Volume 27, Number 4 • Winter 2023/2024

ISSN: 1087-3430

# Electronic Journal for Research in
# Science & Mathematics Education

*Flagship Journal of the International Consortium for*
*Research in Science & Mathematics Education (ICRSME)*

# EJRSME

Electronic Journal for Research in Science & Mathematics Education

## EDITORS

Mark A. Bloom, Science Education, *Dallas Baptist University*
Robert Wieman, Mathematics Education, *Rowan University*
Sarah Quebec Fuentes, Mathematics Education, *Texas Christian University*

## MANAGING EDITOR

Morgan Jansing, *Texas Christian University*

## COPY EDITOR

Audrey Meador, *West Texas A&M University*

## ASSOCIATE EDITORS

Daniel Alston, *University of North Carolina at Charlotte*
Lisa Ann Borgerding, *Kent State University*
Danxia Chen, *Dallas Baptist University*
Matthew Perkins Coppola, *Purdue University*
Kimberly Figaro, *Dallas Baptist University*
Kathryn Green, *Clarke County School District*
Hayat Hokayem, *Texas Christian University*
Gabriela Jonas-Ahrend, *Paderborn University*
Ravinder Koul, *The Pennsylvania State University*
Stefanie Livers, *Missouri State University*
Eryn Maher, *Georgia Southern University*
Cherie McCollough, *Texas A&M University – Corpus Christi*
James A. Mendoza Álvarez, *University of Texas at Arlington*
Erin Peters-Burton, *George Mason University*
Christine Schnittka, *Auburn University*
Byung-In Seo, *Chicago State University*
Julie Westerlund, *Texas State University*
Dawn Woods, *Oakland University*

## EDITORIAL REVIEW BOARD

Matthew Clay, *Fort Hays State University*
Richard Cox Jr., *Winthrop University*
Rachel Gisewhite, *The University of Southern Mississippi*
Tonya Jeffery, *University of Houston - Downtown*
Dieuwertje Kast, *University of Southern California*
Dana Morris, *The University of Texas at Tyler*
Corey Nagle, *University of West Florida*

## PUBLISHER

ICRSME, International Consortium for Research in Science & Mathematics Education

Cover designed by Dusty Crocker

# CONTENTS

Volume 27 No. 4 | Winter 2023/2024

## RESEARCH / EMPIRICAL

Electronic Journal for Research in Science & Mathematics Education (EJRSME)

ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 27, NO. 4, 1-17

# Self-efficacy in Elementary Science: What Impact Do Field Experiences Have on Preservice Teachers

Melissa Hulings
*Stephen F. Austin State University*

**ABSTRACT**

Studies have shown that preservice teachers come to their science methods courses with perceptions about science teaching and learning that can impact their levels of self-efficacy when it comes to teaching science (Bulunuz & Jarrett, 2010; Jarrett, 1999; Kazempour, 2014). Multiple studies have been conducted to document the effects of methods courses on preservice elementary teachers' science self-efficacy, finding the methods course effective in increasing levels of self-efficacy (Flores, 2015; McDonnough & Matkins, 2010; Menon & Azam, 2021) and that these levels of self-efficacy either persist (Wingfield et al., 2000) or decrease due to student teaching (McKinnon & Lamberts, 2014; Settlage et al., 2009). This study sought to examine the relationship between prior experiences, the science methods course, and field experiences for one preservice elementary teacher. Despite having negative experiences with science and an overall sense of overwhelm at the thought of teaching science, Monica displayed high levels of self-efficacy throughout the science methods course and student teaching. By examining STEBI-B surveys, with open questions included, and interview transcripts, this study sought to better understand the interconnectedness of experiences and self-efficacy. Although the results reported here pertain to one preservice elementary teacher, it adds to the overall complex relationship between past, present, and future experiences.

*Keywords:* self-efficacy; pre-service teachers; field experiences

## Introduction

Preservice elementary teachers come to their science methods courses with experiences and thoughts about science that have the potential to influence not only their self-efficacy, but also their desire to teach science content. According to Bandura (1993), low teaching self-efficacy, especially within a certain content area, may lead to avoidance of that subject. Early detection of low self-efficacy in preservice teachers (PSTs) could lead to early interventions and motivate science methods instructors to engage preservice elementary teachers in activities that would increase their self-efficacy in science teaching (Enochs & Riggs, 1990). The science methods course has been shown to increase levels of self-efficacy and that this increase can persist to the end of the student teaching experience (McKinnon & Lamberts, 2014; Palmer, 2006; Palmer et al, 2015; Settlage et al, 2009; Smolleck & Mongan, 2011; Wingfield et al, 2000). What continues to be examined are the experiences that lead to increased self-efficacy, and how PSTs can be encouraged to grow as a classroom teacher.

## Theoretical Framework

### Social Cognitive Theory

This study is grounded in social cognitive theory. As described by Grusec (1992), Bandura's social cognitive theory recognizes the interaction and influence of three separate factors: 1) individuals, 2) their environment, and 3) their behavior. As individuals engage in their social experiences, they take in information, process it and develop a mental model of their environment. Then, they relate these mental models to outcome expectances (goals of a situation), self-efficacy (perceived abilities), and self-reactions (behavior). In addition to setting goals and selecting a plan of action to produce desired outcomes, peoples' belief in their efficacy (ability to cause a change) determines how long they persist in an environment that presents obstacles to goal achievement. People who believe in their abilities will find ways around obstacles to achieve desired goals. Stated another way, personal self-efficacy beliefs determine a person's motivation, perceived effect of that environment, and courses of action within that environment (Bandura, 1989).

If teachers have low self-efficacy in their teaching abilities, especially within a certain content area, then these teachers may create an environment in which they avoid those particular content areas. On the other hand, teachers with high self-efficacy create environments in which students are engaged in classes and can experience success and/or master their experiences (Bandura, 1993). If teachers demonstrate low self-efficacy in relation to the teaching of science, they will not invest a considerable amount of time in planning for and implementing science instruction. When the focus is on preservice elementary science teachers, it is expected that early detection of low self-efficacy could lead to early interventions and motivate science methods instructors to engage preservice elementary teachers in activities that would increase their self-efficacy in science teaching (Enochs & Riggs, 1990).

In addition to the influence on self-efficacy, social cognitive theory proposes that people learn in two ways: direct experience, either rewarding or not, and social modeling (Bandura, 2003). Essentially, people learn by trying things out for themselves and by observing the actions of others. Through both social modeling and experience, one's self-efficacy is developed. When one overcomes challenges through persistence, and sees others like them being successful, their self-efficacy grows. For preservice teachers (PST), it is their cooperating teaching (CT) in the classroom during field experiences that provides this social modeling and opportunities to take on challenges, through their own teaching and the support they provide the PST.

## Literature Review

### Science Teaching Self-Efficacy

Multiple studies have measured the science teaching self-efficacy of preservice elementary teachers at various points in their teacher preparation programs. In studies that examined self-efficacy during a science methods course, which also included teaching experiences, increases were found on both subscales of the Science Teaching Efficacy Belief Instrument, Preservice Version ([STEBI-B], Flores, 2015; McDonnough & Matkins, 2010; Menon & Azam, 2021). However, in another study by Cinici (2016), STEBI-B scores increased with a microteaching activity but decreased slightly after the field experience. In addition, Morrell and Carroll (2003) reported increases for the personal science teaching efficacy (PSTE) subscale only after the science methods course and no changes on either subscale during field experiences. From these studies, we see the impact of the science methods course in increasing PSTs self-efficacy beliefs.

Other studies have examined the persistence of these gains in personal science teaching self-efficacy beyond the science methods course. Several studies have reported PSTs increased their levels of self-efficacy from the beginning to the end of the science methods course and that these increases persisted to the end of their teacher preparation program, which included student teaching (Palmer, 2006; Palmer et al, 2015; Smolleck & Mongan, 2011; Utley et al., 2005). Wingfield and colleagues (2000) also reported gains in self-efficacy due to the methods course and that these gains remained the same after one year in the classroom. However, other studies reporting gains in self-efficacy because of the science methods course tend to see decreases in self-efficacy by the end of student teaching, and later when these PSTs start teaching full time in their own classrooms (McKinnon & Lamberts, 2014; Settlage et al., 2009). In another study by Velthuis and others (2014), PSTs were followed throughout their four-year teacher preparation program, finding increases in PSTE from year one to year two, but then a decrease in year three that was maintained in year four. The differing results from these studies indicate there is more to learn about the persistence of self-efficacy beliefs beyond the science methods course.

## Prior Experiences

Several studies have examined PSTs prior experiences with science throughout their K-12 school years. In a study conducted by Bulunuz and Jarrett (2010), PSTs who had a higher interest in science also reported more science memories from their elementary school years than those who had a lower interest in science. For those who could remember science from elementary school, their enjoyment of science was reported as above average. Jarrett (1999) found that these positive experiences in elementary science were the greatest indicator of interest in science, followed by high school experiences and informal science experiences. This influence of science experiences was found in another study, yet it was overall experiences which negatively impacted attitude and confidence towards science (Kazempour, 2014). In this study, the PST reported how difficult and challenging her experiences with science were during her K-12 school years. These experiences resulted in her having an extremely negative attitude towards science and very little confidence in her abilities to teach science.

