lectures with smaller amounts of teacher-provided reasoning and elaboration. She also asked a limited number of close-ended questions.

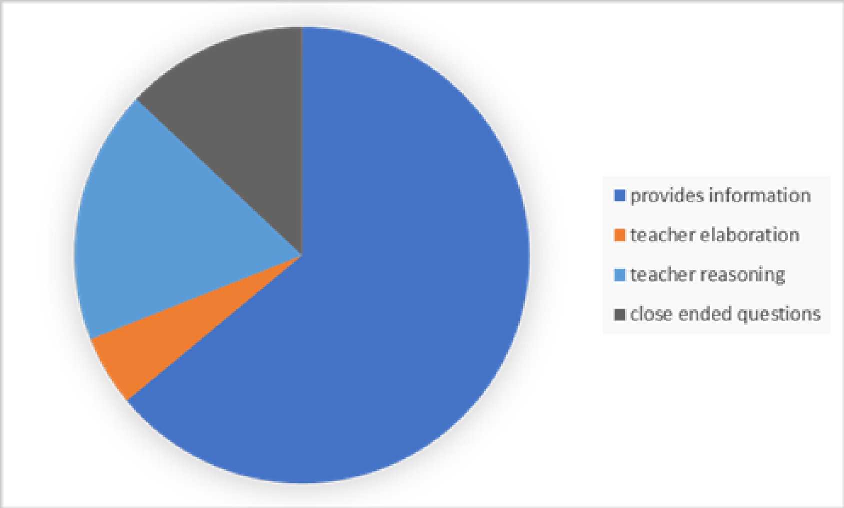

Figure 12 *Mrs. Evans Talk Moves During the Engineering Challenge Lesson*

Mrs. Anderson's Teacher Talk

Mrs. Anderson spoke about five engineering components during the introduction to engineering lesson (Figure 13). She talked about the engineering problem and the background most often the first four days of the lesson, as was indicated in the curriculum unit. She guided students understanding of the problem mainly through a series of open-ended questions. For example, while looking at the engineering design plan poster, she asked them questions such as: "What do you think they are defining?", "Does define go anywhere?" and "Learn. What do you think that means, learn what?" She also helped students understand the design problem's central issue by asking, "What are GMOs?". She then guided the student discussion by asking for elaboration and reasoning until the class created a definition for this construct. She also provided information about the problem, including non-technical definitions for criteria, "A criteria is something that has to happen, let's think of it as a requirement." and constraint, "A constraint limits what you can do so think of it as a limitation."

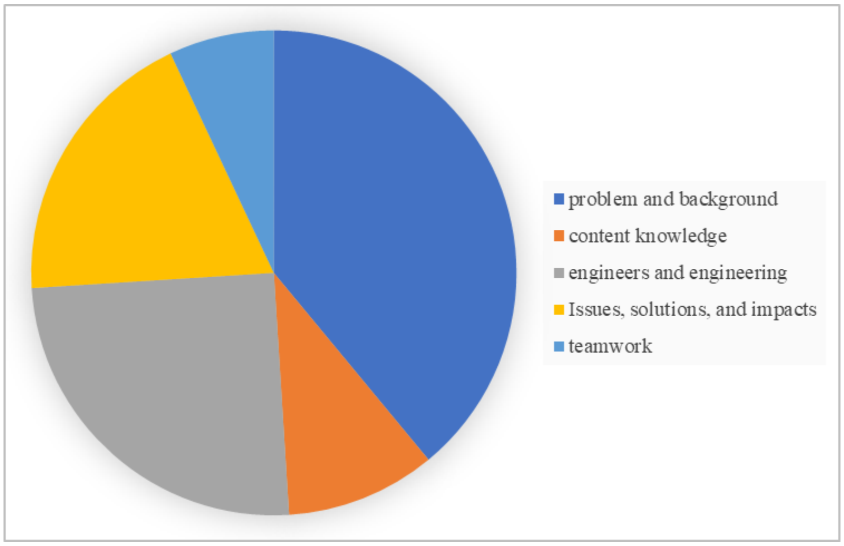

Figure 13 *Mrs. Anderson's Talk About Engineering Components in the Introduction to Engineering Lesson*

She also spoke about engineers and engineering during this lesson. On day 1, she asked, "What do engineers do?". As students were offering suggestions, she created a list on the whiteboard. The next day she repeated the question allowing students to add to the list of characteristics. Once all students shared their ideas, she used the list of characteristics to create a class definition of what an engineer does. She then asked students to identify different types of engineers. She also recorded this information on the board but did not offer a verbal summary of the information for students. This approach was exactly how the curriculum unit suggested teachers discuss this topic with students.

She spoke less often about the issues, solutions, and impacts of the project. Mrs. Anderson's usage of this topic was aligned with that included in the curriculum unit. On day 1, she led the following discussion:

> Mrs. Anderson: In the news recently, GMOs are not seen in a favorable light. What is the concern? Why do people think they do not want to consume these foods?
> Student: They think it is bad.
> Mrs. Anderson: Why?
> Student: It's genetically modified.
> Mrs. Anderson: Why is that bad?
> Student: They don't know how it is modified.