One study examined not just the prior experiences, but also experiences gained during classroom teaching completed during the teacher preparation program and their impact on confidence to teach science (Kazempour, 2013). In this instance, self-efficacy was not only shaped by past experiences with science, but also through experiences gained in the field. For this PST, her past experiences were quite positive, leading to greater interest and confidence in science. It was through her classroom experiences during teacher preparation that further shaped her beliefs about her teaching. Specifically, this PST commented on how she was able to learn more about and implement more effective science instruction by utilizing inquiry-based instruction during her teacher preparation classroom teaching experiences.

## Classroom Experiences

Understanding the impact of classroom experiences on one's science teaching self-efficacy is not bound by the experiences PSTs gained from their own K-12 classrooms. Experiences gained in classroom observations and teaching during the teacher preparation program also need to be considered. In a study by Franks et al. (2016), when asked about the most useful aspect of their methods course on impacting their self-efficacy, 98.2% reported the field experience was the most useful. Results from other studies explain that field experiences help PSTs gain more knowledge about the profession, to also help clarify their thoughts and beliefs about inquiry-based science teaching and learning, and influence their levels of self-efficacy, especially when given the opportunity to teach science (Nikoçeviq-Kurti, 2021; Simsar & Jones, 2021; Soprano & Yang, 2013).

During these classroom experiences, it is the cooperating teacher who appears to be the most influential factor. According to Knoblauch and Woolfolk-Hoy (2008), the classroom teacher working with the PST is more influential than the college supervisor responsible for observing/mentoring the PST. Other studies explain that it is the type of relationship the CT and PST have formed that is the basis of this influence. According to Nikoçeviq-Kurti (2021), it is not only that the CTs support the PST, but also that they model how to build relationships with the students and tailor the teaching to meet student needs. It is this modeling behavior that has shown a direct impact on PSTs' levels of self-efficacy. Simsar and Jones (2021) found that the behaviors modeled by the CTs and the feedback they provided were crucial in the development of self-efficacy in PSTs.

## Purpose and Research Questions

It was the aim of this study to examine the relationship between prior experiences with science, the science methods course, and classroom teaching experiences on the levels of science teaching self-efficacy and perceptions of science teaching for preservice elementary teachers. The overarching research question guiding this study was: How do prior experiences with science and classroom teaching experiences, in addition to the science methods course, affect the level of science teaching self-efficacy and the perceptions of science teaching for preservice elementary teachers? The specific research questions were:

1) What are the personal science teaching efficacy (PSTE) and science teaching outcome expectancy (STOE) beliefs of preservice elementary teachers as measured by the STEBI-B at the beginning and end of their science methods course, and the end of the student teaching semester?
2) What is the impact of prior experiences on self-efficacy and the perceptions of science teaching?
3) What is the impact of the science methods course on self-efficacy and the perceptions of science teaching?
4) What is the impact of classroom teaching experiences during student teaching on self-efficacy and the perceptions of science teaching?

## Methods

This study utilized a convergent parallel mixed methods case study design to better understand the relationship between classroom teaching experiences and the level of science teaching self-efficacy for one preservice elementary teacher. A convergent parallel mixed methods case study design was selected because it would allow a more in-depth examination of the intersection between classroom experiences (both prior and current), the science methods course, and science teaching self-efficacy through the collection of different, yet complementary data sources (Creswell, 2009; Creswell & Plano-Clark, 2011). As a part of this approach, several pieces of both quantitative and qualitative data were collected to develop and understand this one PST's relationship with science and her beliefs in her abilities to teach the subject.

For the quantitative data, this PST completed the STEBI-B (Enochs & Riggs, 1990) at three different points: the beginning of the science methods course, the end of the science methods course, and again at the end of the student teaching semester (which immediately followed the science methods course). For the qualitative data, open questions were answered at the end of the STEBI-B. These questions asked about past and current experiences with science, descriptions of good versus bad days in science, descriptions of good versus bad science teachers, and how this PST envisioned science instruction for her future classroom. Additionally, this PST completed two individual interviews: one at the end of the science methods course and the other at the end of student teaching. These interviews asked the preservice elementary teacher to describe their classroom teaching experiences at both of their placements, during the science methods course and student teaching semester. As a part of the teacher preparation program, PSTs have two field placements during their program which they split their time attending. These placements are designed to provide a variety of experiences both in grade level and content area.

## Participant and Course Context

The participant for this case study was selected because of her varied experiences both prior to the methods course and during her student teaching semester. Monica (a pseudonym) identified herself as a white female and was in her last year of the elementary teacher preparation program at a large urban university in the south.

The teacher preparation program for the elementary grades provides a pathway to certification for grades Pre-kindergarten to sixth grade in all four core content areas: English Language Arts/Reading, Mathematics, Science, and Social Studies. As a part of this program, PSTs are assigned two different field placements during their program; one placement in the lower grade band of pre-K to third grade and the other in the upper grade band of third to sixth grade; ideally, PSTs should have a variety of content areas between the two placements, sometimes in a self-contained classroom teaching all subjects to a single or double subject classroom (i.e., mathematics only or a combination of mathematics and science).

The science methods course was taken the semester prior to student teaching. During the 16-week semester, PSTs are also completing their one-day-a-week field experience where they attend their placements one day each week during the semester (eight weeks at their first placement and eight weeks at their second placement). The science methods course was taught through a hands-on approach where students completed science activities as if they were the students themselves and then analyzed the implementation of the activities from the teacher's perspective. Due to the virtual nature of the course, students completed science activities at home with everyday materials, then the activities were discussed during the virtual synchronous class meeting.

Student teaching is the final semester of the teacher preparation program and immediately follows the semester in which PSTs complete the science methods course. Also 16 weeks in length, PSTs attend their placements all day, Monday-Friday. As with the prior semester, the PSTs split their time between placements, with eight weeks at each placement. Placements during the student teaching semester are the same two placements from the previous semester. In addition to attending their placements, the PSTs attended monthly program seminars, where they reviewed additional topics relevant to their current teaching (i.e., classroom management, job searches, etc.).

## Data Collection

### *STEBI-B*

The STEBI-B (Enochs & Riggs, 1990) measures the levels of PSTs self-efficacy towards their ability to teach science. This survey consists of 23 items, all requiring PSTs to respond to 5-point Likert-type statements. The STEBI-B is divided into two subscales: personal science teaching efficacy (PSTE) and student outcome expectancy (STOE). The STEBI-B was administered at three different points: the beginning of the science methods course, the end of the science methods course, and at the end of student teaching. At the conclusion of the STEBI-B were open questions that allowed PSTs to describe their past and current experiences with science, good versus bad days in science, good versus bad science teachers, and how science would be taught in their future classroom.

### *Interviews*

Individual interviews were completed at the end of the science methods course and then again at the end of the student teaching semester. Both interviews were conducted virtually through Microsoft Teams and lasted about 30 minutes. Both interviews were recorded. The purpose of the first interview was to gain insight into experiences during the science methods semester, including the teaching of the science lesson plan. In addition, questions were asked about confidence to teach science both before and after the science methods course. Example prompts included: Describe your two placements and the science instruction you saw in each. Describe the science lesson plan you wrote for the methods course and what it was like to teach it. If you could teach your science lesson plan again, what (if anything) would you do differently and why? What was your confidence to teach science before the course? What is your confidence to teach science now, after the course? The purpose of the second interview was to gain insight to the student teaching semester and its potential influence on confidence to teach science. Example prompts included: Briefly describe your student teaching experience for each placement. How successful do you feel in your science teaching? What are those feelings based upon? Has anything increased your confidence to teach science? Has anything decreased your confidence to teach science?

## Data Analysis

### *Overall Analysis*

Following the recommendations outlined by Creswell and Plano-Clark (2011), quantitative and qualitative data were collected at the same points and treated equally, owing to the value each piece provided in the overall interpretation. Each piece of data was analyzed separately and then combined to complete an overall interpretation. Specifically, the data was analyzed to determine if, and in what ways, the two sets of results converged, diverged, related, and/or combined to form a better overall understanding of this PST's experiences and self-efficacy towards science teaching. In addition, the use of a single case study will provide a deeper analysis for this PST (Rowley, 2002).

### *STEBI-B Analysis*

Participant responses were entered into Excel using the original protocol from Enochs and Riggs (1990). Ten of the 23 statements were worded negatively and thus were reverse scored to maintain consistency between the positively and negatively worded statements. Responses were totaled for each subscale for each of the survey collection points (pre, post, and delayed post). Total scores for each subscale and each collection point were analyzed and compared for changes.

### *Open Questions*

Responses to the open questions were compiled into a table and organized by question and iteration of survey (i.e., pre-methods course, post-methods course, and post-clinical teaching). Responses were then examined for any changes between the different iterations. Table 1 provides a sample of the questions and Monica's responses.