She again led a discussion about GMOs on day 5 following the debate activity. Similar to the discussion on day 1, Mrs. Anderson used open-ended questions and asked for reasoning.

She spoke the least about applying scientific knowledge to the problem and teamwork. On day 3, she asked, "What are you going to need to learn in order to do this challenge?". As students offered answers, she frequently asked them to elaborate and compiled a list on the board. This interaction was the only time she addressed science knowledge in relation to the engineering challenge during this lesson. While sparse, Mrs. Anderson's talk about science knowledge aligned with the curriculum unit. On day 4, she provided information about how students should work on an engineering team, "As part of a team you need to listen to everyone talk. Everyone gets to share and then as a group you decide what your answer will be." She provided this information just before students worked on the problem scoping sheet in their teams. This interaction was the only reference made to teamwork during this lesson. The curriculum unit suggested a range of interactions about teamwork depending on students' previous experience with working as a team. Therefore, Mrs. Anderson's talk about this engineering concept was appropriate.

Mrs. Anderson omitted one of the engineering concepts that the curriculum developers included in the unit. Her students were supposed to complete the Ethics of GMOs reading before participating in the debate. However, she decided to skip that activity, so she did not talk about ethics during the introduction to engineering lesson.

Mrs. Anderson used various productive talk moves during the introduction to engineering lesson (Figure 14). She primarily sought student opinions by asking open-ended questions. She also used talk moves that caused students to explain or elaborate on statements made by themselves or a peer. Mrs. Anderson provided a small amount of information to her students through lectures, elaboration, and explanations. Lastly, Mrs. Anderson seldom connected information or requested students connect information during this lesson.

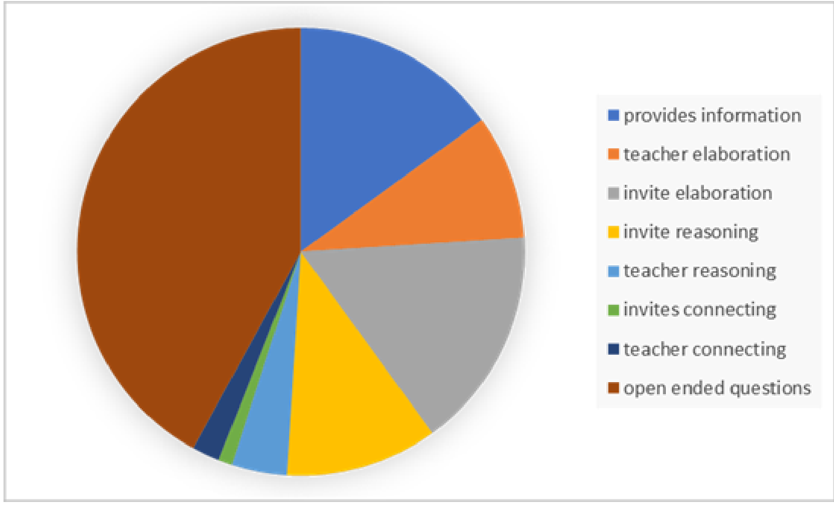

Figure 14 *Mrs. Anderson's Talk Moves During the Introduction to Engineering Lesson*

Mrs. Anderson spoke about three engineering components during the science lessons (Figure 15). She spoke most about applying the science content the students were learning to the engineering challenge. This choice aligns with the curriculum unit, which instructed teachers to connect the content to the engineering project at the beginning and end of each lesson. On day 9, the students were learning about physical traits at the end of the class. Mrs. Anderson used open-ended questions to determine how physical traits were connected to the engineering challenge, "What do physical traits have to do with GMO corn?". At the end of class, on days 11, 12, and 14, she asked similar questions to connect the science information students just learned to the engineering challenge. On day 17, students learned about how scientists create plasmids. Mrs. Anderson asked a series of open-ended questions, which asked students to consider using this technology to solve the engineering challenge. For example, "How can you determine if corn has been genetically modified?" and "What tests could be done?".

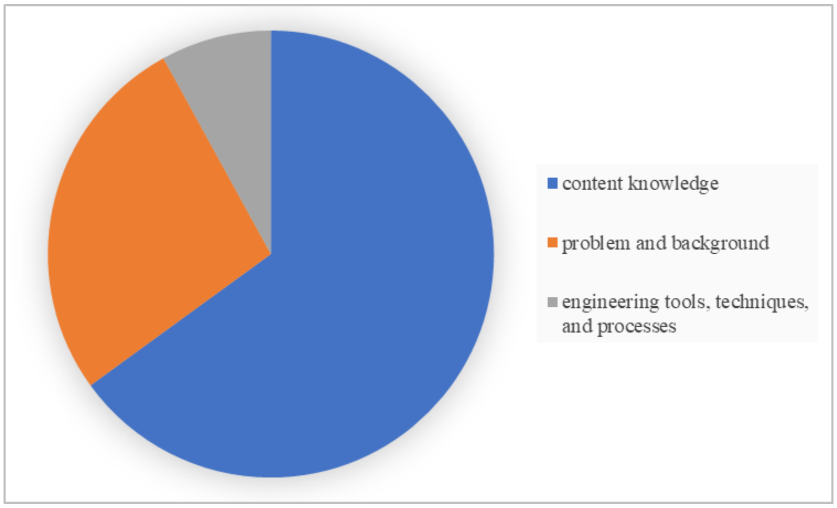

Figure 15 *Mrs. Anderson's Talk About Engineering Components in the Science Lessons*

She spoke less about the engineering problem and background than the curriculum unit indicated she should talk about this engineering component. On days 11, 12, and 14, she prompted the students to discuss the design problem using a series of open-ended questions. For example, "What problem are we trying to solve?" and "Where are we in the engineering design process?". According to the curriculum unit, she should have asked similar questions at the beginning of every science lesson.

She spoke briefly about engineering tools, techniques, and processes consistent with the instructions included in the curriculum unit. On day 8, before the students started the DNA extraction activity, she directed students to the step-by-step procedures on their papers. "I'm not going to tell you what to do because I think it is really important that you learn how to follow directions. And your procedures are right down there at the bottom."

Mrs. Anderson used a limited number of productive talk moves about engineering during the science lessons (Figure 16). Her most common talk move was to ask open-ended questions. Many of her open-ended questions required students to connect the science content to the engineering challenge. Therefore, her second most common talk move was requesting students to connect information. She also occasionally asked students to provide reasoning for their answers. Her most infrequently used talk move was to provide information about how engineering was connected to the science lessons.

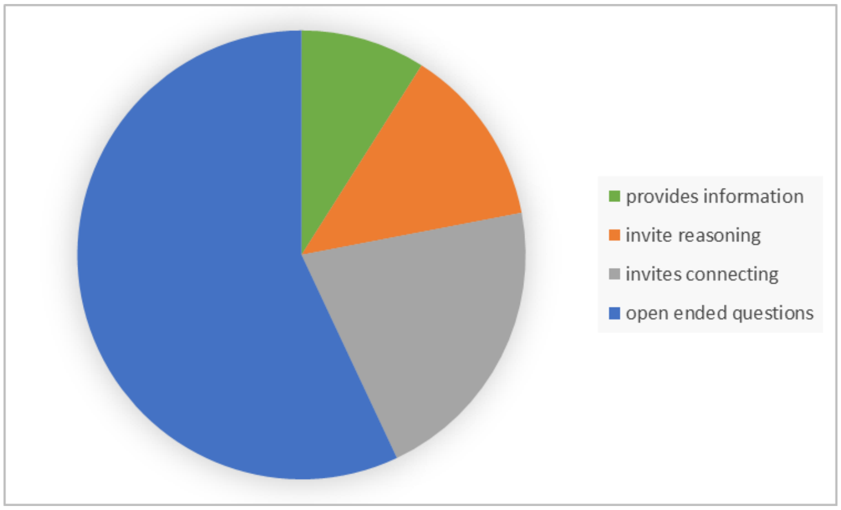

Figure 16 *Mrs. Anderson's Talk Moves During the Science Lessons*

Mrs. Anderson included seven engineering concepts in her talk during the engineering challenge (Figure 17). The most frequently talked about component was plan and design. She spoke about this topic every day of the engineering challenge, which aligns with the instructions in the curriculum unit. She typically provided students information about planning and designing. For example, "You need to work together to come up with two plans. That way, you can compare them and pick the best one." However, occasionally she would ask a close-ended question to determine if students remembered essential information for their projects. For example, "Who can tell me what is limiting our design [constraints]?"

She also spoke about the problem and background component of the engineering project every day during this lesson. She talked about this subject more frequently than indicated in the curriculum unit, which only requested teachers to talk about the problem and background on the first day of the engineering challenge. She typically asked close-ended questions to be sure students remembered important information about the project. Such as, "Who can tell me who the client is?" She also frequently asked where they were in the engineering design plan and what problem they were trying to solve. However, on day 21, most students stopped responding to her questions, and she had to provide this information.

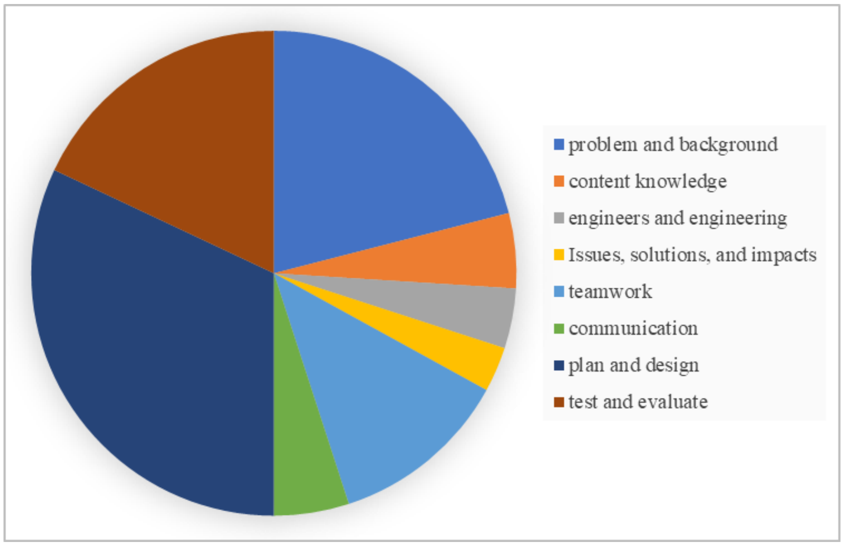

Figure 17 *Mrs. Anderson's Talk About Engineering Components in the Engineering Challenge Lesson*