### *Interview Analysis*

Overall steps followed the procedure outlined by Saldana (2015), which were to: 1) read through the two interviews (post-methods course and post-student teaching) for initial codes; 2) read through the two interviews again to verify and clean the initial codes; 3) develop categories from the codes; and 4) compare categories to literature and the theoretical framework. Initial categories were based on the questions from the structure of the interviews, but then open codes were developed based on the responses, as described by Elliot (2018). To ensure validity, the researcher coded a clean version of the document to ensure coding was consistent (Elliot, 2018). Table 2 displays the categories, codes, and example texts from interviews.

**Table 1**

*Sample of the Open Questions and Participant Responses*

| Prompt | Pre-Methods Course | Post-Methods Course | Post-Clinical Teaching |
|---|---|---|---|
| What three words or phrases would you use to describe a "good day" in science? | Engaging<br>Imaginative<br>Flexible | Fun<br>Hands-on<br>Direct | Engaged<br>Creative<br>Communicating |
| If you are planning on teaching science in the future, what will science instruction look like in your future classroom? If you are NOT planning on teaching science in the future, how could you incorporate science concepts into your classroom instruction in the future? | I plan to use science as a way to discover all types of things that can apply to other subjects or are practical to know and use in daily life. I want to use science as a tool to understand things and ask questions that open students' minds and perspectives on the world. | I plan to have lots of experiments, games, and puzzles | Science instruction will be very engaging, with hands on activities and experiments for students to explore. Lots of time for asking and discussing questions, terms, and ideas. |

**Table 2**

*Categories, Codes, and Example Text from Interviews*

| Categories (based on interview structure) | Initial Codes (based on responses) | Example Text (Interview)<br>1 – post science methods<br>2 – post clinical teaching |
|---|---|---|
| Science Instruction Modeled in Each Placement | Instruction | It [science] was taught on its own (kindergarten placement; Interview 1)<br>would start up with a video [science with CT1] (Interview 2) |
| | Integration | connecting the that to like the word of the day or the question of the day (kindergarten placement; Interview 1)<br>would try and tie in the science with other subjects too (Interview 2) |
| | Assessment | answer through examples (Interview 1)<br>then they would answer some questions [science with CT1] (Interview 2) |
| | Collaboration | discuss it together (Interview 1) |
| | Routine | that's not the norm (placement instruction; Interview 1) |

| **Categories (based on interview structure)** | **Initial Codes (based on responses)** | **Example Text (Interview)**<br>**1 – post science methods**<br>**2 – post clinical teaching** |
|---|---|---|
| | Pandemic | you know circumstance that we're in (Interview 1)<br>normally with like without COVID they would go outside and do like a rock hunt [science with CT1], but they weren't really allowed to go outside 'cause they would kind of be close to each other (Interview 2) |
| | Mentor | I learned from them [CT] (Interview 1)<br>she [CT2] was like I'm here any questions, anything you, you need, like let me know (Interview 2) |
| | Monitoring | [CTs] observed very closely (Interview 1) |
| | Giving Up | And they're [CTs] like, "OK, well, I'm not even going to do anything today because they're going to get mad at me no matter what." (Interview 1) |
| | Planning | she [CT1] didn't want me to make new lessons. She didn't want me to come up with new ideas (Interview 2) |
| Confidence to Teach Science | Confidence | I was like if I don't, even if I wasn't even taught what these kids are going to be taught, how can I teach it? (Interview 1)<br>But I remember being like oh yeah, I'm not going to be good at teaching science like kind of being scared about the thought of doing that. And then now I'm like, oh yeah, I can definitely teach science. Like I loved teaching science. (Interview 2) |
| | Knowledge | thinking like, "OK, well I have to be this super smart I need to know everything and just tell them and like know how to explain it well" (Interview 1)<br>I want to make sure that they're not questioning my content knowledge (Interview 2) |
| | Overwhelm | I remember being overwhelmed by science (Interview 1) |
| Factors Affecting Confidence | Enjoyment | it was fun (teaching the lesson plan from methods course) (Interview 1) |
| | Impact | I think the course definitely did like facilitate that realization for me (ability to teach science) (Interview 1)<br>I notice that the things that we reviewed that I taught them they knew still and the things that we reviewed that they, I didn't teach them they didn't know at all [science]; the hands-on stuff really made a difference (Interview 2) |
| | Ability | that really seems like scared me because I could not do the chemistry. I could not do physics (Interview 1) |
| Experiences with Teaching Science | Challenges | it was hard to narrow down what exactly I wanted to incorporate (Interview 1)<br>you can't give in person kids different assignments than the online kids [due to pandemic]; that was I think the biggest challenge (Interview 2) |
| | Activity(ies) | they can learn through doing (Interview 1)<br>I tried to have them do a lot of hands on stuff and she [CT2] did too (Interview 2) |
| | Choice | if I don't like this activity or if it doesn't really fit with my assessment questions, I can change it to another one (Interview 1)<br>she [CT2] was like, you know, anything you want to do, you can do (Interview 2) |
| | Application | on paper it was a lot more, you know, hands on, than the actual lesson (Interview 1) |
| | Multiple Days | I would want to spend more than just one class (Interview 1) |

| **Categories (based on interview structure)** | **Initial Codes (based on responses)** | **Example Text (Interview)**<br>**1 – post science methods**<br>**2 – post clinical teaching** |
|---|---|---|
| | Scaffolding | it's really good when science lessons are built on each other (Interview 1) |
| | Rigid/Flexible | have to use this book and only this set of standards and only these topics (Interview 1)<br>I had to adapt it [instruction/activities] a lot (Interview 2) |
| | Responsibility | she [CT2] let me take more control with that; I liked it a lot (Interview 2) |
| | Enjoyment | I was having a really great time with them [5th graders] and they were really excited to do the science (Interview 2) |
| | Technology | I used a lot of like online tools (Interview 2) |
| | Engagement | they could do more of this stuff as a class and so the online kids would be engaged in the same way that the in person kids were [using online tools] (Interview 2) |
| Experiences with Science in General | Experiences | I think like it [confidence in science] goes back to my own experience in school like my science, I never had like that hands on kind of experience. Like it was mostly just lecture and then textbook questions. (Interview 1)<br>So she [CT2] kind of pushed me off the diving board in a way and I was scared. But I felt so grateful for that experience because at the end of it I was like oh, I'm totally ready to do this 'cause I've been doing it this whole time (Interview 2) |

# Findings

## Early Experiences

Monica attended a small, faith-based school for all her K-12 school years. Science in this school was aligned to a very narrow curriculum that fit within the bounds of the religious beliefs of the school. She remembers completing science experiments, which she found to be fun and enjoyable, however she also realized these experiments were not the norm. When asked to describe a positive experience, Monica described a time in fourth grade when her class conducted an experiment where they observed the growth of mold on bread after being rubbed on a variety of surfaces. On the other hand, when asked to describe a negative experience, Monica mentioned a specific teacher in eighth grade who tried to trick students on tests by giving questions that could have multiple answers or on topics not yet covered.

Looking back on her past experiences, Monica came to the realization that she would have to "do basic science research" (Interview 1) to become more familiar with topics she would have to teach in the future. This led to feelings of overwhelm and that she "would have to be this super smart science person" (Interview 1) to be able to teach science to her future students. Essentially, Monica came to her science methods course feeling that if she "wasn't even taught what these kids are going to be taught, how can I teach it" (Interview 1)?

## Experiences in the Methods Course

### *Self-efficacy at the Beginning of the Science Methods Course*

Based on the STEBI-B taken at the start of the science methods course, Monica held moderately high levels of PSTE, with a score of 53/65 on this subscale. Specifically, Monica strongly agreed with the statement "I will continually find better ways to teach science." Whereas she agreed with the statement "I wonder if I will have the necessary skills to teach science." As for the STOE subscale, Monica held a moderate level, scoring 33/50 on this subscale. She agreed with the statement "The teacher is generally responsible for the achievement of students in science" and was neutral to the statement "Students' achievement in science is directly related to their teacher's effectiveness in science teaching." When asked to describe her level of confidence to teach science, Monica stated that it was neutral to negative and that she felt "overwhelmed by science."

### *Thoughts about Science Teaching at the Beginning of the Science Methods Course*

When asked to share her thoughts about a good day in science, Monica stated it would be engaging, imaginative, and flexible, whereas a bad day in science was described as restrictive, overwhelming, and confusing. Monica described a good science teacher as creative, communicative, and open-minded, but a bad science teacher as boring, unclear, and rude when students do not understand the content. Monica believed that her ability to be an effective elementary science teacher was "above average." When asked to describe how science should be taught, Monica said it should be more activity-based instruction than a textbook-based presentation. Specifically, Monica stated:
"I plan to use science as a way to discover all types of things that can apply to other subjects or are practical to know and use in daily life. I want to use science as a tool to understand things and ask questions that open students' minds and perspectives on the world" (pre-course survey).