The last engineering concept she spoke about consistently during this lesson was teamwork. She spoke about engineering teams on days 18, 19, 20, and 23. Every time she spoke about this component of engineering, she was providing information. She never invited students to participate in the conversation on working in teams. Instead, she would say things such as, "Everyone needs to contribute to the project." or "You are team members, that means everybody has something to do. At the end, you should combine your parts to have a complete project." Mrs. Anderson talked about this part of engineering more than indicated in the curriculum unit. The curriculum developers only indicated that teachers should discuss teamwork when students were planning their projects.

She briefly spoke about several other engineering components during this lesson, including testing and evaluating, applying science content, engineers and engineering, and engineering communication. She provided information about testing and evaluation on days 19 and 20. For example, on day 20, after she passed out the results of the test to each group, she remarked, "You need to look at that paper and figure out what worked and what didn't. Then make changes to the things that didn't work." This type of talk does not reflect the instructions in the curriculum unit. The curriculum designers intended teachers to talk to students about using mock data to "test" their design. Instead, Mrs. Anderson tested the projects for students, so she only spoke about students interpreting the test results distributed to each group. She provided information about students applying science knowledge to the engineering problem on days 19 and 21. For instance, on day 19, she reminded students about how pollen moved and the importance of considering that while creating a plan. The curriculum unit did not include instructions to incorporate teacher talk about the science content into the engineering challenge lesson, so this was an addition made by Mrs. Anderson. Engineers and engineering was the only component Mrs. Anderson requested students' input on during this lesson. On day 18, she asked, "How do engineers solve problems?". She also provided information to students on this topic. On day 19, she told students about how engineers made decisions while working on engineering projects. The inclusion of this topic was in addition to the engineering components included in the curriculum unit. The next engineering component she spoke about during the lesson was engineering communication. She did not even notify students that there was a presentation component to the project until day 22. At the end of that day, she provided information about the expected presentation to the students. Then on day 23, in the minutes before the presentations were to begin, she again provided information saying, "Everyone should have something to say during your presentation. Take a minute and decide who is going to say what." She spoke about this topic much less than what the curriculum unit indicated. For instance, the curriculum stated that teachers should introduce the presentation component to students on day 20 to allow groups plenty of time to complete the requirement. The last engineering component included in Mrs. Anderson's talk during the engineering challenge lesson was issues, solutions, and impacts. She spoke about this topic on day 23 when discussing topics students should include in their presentations. The curriculum developers did not include this topic in the unit; it was an additional topic selected by Mrs. Anderson.

Mrs. Anderson used five types of teacher talk during the engineering challenge lesson (Figure 18). She mainly provided information in the form of lectures, elaborations, and explanations. However, she did invite students to participate in the conversation by asking them to answer close-ended questions and, to a lesser degree, connect topics.

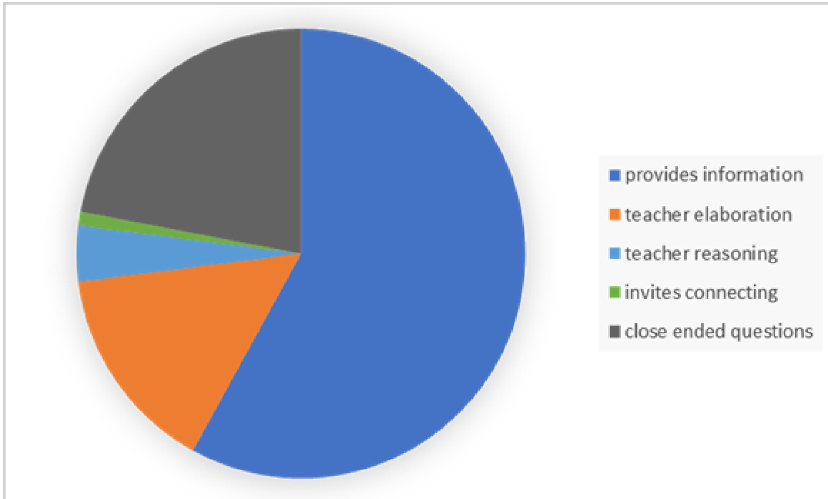

Figure 18 *Mrs. Anderson's Talk Moves During the Engineering Challenge Lesson*

Cross-case Analysis

Mrs. Evans and Mrs. Anderson both altered their talk about engineering components from the curriculum unit during the introduction to engineering lesson. Mrs. Evans spoke about the two required elements, problem and background and engineers and engineering, in a manner that reflected the curriculum designer's intent. However, half of the engineering components she talked about during this lesson, content knowledge and teamwork, were not included in the curriculum unit. Alternatively, Mrs. Anderson did not talk about any additional engineering components during this lesson. Of the six engineering components included in the curriculum unit, she discussed five in a manner that aligned with the curriculum unit. However, the sixth component, ethics, she omitted by leaving out one of the learning activities. The curriculum indicated that students should have read a handout, *Ethics of GMOs*. However, Mrs. Anderson did not distribute this sheet to students, which removed engineering ethics from her teacher talk during the lesson.

The talk moves that the teachers used to incorporate the engineering concepts into the lesson were also similar. Both teachers used questioning as their primary talk move when speaking about the engineering problem and background. They differed in the type of questioning they used, with Mrs. Anderson asking open-ended questions while Mrs. Evans asked close-ended questions. Also, Mrs. Evans provided some information on the engineering problem and background. Similarly, both teachers used questioning as their primary talk move when speaking about engineers and engineering. Mrs. Evans and Mrs. Anderson both used open-ended questions to engage students in discussing this engineering component. Again, Mrs. Evans supplemented her questions by providing some information. Despite teaching different units Mrs. Evans and Mrs. Anderson had almost identical talk moves when guiding students to identify science content they would need to learn to complete the engineering challenge. Once again, the teachers used the same talk move, providing information when speaking about engineering teams. Mrs. Anderson used open-ended questions when she included the additional engineering component of issues, solutions, impacts in her unit.

The two participants had different approaches to talking about engineering concepts during the science lessons. Mrs. Evans omitted all the engineering concepts from her talk during these lessons. Alternatively, Mrs. Anderson spoke about all three required concepts, although she spoke about the problem and background less than requested in the curriculum unit.

The participants in this study both made alternations to the engineering talk during the engineering challenge lesson. Mrs. Evans spoke about the four required engineering concepts. However, she only spoke of one, planning and design, in a manner that corresponded to the curriculum developer's intention. She spoke more about communication than was indicated in the unit and less about testing and evaluating and content knowledge. She also included two additional engineering concepts, problem and background and teamwork, in her talk during this lesson. Mrs. Anderson also included additional engineering concepts: content knowledge, engineers and engineering, and issues, solutions and impacts, to this lesson. Like Mrs. Evans, the only required engineering component that Mrs. Anderson talked about as the curriculum designers intended was planning and design. She also spoke about some of the required elements, problem and background and teamwork, more than the curriculum designers intended, while she spoke of other elements, testing and evaluation, less than expected. It is interesting to note that both teachers spoke less about testing and evaluating than what the curriculum units indicated teachers should talk about this subject. Also interesting was the difference in the ways teachers altered their talk about communication, with Mrs. Evans speaking more than expected and Mrs. Anderson speaking less than expected.

The talk moves used when talking about the engineering concepts were similar between teachers. Both teachers primarily provided information to their students during this portion of the unit. However, Mrs. Evans did explain some concepts related to planning and designing and applying science content to her students. Mrs. Anderson included some questioning in her talk during this lesson. She asked close-ended questions about the problem and background and open-ended questions about engineers and engineering.

Conclusions

This multiple case study investigated the engineering components that two 8th grade science teachers discussed during an integrated STEM unit, and the talk moves those teachers used to discuss engineering components with their science classes. The data was interpreted through sociocultural learning perspective which allowed me to determine how the teacher's talk impacted the classroom community. Mrs. Evans talked about five of the nine major engineering components during the introduction to engineering lesson and the engineering challenge lesson. She did not speak about engineering during the science lessons. During the introduction to engineering lesson, she used a mixture of dialogic and providing information talk moves. However, during the engineering challenge lesson, when students design their solutions, she just offered information. Mrs. Anderson talked about seven of the nine major engineering components throughout the introduction to engineering lesson, the science lessons, and the engineering challenge lesson. At the beginning of the unit, she used primarily dialogic talk moves, frequently questioning students and asking for reasoning. However, at the end of the unit, as students worked in small teams to design their solutions, she mainly provided information and asked very few questions.

The teachers in this study used different talk moves during the introduction to engineering lesson, lesson 1, compared to the engineering challenge lesson, the last lesson. During lesson 1, both teachers mainly used talk moves that enabled students to contribute to the conversation. Mrs. Anderson's talk moves were more open and allowed students to have greater control of the conversation. However, the combination of close and open-ended questions and elaborations in Mrs. Evans's talk also permitted students to share their ideas. This inconsistent use of talk moves differs from the findings of a similar study on teacher talk during an integrated STEM unit. While the two participants in that study had different talk styles, one dialogic and the other controlling, that style did not change during the unit (Aranda et al., 2018). The teachers in this study may have altered their talk moves because they were short on time and needed to finish the unit. Alozie and colleagues (2010) found similar findings during an investigation of project-based science. The researchers found that several teachers did not invite students to participate in the dialogue when they needed to finish the lesson quickly (Alozie et al., 2010).