### *Early Field Experiences During the Science Methods Course*

During the semester Monica took the science methods course, she also had early field experiences in two different classrooms. As part of these experiences, she spent one day each week in the classroom, eight weeks in Placement one, and eight weeks in Placement two for a total of 16 weeks. For Monica's first placement, she visited a kindergarten classroom where all subjects were taught by her CT, and more than half of the instruction was face-to-face. When asked about the format of science instruction, Monica explained that science was taught on its own, but was connected to a word or question of the day. Additionally, science instruction involved mostly the showing of videos and then completing worksheets and took up approximately 150 instructional minutes per week. For her second placement, Monica visited a fifth-grade mathematics and science classroom, where her CT taught both subjects and more than half of instruction was face-to-face. Science was taught on its own and involved the use of videos and online questions, taking up approximately 100 instructional minutes per week.

### *Self-efficacy and Beliefs About Teaching at the End of the Science Methods Course*

At the end of the course, Monica again took the STEBI-B, indicating very little change on the PSTE subscale, scoring 55/65 (+2 versus the pre-test). These small changes can be seen in her responses to the statement "Even if I try very hard, I will not teach science as well as I will most subjects," moving from disagree to strongly disagree, and to the statement "I know the steps necessary to teach science concepts effectively," moving from agree to strongly agree. On the other hand, Monica's scores on the STOE subscale increased from 33 to 41/50 (+8 versus the pre-test). These changes can be seen in her responses to the statement "When a student does better than usual in science, it is often because the teacher exerted a little extra effort," moving from disagree to agree, and to the statement "When a low-achieving child progresses in science, it is usually due to extra attention given by the teacher," moving from neutral to agree.

When asked to describe her level of confidence to teach science, Monica stated that it was definitely positive, explaining that "I know more than I thought I did" (Interview 1). Monica shared that, through the methods course, she learned she can use experiments and activities to assist in her teaching, that students can learn through doing, and that the course helped her to learn that there are different ways to teach science than how she learned in her K-12 school years. Monica also explained that seeing her CTs teach science (and having fun with it) helped increase her own level of confidence to teach science.

### *Thoughts about Science Teaching at the End of the Science Methods Course*

Again, Monica was asked to describe a good day in science and a bad day in science. For her, a good day is "fun, hands-on, and direct," whereas a bad day is "confusing, disinterested, and includes worksheets." Likewise, Monica was asked to describe the characteristics of a good science teacher and a bad science teacher. She described a good science teacher as "creative, expressive, and encouraging," and a bad science teacher as "unenthusiastic, disengaged, and boring." As in the pre-course survey, Monica stated that her effectiveness as a future elementary science teacher would be "above average." Again, Monica stated that science instruction should be more activity-based than a textbook-based presentation. As for her future classroom, she plans to have lots of experiments, games, and puzzles.

## Experiences in Student Teaching

Immediately following the science methods course, Monica had her student teaching semester. During this semester, she visited the same two classrooms from her early field experiences, this time spending all day Monday to Friday in each placement, again eight weeks in Placement one (kindergarten, all subjects) and eight weeks in Placement two (fifth-grade mathematics and science). In Monica's first placement, science instruction began to be incorporated with other content occasionally, taking approximately 100 instructional minutes each week. There were more hands-on activities, in addition to the videos, and use of the interactive web platform SeeSaw. When describing her experiences from her first placement, Monica explained that her CT developed the science lessons for the grade level team and that her experience teaching was "a little more restrictive" (Interview 2). When asked to explain further, Monica said they were not able to do much because of the pandemic, with half of the students online and the other half in person. She stated the overall experience was tough, but that it was also good to get that experience.

During the student teaching semester in her second placement, Monica noted that science was once again taught on its own, taking approximately 150 instructional minutes per week. There were some hands-on activities, in addition to the videos, and copying terms into a notebook. When describing her experiences from her second placement, Monica explained that another teacher on the grade level team developed the science lessons, but that she and her CT modified them. Monica stated that her CT in this placement encouraged her to try anything she wanted, explaining that the students' lowest benchmark scores were in science, so the CT wanted to engage them more. Overall, Monica liked having more responsibility and control, stating that her second CT "pushed me off the diving board in a way" (Interview 2). Monica also indicated that she felt more comfortable teaching to this age group of students.

### *Self-efficacy at the End of Student Teaching*

At the conclusion of her student teaching semester, Monica completed the STEBI-B for a third time. Table 3 provides her scores for all three iterations of the STEBI-B.

**Table 3**

*Monica's STEBI-B Results*

| ***STEBI-B Subscale (Highest Possible Score)*** | **Pre-test** | **Post-test** | **Change (Pre to Post)** | **Delayed Post-test** | **Change (Post to Delayed Post)** |
|---|---|---|---|---|---|
| *PSTE (65)* | 53 | 55 | +2 | 64 | +9 |
| *STOE (50)* | 33 | 41 | +8 | 43 | +2 |

For her PSTE, Monica held moderately high levels at the start of the science methods course, with very little increase at the end of the science methods course, and then a large increase at the end of student teaching. The statement on the PSTE subscale that showed the largest change was "I wonder if I will have the necessary skills to teach science," moving from agree to disagree. Most of the other statements in this subscale moved from agree to strongly agree.

As for her science teaching outcome expectancy, Monica held a moderate level at the start of the science methods course, with a large increase at the end of the science methods course and then very little increase at the end of student teaching. The statement on the STOE subscale that showed the largest change was "When a student does better than usual in science, it is often because the teacher exerted a little extra effort," moving from disagree (pre-test) to agree (post-test) to strongly agree (delayed post-test). Other statements moved from neutral to agree (e.g., "When a low-achieving child progresses in science, it is usually due to extra attention given by the teacher") or from disagree to neutral ("If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher").

### *Beliefs about Teaching Science at the End of Student Teaching*

Table 4 includes the phrases Monica used to describe good and bad days in science, as well as good and bad science teachers at all three data collection points.

**Table 4**

*Descriptions of Classroom and Teacher Characteristics*

| **Category** | **Pre-test Phrases** | **Post-test Phrases** | **Delayed Post-test Phrases** |
|---|---|---|---|
| Good Days | Engaging<br>Imaginative<br>Flexible | Fun<br>Hands-on<br>Direct | Engaged<br>Creative<br>Communicating |
| Bad Days | Restrictive<br>Overwhelming<br>Confusing | Confusing<br>Disinterested<br>Worksheet | Confusing<br>Boring<br>Anxious |
| Good Science Teacher | Creative<br>Communicative<br>Open-minded | Creative<br>Expressive<br>Encouraging | Flexible<br>Knowledgeable<br>Fun |
| Bad Science Teacher | Boring<br>Unclear<br>Rude when students do not understand | Unenthusiastic<br>Disengaged<br>Boring | Bad communicator/unclear<br>Closed off<br>Difficult |

When examining the words Monica chose to describe a good day in science, the phrase "engaging/engaged" appears at two different points, indicating Monica's belief that the central feature of a good day in science is when students are a part of the learning process. On the other hand, when it comes to a bad day in science, Monica was consistent in the use of the phrase "confusing," indicating a belief in that when students do not understand the material, this leads to a bad day in science. When describing the characteristics of a good science teacher, Monica used the phrase "creative" at two different points and then "flexible" on the third iteration. For Monica, being a good science teacher involves imagination on the part of the teacher and not being fully bound to one idea. When describing the characteristics of a bad science teacher, Monica used the phrase "boring" at two different points, indicating that bad science teachers are either not engaged with students or materials or excited to be teaching.

When asked to describe how science should be taught, once again Monica felt science instruction should be more activity-based instruction than textbook-based presentation. As for science in her future classroom, it will be very engaging, with hands on activities and experiments for students to explore and lots of time for asking and discussing questions, terms, and ideas. Maintaining a consistent belief in her effectiveness as a future elementary science teacher, Monica stated she would be "above average" yet again. When it came to describing her overall beliefs in her ability to teach science and how they changed from the start of the science methods course to end of student teaching, Monica explicitly stated:

> I remember being like oh yeah, I'm not going to be good at teaching science like kind of being scared about the thought of doing that. And then now I'm like, oh yeah, I can definitely teach science. Like I loved teaching science!

## Discussion

The overarching research question guiding this study was: How do prior experiences with science and classroom teaching experiences, in addition to the science methods course, affect the level of science teaching self-efficacy and the perceptions of science teaching for preservice elementary teachers? The specific research questions were:

1) What are the PSTE and STOE beliefs of preservice elementary teachers as measured by the STEBI-B at the beginning and end of their science methods course, and the end of the student teaching semester?
2) What is the impact of prior experiences on self-efficacy and the perceptions of science teaching?
3) What is the impact of the science methods course on self-efficacy and the perceptions of science teaching?
4) What is the impact of classroom teaching experiences during student teaching on self-efficacy and the perceptions of science teaching?

### Research Question 1: Changes in Self-efficacy

As shown previously in Table 1, Monica's scores on both subscales of the STEBI-B increased from the beginning of the science methods course semester to the end of the clinical teaching semester. From the beginning to the end of the science methods course, Monica's scores on the STOE subscale showed a greater increase than on the PSTE subscale, indicating the methods course had a greater impact on her beliefs in her ability to affect student outcomes. The increases on the STEBI-B during the science methods course support the findings reported in previous studies (Flores, 2015;

McDonnough & Matkins, 2010; Menon & Azam, 2021). From the end of the science methods course to the end of clinical teaching, Monica's overall STEBI-B increased, yet this time it was the PSTE subscale that showed the greater increase. This continued increase in scores on the STEBI-B during student teaching support the results from other studies (Palmer, 2006; Palmer et al, 2015; Smolleck & Mongan, 2011; Utley et al., 2005). For Monica, the greatest increase for the PSTE subscale occurred from the end of the science methods course semester to the end of the student teaching semester. On the other hand, the greatest increase for the STOE subscale occurred from the beginning to the end of the science methods course semester. These results indicate that, for Monica, the methods course had a greater impact on her beliefs in her ability to affect student outcomes, whereas the student teaching semester had a greater impact on her beliefs in her ability to teach science, supporting the findings from several other studies.

## Research Question 2: Impact of Prior Experiences

Monica stated that she felt unprepared and overwhelmed when it came to teaching science, mostly due to her own K-12 science experiences. According to Monica, the science taught in her small school was very limited and she knew she would have to learn more science content to be able to teach it effectively to her future students. Like the findings presented by Kazempour (2014), experiences with science in K-12 classrooms can directly impact confidence in science. However, Monica's acknowledgement that she would need to further her study of science topics seems to contradict the findings reported by Jarrett (1999) in that negative, or limited, experiences do not necessarily turn someone away from science. For Monica, she was aware of her limited science content and recognized the need for continued study if she were to be able to teach science to her future students. This realization may explain Monica's moderately high scores on the initial STEBI-B.

## Research Question 3: Impact of the Science Methods Course

As illustrated in the larger increase on the STOE subscale, the science methods course had a greater impact on Monica's beliefs in her ability to affect student outcomes. These findings contradict those by Morrell and Carroll (2003). By modeling the implementation of science activities into the elementary classroom, Monica stated that the science methods course showed her the steps necessary for engaging students in the learning process. By encouraging students to learn by doing, Monica realized that instruction was not fully dependent on her content knowledge and being solely responsible for passing on that knowledge, but rather that students would gain understanding through activities.

## Research Question 4: Impact of Classroom Teaching Experiences

Monica experienced more flexibility and freedom in her teaching during her second placement, a fifth-grade mathematics and science class. She explained that her CT in this particular classroom modified the grade-level developed lesson plans and encouraged her to try different activities or methods of instruction. Overall, her CT gave Monica more responsibilities than her previous CT. Monica noted that students seemed to comprehend the concepts more and show more excitement when hands-on activities were implemented. Monica felt it was this level of responsibility that directly impacted her confidence to teach science. Monica's explanation of how her teaching impacted her confidence to teach science mirror the findings from several studies (Nikoçeviq-Kurti, 2021; Simsar & Jones, 2021; Soprano & Yang, 2013), indicating that the actual act of teaching is what impacts self-efficacy the most. It appears that for Monica, it was the mentorship and modeling of the CT that were at the center of further developing self-efficacy during the student teaching semester, as noted in prior research (Knoblauch & Woolfolk-Hoy, 2008; Simsar & Jones, 2021).

## Implications

Although the findings presented here are limited to only one PST and her perceptions about science teaching, much can be learned from her experiences. The science methods courses within teacher preparation programs lay the foundation for science instruction in the elementary classroom. Modeling science activities, especially those that allow students to gain understanding for themselves, is crucial for three reasons. One, these activities allow PSTs to see first-hand what is needed to implement a science activity, both from the student perspective and the teacher perspective, leading to increased levels of science teaching self-efficacy. Second, when PSTs experience the science activities for themselves, they are able to connect these activities to their future teaching and how they provide meaningful learning experiences for their future students. Third, these activities provide an opportunity to address preservice elementary teacher understanding of science concepts common to the elementary curriculum. This will lead PSTs to understand the level of science understanding they need to possess themselves, and also how to help their future students increase their own level of understanding in science.

Building from teacher preparation courses, the student teaching experience provides opportunities for PSTs to practice the implementation of science activities when they are supported by their CTs. It is vital for CTs to encourage and support these PSTs as they are practicing. First, CTs need to be willing to allow the PSTs opportunities to take on more responsibilities gradually throughout their time in the clinical teaching experience. The CT should be there to gently push PSTs, but also model interactions with students, fellow teachers, administrators, and parents. Second, CTs can provide some flexibility to the preservice elementary teachers to implement the strategies learned from the courses within their teacher preparation program, as they gradually take on more responsibility.

This second point requires collaboration between multiple stakeholders: the teacher preparation program, the school administration, and the classroom teacher. Teacher preparation programs should be in constant communication with school administration so both parties are aware of best practices, the teacher preparation program providing the research aspect and the school administration providing the field-based aspect. Teacher preparation programs need to be aware of the most current classroom situations teachers are facing so they can ensure the courses reflect those occurrences and teach to those practices. School administration needs to be aware of current research trends and how those might affect classroom practice. Finally, CTs need to be given flexibility in creating supportive environments for preservice teachers, encouraging them to practice strategies reflective of the most current research and needs of the students and schools.

## Conclusions

Many factors affect the development of science teaching self-efficacy: prior experiences, the science methods course, and classroom teaching experiences. This is a very complex relationship that is not a *one-size-fits-all* situation. Some PSTs who have limited or negative experiences with science will either avoid science and develop low science teaching self-efficacy, while others with those same limited or negative experiences will use them as a launchpad to learn more about science and how best to teach it. Regardless of the type of prior experiences PSTs have with science, they must come to acknowledge them and how they might affect their abilities to teach science and then proactively participate in science methods courses that are designed to model the most current research and best practices for the elementary science classroom. Then, when these PSTs go into their student teaching experiences, they need to be supported by their CTs and schools to try out these practices. The preparation of the next generation of teachers requires the collaboration of classroom teachers, their school administration, and the teacher preparation program. Further research should examine how early years of teaching continue to shape science teaching self-efficacy. This could lead to the development of support systems for recent graduates and other in-service teachers.

*This work was supported by the Research Seed Grant Competition sponsored by the Center for Research on Teaching and Learning Excellence at the University of Texas at Arlington.*

**Melisa Hulings** (melissa.hulings@sfasu.edu). Before moving to higher education, Dr. Hulings was a classroom science teacher, with teaching experience in grades 7-12. Dr. Hulings currently teaches science methods courses in the elementary and middle grades certification programs. Her research focuses on understanding how pre-service teachers' past experiences with science influence their current attitudes toward science and their beliefs in their abilities to teach science in the future.

## References

Bandura, A. (1989). Human agency in social cognitive theory. *American psychologist, 44*(9), 1175.

Bandura, A. (1993). Perceived self-efficacy in cognitive development and functioning. *Educational Psychologist, 28*(2), 117-148.

Bandura, A. (2003). Social cognitive theory for personal and social change by enabling media. In A Singhal, M. J., Cody, E. M. Rogers, & M. Sabido (Eds.), *Entertainment-education and social change* (pp. 97-118). Routledge.

Bulunuz, M., & Jarrett, O. S. (2010). Developing an interest in science: Background experiences of preservice elementary teachers. *International Journal of Environmental & Science Education, 5*(1), 65-84.

Cinici, A. (2016). Pre-service teachers' science teaching self-efficacy beliefs: The influence of a collaborative peer microteaching program. *Mentoring & Tutoring: Partnerships in Learning, 24*(3), 228-249.

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). SAGE Publications.

Creswell, J. W., & Plano-Clark, V. L. (2011). *Designing and conducting mixed methods research* (2nd ed.). SAGE Publications.

Elliot, V. (2018). Thinking about the coding process in qualitative data analysis. *The Qualitative Report, 23*(11), 2850-2861. https://doi.org/10.46743/2160-3715/2018.3560

Enochs, L. G., & Riggs, I. M. (1990). Further development of an elementary science teaching efficacy belief instrument: A preservice scale. *School Science and Mathematics, 90*(8), 694-706.

Flores, I. M. (2015). Developing preservice teachers' self-efficacy through field-based science teaching practice with elementary students. *Research in Higher Education Journal, 27*, 1-19.

Franks, B. A., McGlamery, S. L., & VanWyngaarden, K. (2016). Effects of teaching in a science summer camp on the science self-efficacy of preservice teachers. *The Delta Kappa Gamma Bulletin: International Journal for Professional Educators,* 63-73.

Grusec, J. E. (1992). Social learning theory and developmental psychology: The legacies of Robert Sears and Albert Bandura. *Developmental Psychology, 28*(5), 776-786.

Jarrett, O. S. (1999). Science interest and confidence among preservice elementary teachers. *Journal of Elementary Science Education, 11*(1), 47-57.