A fundamental component of an integrated STEM unit is that students should use knowledge from the discipline-centered lessons to solve the engineering challenge. Both teachers in this study explicitly connected the science content to the engineering project during the last lesson of the unit. Johnston and colleagues (2019) observed a similar integration of content knowledge during an integrated unit. This type of integration is beneficial for students, as observed in Valtorta and Berland (2015). The researchers found that when a teacher explicitly connected content knowledge that students were familiar with to the engineering project, they could use it in their prototype. The teachers demonstrated proficiency in teaching an integrated STEM unit by integrating the content knowledge to the engineering project. In a longitudinal study by Guzey and colleagues (2019), it took the teacher three years to reach that level of proficiency. Nevertheless, the participants in this study accomplished that the first time they implemented the unit in their classrooms.

Teachers must spend time during the unit talking about engineers and engineering. The teachers in this study approached this topic differently than the participants in similar studies (Johnston et al., 2019; Tank et al., 2018). The teachers in those previous studies attempted to build engineering identities in their students by referring to them as engineers. In comparison, the participants in this study used a more factual approach by having students share their understanding of engineers and then evaluated it for correctness. The participants also presented information on engineering to students during the unit. Both approaches to integrating engineers and engineering in the curriculum have merit. By referring to students as engineers, a teacher creates a personal connection to the profession, which may remain after the unit ends. Alternatively, it is also important to explicitly state what engineers do and the educational requirements to become engineers. Therefore, the best method of integrating engineers and engineering in an integrated STEM unit is by referring to students as engineers and giving factual information about engineering.

This study demonstrates that the components of engineering a teacher talks about depends on the curriculum unit. Both units focused on genetic engineering and provided guidance and clear instructions to the teachers for successful implementation. Mrs. Anderson's curriculum unit included a student debate on the usage of GMO crops. This activity allowed her to incorporate issues, solutions, and impacts in her talk. The unit Mrs. Evans was teaching did not include any activities that would allow her to discuss this engineering component with her students. As Moore and colleagues (2014) suggested, issues, solutions, and impacts associated with the engineering challenge are critical for students because it makes the project authentic. Curriculum writers need to consider including this aspect of engineering in integrated STEM units. This aspect of engineering can increase student interest, as seen in a study by Wilson-Lopez and colleagues (2016), which found that students become invested in the project when they understand how it could help their community.

Limitations and Suggestions for Future Research

This study's findings highlighted how teachers talk about engineering in a science classroom. However, this multiple case study investigated two teachers’ talk; thus, the findings cannot be generalized. The talk moves used to discuss each component of engineering reflect an individual's personality and teaching philosophy. Accordingly, readers should not misinterpret this study's results as a guide for how teachers should talk about the engineering components. A variety of internal and external factors influence teacher talk. Future research should consider the impact of contextual factors such as student background and prior experiences on teachers' engineering talk. Researchers need to carry out additional investigations to determine the most effective talk moves to integrate engineering concepts in diverse settings.

Implications

This study has several implications. First, curriculum developers need to include the components of A Framework for Quality K-12 Engineering Education (Moore et al., 2014) in integrated STEM units to help students learn a variety of engineering concepts and engage in multiple engineering practices. Since most science teachers do not have enough background knowledge in engineering, curriculum designers must explicitly state why the engineering components are included in the unit and provide background information and instructions. This study has shown that if curriculum designers include engineering components in the curriculum, teachers will most likely incorporate them in their teaching. However, it is unlikely a teacher will include these elements without guidance from the curriculum designers. Second, facilitators of professional development workshops need to explain how teachers should integrate these engineering components into the unit. They should model such instruction for the teachers and provide background information about these components. This information will make teachers more comfortable with the new concepts. Once teachers understand the concepts, they will include them in the unit. Last, researchers should act as a coach or serve as a co-teacher while teachers are implementing an integrated STEM unit for the first time. If there is someone more knowledgeable in the room with the teacher, they can assist with presenting the engineering components if necessary or remind the teacher when it is appropriate to speak of each component. As observed during the unit, teachers do not always talk about all the engineering components included in the curriculum unit. If there was a coach in the room, that person could remind the teacher to include all the engineering components from the curriculum unit. They could also model the most effective way for including the engineering components during all the required lessons. Alternatively, the teachers could point out additional engineering elements that curriculum developers should include in the lessons. This exchange of information would lead to better implementation by the teacher and an improved curriculum unit for future teachers to use in their classrooms.

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ANALYSIS ACROSS ALL THREE STUDIES

Each study in this dissertation investigated a different aspect of teacher talk during an integrated STEM unit. Despite the differences between studies, there were some common themes in the findings of all three studies. This chapter examines the across-study themes to address the research question: What talk moves do teachers use during an integrated STEM unit, and how does the teacher talk affect student engagement and learning?