Kazempour, M. (2013). The interrelationship of science experiences, beliefs, attitudes, and self-efficacy: A case study of a pre-service teacher with positive science attitude and high science teaching self-efficacy. *European Journal of Science and Mathematics Education, 1*(3), 106-124.

Kazempour, M. (2014). I can't teach science! A case study of an elementary pre-service teacher's intersection of science experiences, beliefs, attitude, and self-efficacy. *International Journal of Environmental & Science Education, 9*, 77-96.

Knoblauch, D., & Woolfolk-Hoy, A. (2008). "Maybe I can teach *those* kids." The influence of contextual factors on student teachers' efficacy beliefs. *Teaching and Teacher Education, 24*, 166-179.

McDonnough, J. T., & Matkins, J. J. (2010). The role of field experience in elementary preservice teachers' self-efficacy and ability to connect research to practice. *School Science and Mathematics, 110*(1), 13-23.

McKinnon, M., & Lamberts, R. (2014). Influencing science teaching self-efficacy beliefs of primary school teachers: A longitudinal case study. *International Journal of Science Education, Part B: Communication and Public Engagement, 4*(2), 172-194.

Menon, D., & Azam, S. (2021). Investigating preservice teachers' science teaching self-efficacy: An analysis of reflective practices. *International Journal of Science and Mathematics Education, 19*, 1587-1607.

Morrell, P. D., & Carroll, J. B. (2003). An extended examination of preservice elementary teachers' science teaching self-efficacy. *School Science and Mathematics, 103*(5), 246-251.

Nikoçeviq-Kurti, E. (2021). Fostering student teachers' self-efficacy and professional identity through vicarious experiences. *International Journal of Education and Psychology in the Community, 11*(1 & 2), 140-163.

Palmer, D. H. (2006). Sources of self-efficacy in a science methods course for primary teacher education students. *Research in Science Education, 36*, 337-353.

Palmer, D., Dixon, J., & Archer, J. (2015). Changes in science teaching self-efficacy among primary teacher education students. *Australian Journal of Teacher Education, 40*(12), 27-40.

Rowley, J. (2002). Using case studies in research. *Management Research News, 25*(1), 16-27.

Saldana, J. (2015). *The coding manual for qualitative researchers* (3rd ed.). SAGE Publications.

Settlage, J., Southerland, S. A., Smith, L. K., & Ceglie, R. (2009). Constructing a doubt-free teaching self: Self-efficacy, teacher identity, and science instruction within diverse settings. *Journal of Research in Science Teaching, 46*(1), 102-125.

Simsar, A., & Jones, I. (2021). Field experiences, mentoring, and preservice early childhood teachers' science teaching self-efficacy beliefs. *International Journal on Social and Education Sciences, 3*(3), 518-534.

Smolleck, L. A., & Mongan, A. M. (2011). Changes in preservice teachers' self-efficacy: From science methods to student teaching. *Journal of Educational and Developmental Psychology, 1*(1), 133-145.

Soprano, K., & Yang, L. (2013). Inquiring into my science teaching through action research: A case study on one pre-service teacher's inquiry-based science teaching and self-efficacy. *International Journal of Science and Mathematics Education, 11*, 1351-1368.

Utley, J., Mosely, C., & Bryant, R. (2005). Relationship between science and mathematics teaching efficacy of preservice elementary teachers. *School Science and Mathematics, 105*(2), 82-87.

Velthuis, C., Fisser, P., & Pieters, J. (2014). Teacher training and pre-service primary teachers' self-efficacy for science teaching. *Journal of Science Teacher Education, 25*(4), 445-464.

Wingfield, M. E., Freeman, L., & Ramsey, J. (2000, April 28-May 1). *Science teaching self-efficacy of first year elementary teachers trained in a site based program* [Paper presentation]. Annual meeting of the National Association for Research in Science Teaching, New Orleans, LA, United States.

ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 27, NO. 4, 18-58

# Scripted Curriculum vs. Understanding by Design: A Comparative Study of Curriculum Design Using Biology Curriculum

Masomeh Mahzoon-Hagheghi
*Texas A&M University-Corpus Christi*

Faye Bruun
*Texas A&M University-Corpus Christi*

## ABSTRACT

The purpose of this study was to analyze the effectiveness of scripted biology curriculum as a means of providing students with the information required to increase content knowledge, while comparing curriculum developed by the teacher that utilizes the Understanding by Design (UbD) framework (Wiggins & McTighe, 2005). The study used a mixed method, concurrent triangulation design which revealed that there was a significant difference between student growth from the pretest to the posttest. The teacher reflection logs and student focus groups identified two themes regarding science content knowledge: instructional/learning style and using discussion within the instructional cycle for both curricula. It was evident that the increase in content knowledge was associated with the utilization of discussion during the learning cycle. The teacher reflection logs and student focus groups also identified two themes when looking at the perception of the learning environment: the effect of teacher relationship on instruction and the effect of time on the learning environment. According to the instrument used, both groups of students showed growth, however, there was a larger gain among the students receiving the Understanding by Design curriculum. A major contributing factor for the growth among all students was the relationship the teacher had with them to meet their individual academic needs.

*Keywords:* scripted science curriculum, Understanding by Design

## Introduction

From the beginning of American education, the fundamental purpose was to "instill in students' moral values, a common cultural identity, and civic values" (Spring, 2014, p. 7). This idea has continued throughout education, but over the last decade has become more influenced by politics and federal mandates from people who are far from the realm of education. Because America is such a diverse country, the education system has had to make accommodations and broaden the spectrum of curriculum. Due to an increase of federal involvement, the government now has direct control over student learning, more specifically teachers teaching to the test (Spring, 2014, p. 225).

With the 1957 launch of the Russian Satellite Sputnik, and the fear of falling behind other nations, there was demand for innovation in technology and engineering in the United States. Following Sputnik, President Eisenhower called for action, stating that America needed scientists and it would be a collaborative effort of the federal, state, and local governments to meet these demands. Shortly after, the National Aeronautics and Space Administration (NASA) was created in 1958 and the space program began to unfold. This drove Americans to put men on the Moon, send robots to Mars (Apollo), explore the depths of the Earth, and increase the knowledge of the planet and solar system at the beginning of the Space Race. In 1983, during the Regan administration, the National Commission on Excellence in Education (1983) published *A Nation at Risk* that further reformed science and engineering programs as a means to keep the United States competitive. This initiative called for seven-hour school days and a high school curriculum that needed to include: four years of English, three years of mathematics, three years of science, three years of social studies, and a half year of computer science.

With federal agendas and grants such as No Child Left Behind (NCLB) Act and the Bill and Melinda Gates Grant, educational policies and political agendas push for stronger curriculum mandates and greater teacher accountability (Cunningham et al., 2009). These agendas have created a culture of fear and anxiety among teachers by linking scores to teacher performance and whether they keep their jobs, especially in schools with high populations of special education, English language learners, and low socio-economic groups (Ravitch, 2010, p. 269). With the implementation of high-stakes accountability and standardization, there is now a lack of teacher autonomy which has led to the adoption of reductionist notions and in turn has caused teachers to oppose their professional beliefs and values. McLaren (2007) suggests that educators must provide an education that is relevant to students in order to be critical, transformative, and to change the world to help those who suffer and need the most. Freire (2005) further explains that educators cannot teach content as if that were all there is, but they should give creative wings to the students' imaginations and demonstrate to students the importance of imagination for life, because imagination helps curiosity and inventiveness, just as it enhances adventure, without which we cannot create (p.93).

Due to the increase of federal involvement in education, teachers are not given the autonomy to teach the content but are required to cover a large body of state and federal standards. Kang (2016) explains that high stakes accountability driven times is a direct result of national, state, and district policies affecting how teachers teach. These standards are generally proposed by politicians, and based on these results, the teachers, principals, schools, and school districts are then categorized. MacGillivray et al. (2004) suggest that these curriculum mandates are a form of colonization that serve to control teachers' work by limiting their professional autonomy. Giroux (1988) explains that the dominant culture in school is organized around curricular, instructional, and evaluation experts that do the thinking while the teachers are expected to implement what they are given.

The standardization paradigm is based on the standardization of curriculum, accountability of standardized test scores, and the deskilling of the teaching profession (Spring, 2014, p. 87). Apple (2006) explains that politicians and corporate leaders believe education is a business and should be treated no differently than any other business, thereby wanting to raise standards and require more high-stakes testing that they believe will guarantee schools will return to time-honored content and more traditional methods (p. 129). With the implementation of high-stakes accountability and standardization, there is now a lack of teacher autonomy which has led to the adoption of reductionist notions and in turn has caused teachers to oppose their professional beliefs and values. According to Apple (2006), "traditional content and methods have been jettisoned as our schools move toward more trendy subjects that ignore knowledge that made us such a great nation" (p. 129).

The goal of education should be to inspire students to learn and acquire knowledge of a variety of content through various methods; "education depends on the intimate contact between a good teacher and an inquiring student" and should be a "catalyst to interest students in learning for themselves" (Ravitch, 2010, p. 284). Freire (1970) indicates that the current education system is training students to passively receive, memorize, and repeat information. Freire goes on to say that education could function in one of two ways:

> As an instrument that is used to facilitate the integration of the younger generation into the logic of the present system and bring about conformity to it, or it becomes 'the practice of freedom,' the means by which men and women deal critically and creatively with reality and discover how to participate in the transformation of their world" (Freire, 1993, p. 16).

McLaren (2007) suggests that educators must provide an education that is relevant to students in order to be critical, transformative, and to change the world to help those who suffer and need the most. Freire further explains that educators cannot teach content as if that were all there is, but they should give creative wings to the students' imaginations and demonstrate to students the importance of imagination for life, because imagination helps curiosity and inventiveness, just as it enhances adventure, without which we cannot create (Freire, 2005, p. 93).

The purpose of this study was to analyze the effectiveness of scripted biology curriculum as a means of providing students with the information required to be successful on standardized assessments, while comparing curriculum developed by the teacher that utilizes the Understanding by Design (UbD) framework. According to a review done by Roth (2007), Understanding by Design overcomes the impasse of development of coherent and cohesive curriculum by providing concise and practical guidance for experienced and inexperienced teachers. Roth (2007) goes on to explain that "UbD describes a practical and useful "backward" design process in which anticipated results are first identified; acceptable evidence for learning outcomes is established and, only then, are specific learning experiences and instruction planned" (p. 95). According to Wiggins and McTighe (2011), backward design is "an approach to designing a curriculum or unit that begins with the end in mind and designs toward that end" (p. 338).

## Background Research

With the expansion of scripted curriculum across schools and the increasing importance placed on standardized testing, it is necessary to begin researching how this type of curriculum affects student achievement. Along with looking at the effectiveness of scripted curriculum, it is important to add to the research on alternative curriculum and instruction methods for teaching science, such as the use of the Understanding by Design framework. According to Amrein and Berliner (2002), high stakes or standardized test scores have come to dominate the discourse about schools and their accomplishments. The authors further explain that policymakers borrowed principles from the business sector and attached incentives to learning and sanctions to poor performance on tests, where high performing schools would be rewarded and under performing schools would be penalized and would have to improve themselves to avoid further penalties (Amrein & Berliner, 2002).

Kang (2016) explains that the high-stakes accountability times have driven national, state, and district policies to play a role in how teachers teach. The author goes on to say that the current sociopolitical climate emphasizes standardized, regimented, and prescribed curriculum and instruction in order for schools and classrooms to be controlled. Smith et al. (1989) found that pressure to improve students' test scores caused some teachers to "neglect material that the external test does not include...reading real books, writing in authentic context, solving higher-order problems, creative and divergent thinking projects, longer-term integrative unit projects, [and] computer education..." (p. 268). Problematic side effects of high stakes testing for low-income students are the narrowing of curriculum and training students to pass a test without broader notions of learning and education (Amrein & Berliner, 2002).

Science curriculum is often described as "unrelated, difficult, and boring to learn in comparison with other topics" (Alwahaibi, et al., 2019). It is important for teachers to actively engage students in the learning process and have the ability to differentiate instruction in order to meet the needs of all students. Without students' interest in science, they may not make the effort to learn and understand the concepts that they are taught (Helldén 2005). Remillard et al. (2014) explains curriculum materials can be defined as resources to guide teacher instruction that can include textbooks and supplementary units or modules. Many studies show that science curriculum materials can have positive effects on student learning, including an increase in students' attitudes and motivation toward science (e.g., Häussler & Hoffmann, 2002; Roblin et al., 2017; White & Frederiksen, 1998), an increase in student understanding of science concepts (e.g., Harris et al., 2015; Sadler, et al., 2015), and an increase in their abilities to engage in science practices. Dias, Eick, and Dias (2011) as well as Wyner (2013) suggest that curriculum materials have also shown to have an influence on teachers' beliefs about science teaching and learning, the nature of science, and about themselves as knowers of science.

The current structure of the public-school system has made both learning and teaching difficult; "Just as it is difficult to communicate the complexities of teaching to the lay public, so it will be difficult to communicate to policymakers how full of conflict, how rife with contradictions, their decisions about accomplished teaching will be" (Wineburg, 2001, p 208). According to Wineburg (2001), knowledge of a subject is central to teaching, but expert knowledge of content does not determine good teaching and learning, but it requires a rich and deep understanding of many things (p 170). Pestalozzi (1951) affirms that learning slowly by one's own experience is better than to learn by rote memorization of facts that other people know, because this can lead to lose one's own free, observant and inquisitive ability to study (p. 35). Piaget (1973) explains that teachers should cease being a lecturer that is satisfied with transmitting ready-made solutions, but rather use a constructivist approach and become a mentor stimulating initiative and research (p. 16).

### *Constructivist Theory*

According to Resnick (1989), constructivism is a theory of learning or *meaning making* where individuals create their own new understandings on the basis of an interaction between what they already know and believe and ideas and knowledge that they come into contact with. Piagetian Constructivism is a complex blend of biology, epistemology, philosophy, and psychology with the entire purpose of intellectual growth as one of coming to know reality more objectively through developing increasingly decentered-and hence more objective-perceptions of reality (O'Loughlin, 1992). Piaget (1973) explains two misconceptions of active methods of instruction to be 1) a fear that the teacher would have no role to play in these experiments and success would depend on leaving the students entirely free to work or play as they will, 2) the teacher is needed to provide counterexamples that will lead to reflection and reconsideration of hasty solutions (p. 16).

By allowing teachers the freedom and autonomy to teach necessary content, both students and teachers will be able to express their knowledge and skills in a variety of methods, not simply through a standardized, multiple-choice test. According to Devetak and Glazar (2014) good teaching involves activities that require students to identify and activate relevant prior knowledge, includes *active* learning, encourages students to reflect on their thinking and ongoing learning, and pushes students to discuss their work. Kumar and Gupta (2009) explain that a constructivist classroom provides opportunities to observe, work, explore, interact, raise question inquiry, and share their expectation to all. Constructivist teaching is a process of personal knowledge construction that occurs within the minds of individual learners and is contingent upon the way the learner constructs his/her thinking (Taber, 2019).

## Scripted Curriculum

Schools face the pressure of passing standardized tests, causing many districts across the country to implement various forms of scripted curriculum. This scripted curriculum or lesson plan as defined by Demko (2010) is a series of scripts that determine instruction, which must be followed with perfect implementation. The role of the teacher is to "execute the commercial, scripted program without making adjustments" or the guarantee is lost (p. 62). Cilliers et al. (2019) further explain that this type of curriculum outlines what the teacher is to say, how the script should read, and what teaching strategies should be used. Scripted curriculum creates a precise process beginning with attention getting, linking prior knowledge or review, clearly stating the objectives of the lesson, followed by guided practice that involves MODEL, PROMPT, and CHECK steps (Gunter & Reed, 1997).

Several forms of scripted science curriculum have been introduced in Texas and other states over the years, such as CSCOPE, Pearson Interactive Science, and STEMscopes. The above-mentioned curriculum types are often recommended and sold to school districts by Regional Education Service Centers. Once adopted and introduced, it is the responsibility of the superintendents, principals, and teachers to implement the curriculum as intended. These curricula use an inquiry-based design to learn known as 5E lesson design. The Biological Science Curriculum Study's 5E instructional model refers to five steps of inquiry: engagement, exploration explanation, elaboration, and evaluation (Bybee et al., 2006).

The scripted curriculum used in this study is STEMscopes, an online, comprehensive, and inquiry-based approach to science that is "100% aligned to the Texas science standards and combines online content, activities, and teacher materials with hands-on experiments and explorations" (Rice University, 2017). This program is designed to guide students toward discovery of concepts and skills instead of using direct instruction. By using this program, the STEMscopes pedagogical models adds two key steps: intervention and acceleration. These two key steps provide teachers with tools for identifying students that may struggle with a particular concept, allowing for additional opportunities to learn, as well as provide teachers with activities for students that have demonstrated mastery of concepts. In a study conducted during the 2012-2013 school year, 5th grade state assessment data was collected and examined, indicating that teachers who used STEMscopes more often had students whose average scale scores were 46.6 points higher than teachers who used fewer steps per learning standard (Rice University, 2017).

***Research Supporting Scripted Curriculum.*** Proponents of scripted curriculum believe that using a curriculum that is scientifically based will help students become more successful and increase their standardized scores. Gunter and Reed (1997) suggest that the foundation of scripted lessons is based on the model, prompt, and check steps to ensure learning of material.

Hiralall and Martens (1998) suggest that scripted curriculum may help reduce the inequality that exists in the classroom. According to an article written by Milner (2013), scripted and narrowed curriculum can be used to help teachers that are underprepared by way of what to teach, when to teach it, and how. The author explains that this form of curriculum ensures all students are exposed to the same curriculum no matter the teacher's skillset, where the students live, or even the particular needs of the individual student.