Cross-Study Themes

The Complex Nature of Teacher Talk

The studies in this dissertation demonstrate that teacher talk is complex, and it is difficult to make direct connections between something a teacher says and student engagement or learning. In all three studies, teacher talk elements interacted, making it difficult to determine the effect of one element on student outcomes. For example, in study 1, I focused on the elements of a dialogic discussion and attempted to determine the effect on student learning. However, there was an additional element of teacher talk, presenting information, that interfered with that analysis. Study 2 focused on the effect of autonomy-supportive or suppressive talk on student engagement. Many researchers have determined that the more autonomy-supportive a teacher is, the more engaged their students are in the lesson (Furtak & Kunter, 2012; Jang et al., 2012; Jang et al., 2010; Reeve et al., 2004; Struyf et al., 2019; Tsai et al., 2008). However, this study did not wholly support those results. Instead, the two teachers, one of which was autonomy-supportive and the other autonomy suppressive, had highly engaged and disengaged students. The teacher's tone of voice could have affected student engagement. Mr. Hale, who tended to use autonomy suppressive talk, did so with a jovial tone of voice, often laughing in a friendly manner when someone made a mistake. Alternatively, Mr. Winchester, who tended to use autonomy-supportive talk, often had a condescending tone with certain target group members. Thus, the discrepancy in findings could have been due not to what teachers said but how they said it. Study three investigated the teachers' talk moves and which aspects of A Framework for Quality K-12 Engineering Education (Moore et al., 2014) they talked about during the unit. The two teachers demonstrated differences in the talk moves used to discuss elements of the framework. For example, Mrs. Anderson used open-ended questions to discuss the engineering design plan, while Mrs. Evans used close-ended questions. If I had attempted to connect this component of the teacher talk to student outcomes, it would have been difficult to determine which part of the talk was more impactful on the students. This dissertation demonstrates the difficulties researchers have when they try to connect teacher talk to student outcomes.

Additional Factors That Affect Student Outcomes

The second theme of this dissertation is that there are non-talk-related factors that affect student learning and engagement. The non-talk factors in these studies include classroom management, teacher/student relationships, context, peers, personal issues, and the curriculum unit.

In study 1, the factors of classroom management and teacher/student relationships affected student learning. Classroom management issues interfered with the learning in Mrs. Anderson's class. Every day of the unit, she had to stop class to correct at least one student's behavior or to speak to a school official about a particular student. These breaks in the educational process may have affected some of the students' ability to learn the content. The learning in Mr. Hale's classroom was affected by the relationship he had with his students. Despite using mainly teacher-centered speech, his students learned the content as well as the students in Mr. Winchester's classroom. This effect could have been because Mr. Hale had a good relationship with most of his students, evidenced by side conversations about outside activities and joking with students. When given the opportunity, the students responded to him with enthusiasm, and the majority seemed interested in what was happening in the classroom, even when they were listening to the teacher.

The teacher talk in study 2 was affected by context, peers, and personal issues. It appears that the context in which a teacher used autonomy-supportive or suppressive talk affected some of the students' engagement. For example, Lydia responded to Mr. Hale's controlling language differently when that language occurred at the beginning of class versus during an inquiry activity. The next non-talk element present in this study was peer interactions. All three female students in Mr. Winchester's target group had their engagement reduced during the unit due to the actions of their peers. These frequent off-topic conversations caused these students to divert their attention from the activity and thus reduced their engagement. The effect of peers on student engagement levels was not surprising as researchers have identified peer interactions as one of the most common reasons students are off task (Godwin et al., 2016). However, peers can have a more substantial effect on a student's classroom performance than a short distraction. Such an interaction occurred in Mr. Hale's class. At the beginning of the unit, Jack attempted to participate in the small group discussions at his table. However, after he was rebuffed several times by his teammates, he stopped participating, and his engagement suffered. Wieselmann et al. (2019) recorded a similar occurrence during an integrated STEM unit when the male students controlled how the females students participated in the activity. The study in this dissertation demonstrates that gender is not the only reason students prevent a classmate from participating during an integrated STEM unit. Therefore, a teacher needs to instruct students on how to interact with peers during small group collaborations. Research has found that teachers must set rules and offer students guidelines for effective group work; otherwise, students struggle with social interactions and do not complete the assigned tasks (Fung et al., 2018). The last non-talk element evident in study 2 were personal issues. At least one student's engagement was affected by personal issues during the unit. For example, Lydia mentioned that the veterinarian was euthanizing her cat at the beginning of class and her engagement was noticeably lower that day.

The additional factor in study 3 was the curriculum unit. The unit each teacher was using directly affected the engineering components that the teacher included in their talk. For example, Mrs. Anderson included *Issues, Solutions, and Impacts* in her talk because of the debate activity included in the curriculum unit. While Mrs. Evans was unable to speak about that component of A Framework for Quality K-12 Engineering Education (Moore et al., 2014) because there were no applicable activities in the unit she taught. Therefore, the students in Mrs. Evans's class could not learn about how their engineering project affected society.

The Importance of Dialogic Discussion

All three of the studies in this dissertation identified the importance of dialogic discussion during an integrated STEM unit. A dialogic discussion is a student-centered form of communication that involves teachers using open-ended questions, asking students to elaborate on their answers, requiring students to provide reasoning for their responses, and students making connections between topics (Alexander, 2004). Each teacher used whole-class discussion as a classroom activity during the unit, although they did not implement them in the same manner. Mrs. Evans used close-ended questions primarily. Occasionally, she also used open-ended questions in her discussions. However, she did not include many of the elements expected in a dialogic discussion as she never asked for student elaboration or reasoning and only occasionally asked them to connect information. Mr. Hale also used more close-ended questions than open-ended, but he occasionally included other dialogic discussion elements, such as asking for reasoning and elaboration. Mrs. Anderson and Mr. Winchester used primarily open-ended questions and frequently asked students to elaborate and provide reasoning during their whole-class discussions. Despite the differences in how teachers implemented the discussions, this pedagogy successfully engaged students with the content. In all classrooms, observers saw multiple students raising their hands when the teacher asked a question. Most students were eager to share their ideas and for the teacher to validate their worth by calling on them. In two of the classrooms, students were desperate to participate in the conversation. In Mrs. Evans's class, several students interjected their ideas into Mrs. Evans's explanation of how engineers use the engineering design process to design a product. In Mr. Winchester's class, one student was so desperate for the teacher to call on her that she repeatedly raised her hand to answer a question when she did not have anything to add to the conversation. The above examples demonstrate that holding dialogic discussions during an integrated STEM unit is beneficial to students. Unfortunately, most of the discussions during these studies occurred in the first lesson of the unit. When teachers are using integrated units, they need to include dialogic discussions throughout so students can share their ideas and learn from their peers.

Implications for Teaching

The three studies in my dissertation resulted in some key implications for professional development facilitators and curriculum developers. This section discusses those findings.

Restructuring of Curriculum Materials

The results of the studies in this dissertation have shown that the curriculum units need to be more educative. An educative curriculum unit contains instructional materials for teachers on the new pedagogies used in the unit (Ball & Cohen, 1996). Researchers have found that if teachers read the educational materials, they are more successful at implementing the unit in their classroom (Schneider & Krajcik, 2002). If I were to redesign the curriculum units used in this study, I would include a section on dialogic discussions. In addition to the instructional materials, I would also include discussion prompts in the teacher guide. These prompts would include open-ended questions for starting the discussion, examples of follow-up questions, and reminders to ask students to elaborate on their answers or provide reasoning. I would also add a section on autonomy-supportive and suppressive talk. In addition to this instructional guide, I would include reminders of how teachers could support student autonomy during the unit. For example, in lesson two, I would remind teachers to use informational language when explaining the cell model activity. That would allow students to have autonomy over how their group created their model cell. Lastly, I would add information on A Framework for Quality K-12 Engineering Education (Moore et al., 2014). In addition to the educational material, I would place prompts in the teacher guide that reminds instructors when it is appropriate to talk about a particular engineering component. For example, I would remind teachers to connect the content information to the engineering challenge during the science lessons. By adding more educational materials to the curriculum unit, teachers will have the skills necessary to implement a student-centered unit that integrates engineering procedures with science knowledge.

Teachers Should be Coached

This dissertation demonstrates that professional development facilitators should coach teachers as they implement an integrated STEM unit for the first time. While all the teachers in these studies participated in professional development workshops during the summer, there was considerable time between the workshop and teachers implementing the unit in their classrooms. Each participant failed to include some of the aspects of STEM education during their implementation. To avoid these same mistakes with future teachers, professional development facilitators should act as instructional coaches while teachers implement the unit for the first time. If the teachers in these studies had an instructional coach, the results might have been different. In study 1, an instructional coach could have modeled conducting a dialogic discussion for the teachers. Then when the teachers were guiding a dialogic discussion for the first time, the coach could have reminded them to ask students to elaborate, provide reasoning, or connect information. In study two, an instructional coach could have met with the teachers after class to discuss the type of language they were using and its effect on the students. If these meetings continued throughout the unit, the teacher talk in both classrooms would have improved, and student engagement may have increased. In study 3, the teachers would have benefitted if an instructional coach was present to remind them of the engineering aspects they needed to discuss with students. For example, the coach could have reminded teachers to connect the science content to the engineering challenge at the beginning of each science-centered lesson. Instructional coaches would improve most teachers' first attempt at implementing an integrated STEM unit.

Future Work

This line of research should continue by investigating the effect of teacher talk on different types of students. In the future, researchers should use a pre and post-test when investigating the effect of teacher talk on student learning during an integrated STEM unit. By including a pre and post-test, researchers could determine if the effectiveness of teacher talk depends on a student's prior knowledge. Researchers also need to investigate the effect of teacher talk on student learning and engagement with a diverse group of students. This investigation would determine if teacher talk affects certain groups of students more than other groups. Lastly, researchers should investigate the dynamics of student groups during integrated STEM units. It is essential to determine how students interact during these units and if the teacher talk has any effect on those dynamics.

Future work should also examine the effectiveness of a professional development program that uses an educative curriculum and instructional coaches to guide teachers as they implement an integrated STEM unit. This research should focus on the quality of the teacher talk during dialogic discussions, the teachers' use of autonomy-supportive or suppressive language, and how teachers integrate engineering components into the science content. Researchers should include a diverse group of educators in the professional development workshop to obtain findings that apply to most teachers.

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