Supporters of scripted curriculum believe it makes teacher-led instruction "more efficient and predictable by scripting the teacher's spoken words and the child's likely responses" (Walsh, 1986). Watkins and Slocum (2004) argue that scripted curriculum accomplishes two goals: 1) it assures well designed instruction, and 2) it relieves the teacher of the responsibility to design, test, and refine instruction for every subject they teach. The authors explain that scripted programs provide systematic, structured, predictable, and consistent routines and learning environments while permitting training and supervision to ensure standardized instructional delivery (p. 306). They go on to explain that the detailed scripts are tools that are designed to allow teachers to relate to the students through the words in the scripts and the role of teacher is to focus on the critical job of delivering instruction and solving unexpected problems.

Vasquez Heilig and Jez (2014) explain that teacher education programs, such as Teach for America, make scripted curriculum necessary because many of the teachers are not prepared to make curricular decisions that are rational, appropriate, and responsive. Zhao et al. (2019) further explain that scripted curriculum narrows the lens to ensure that the teacher would focus on aspects that would most likely be tested in a given year. Twyman and Heward (2018) suggest that scripted curriculum offers continuity by using systematic methods for teaching specific content and ensure students have sufficient information to formulate the correct responses to the content. An analysis done by King and Zucker (2005), explains that the purpose of narrowing the curriculum was to allow teachers to focus on aspects of the curriculum that they would most likely be tested on in any given year.

***Research Not Supporting Scripted Curriculum***. While there is research in favor of scripted curriculum, several disadvantages have been brought to light after a critical review of research. Although scripted curriculum is not a recent phenomenon, it was created as a means of regulating, managing, and regimenting teachers' frameworks and instruction (Doyle, 1992).

Teachers are concerned that the reason for educational policies and scripted mandates is due to the belief that teachers can no longer do their job effectively (Eisenbach, 2012). They believe that it sends the message that teachers are not capable of providing their students with rigorous instruction and generate intelligent lessons and activities that promote student engagement and intellectual growth (Eisenbach, 2012).

In a longitudinal study conducted by Valli and Buese (2007), the authors examined the changes in teacher tasks over a 4-year period. Through detailed analysis, the authors explain that these changes greatly affected curriculum and instruction. One such change was the introduction of a scripted curriculum that required teachers to move through the curriculum on the district's schedule, with tests given at a prescribed time. This rapid paced content delivery or *drive-by teaching* hindered the teacher's ability to create lessons that involved inquiry. This form of curriculum limits teachers' flexibility, autonomy, creativity, and ability to ask critical questions within the content (Valli & Buese, 2007).

Srikantaiah (2009) and Milosovic (2007) explain that by narrowing the curriculum, teacher's efforts to align curriculum to standards and focus on tested material has diminished available class time for science, social studies and other activities in the elementary grades (p.2). Jerald (2006) affirms that taking time from other subjects, such as science and social studies, produces significant long-term costs on student reading comprehension and thinking skills, increases inequity among students, and makes the job of secondary teachers more difficult.

Smagorinsky et al. (2002) found that when implementing scripted curriculum, teachers were expected to use the same curriculum materials, in the same order, at the same time of day, across a diverse school district. During the study, students described the scripted materials provided as "unappealing" (p. 199) and that the flow and organization of the lesson did not meet the needs of the students.

Freire (2005) states, educators must constantly adapt their way of thinking, learning, and teaching, in order to become a better teacher, yet use "pre-packaged" materials to teach differentiated instruction to a classroom full of people from all walks of life (p. 32). These "pre- packaged" teaching materials are not only taking away the creativity of the students, but also that of the teacher. With the idea of a prepackaged curriculum, there is little room for teachers to adapt to the needs of students within the classroom setting, therefore hindering teacher creativity and limiting their input, as well as fostering an education rooted in lower-order skills (Firestone et al., 2000). Katz (2015) explained that scripted curriculum fails to acknowledge the creative potential of educators in the classroom and their ability to shape environments according to the lived experiences and actual educational needs of their students. Ede (2006) and Kang (2016) explain the diverse ethnic and cultural backgrounds of students within any given classroom makes it unlikely that one single curriculum will meet the needs and interests of all students. In a study conducted by Crocco and Costigan (2007), they found that in scripted lessons and mandated curriculum, teachers in New York City felt their personal and professional identity was thwarted, creativity and autonomy was undermined, and their ability to create relationships with their students was diminished. When the scripts and expectations are shaped by someone else, teachers and consequently students become robots (Milner, 2013). According to Eisenbach (2012) and Powell et al. (2017), the use of scripted curriculum provides teachers with three choices: accommodate, negotiate, or resist. In the study done by Eisenbach (2012), the author describes each of these choices: 1) Teachers that tend to accommodate believe they must set the example and follow the mandates set by the policy makers; 2) Teachers that negotiate or subtly oppose tend to incorporate their own ideas and beliefs into the scripts and create a hybrid classroom; 3) Teachers that resist do not use any of the curriculum provided and use what they believe works best for their student. A similar study done by Powell et al. (2017), describe these choices as acquiesce, subtly oppose, or actively resist. In this study, the authors describe the first two choices similar to Eisenbach (2012) but also explain that in the last choice, the teachers may not only resist use of curriculum, but some will even leave teaching altogether.

Kohl (2009) and Powell et al. (2017) suggest that the role of a teacher is changing as a consequence of scripted curriculum, teacher accountability, continuous monitoring of student performance, and high stakes testing. Kohl (2009) explains that scripted curriculum turns teachers into delivery systems that is leading to the erosion of self-respect and pride in one's work by treating teachers as objects with no independent educational knowledge or judgment of their own. Powell et al. (2017) suggest that the layers of control have become visible with the corporation making the decisions, school administrators requiring teachers to comply, and teachers fearing reprisal if they do not follow the rules. Herr and Arms (2004) describe standardized curriculum as mandates, where even administrators are held accountable for implementing them and bringing a sense of surveillance to the classroom (p. 536). Moustafa and Land (2002) describe scripted curriculum to be less effective than reading instruction where teachers are allowed to use their knowledge and experience to differentiate instruction based on the needs of the students. Mills (2008) and Carl (2014) explain that scripted curriculum may limit a teacher's ability to exercise professional judgement which may limit teacher efficacy and student potential. Elkind (1986), Flipo (1999) and Hargreaves (1994) are also concerned about academic achievement and the ability of the programs to develop deep lasting engagement that will increase student achievement as advertised by the program developers. In an audit done by Hos and Kaplan-Wolff (2020) they examined the New York State Education Department of the Sunnyside School District's curriculum and concluded that there was a disconnection between what was taught in the school district when compared with the state standards. The results of this study support the conclusion that teachers who choose to resist the scripted curriculum would rather engage their students in purposeful activities that represent their own professional identity and beliefs about learning (Hos & Kaplan-Wolff, 2020). With the growing concern about student achievement, other curriculum frameworks can be explored to allow for more autonomy, such as the understanding by design framework.

### *Understanding by Design*

Understanding by Design (UbD) is a lesson plan framework designed to focus both curriculum and instruction on the development and deepening of student understanding and transfer of learning (Wiggins & McTighe, 2011). The purpose of the UbD framework is to 'teach' students that their job is not merely to learn facts and skills, but to question them for further meaning (Wiggins & McTighe, 2005, p. 104). The UbD model allows students to go beyond the information and make inferences, connections, and associations that will bind together seemingly disparate facts into coherent, comprehensive, and illuminating accounts and experiences (Wiggins & McTighe, 2005, p. 86). The UbD framework is rooted in the idea that teaching in and of itself never causes learning, but successful attempts by the learner to learn causes learning and achievement is the result of the learner successfully making sense of the teaching (Wiggins & McTighe, 2005, p. 228). Wiggins and McTighe suggest that by simply covering content required by state and national standards, learning becomes a more difficult task and levels everything to verbal stuff for recall (p.234). It is only when a concept becomes "real" instead of abstract that it makes sense and the learner can connect the learning with experience and knowledge (Wiggins & McTighe, 2005, p. 234). By using the method of teaching after revealing experience, students will have a more concrete understanding of the concept being taught, allowing for transferability. According to Wiggins and McTighe (2005) in order to ensure learning is fluid, a spiral approach should also be incorporated as a means to develop curriculum around recurring, ever-deepening inquiries into big ideas and important tasks (p. 297).

***Reviews of Understanding By Design***. A study done by Schiller (2015) was conducted using UbD to design unit lesson plans for the Next Generation Science Standards (NGSS) for the topic of evolution and correlated it to the NGSS performance expectations. The author explained that the findings showed the UbD unit lessons increased student achievement in the unit, using the NGSS assessment, as well as an increase in student interest in learning the science content.

According to a review done by Roth (2007), Understanding by Design overcomes the impasse of development of coherent and cohesive curriculum by providing concise and practical guidance for experienced and inexperienced teachers. Roth (2007) goes on to explain that UbD utilizes a practical and useful "backward" design process in which anticipated results are first identified, acceptable evidence for learning outcomes is established, and finally specific learning experiences and instruction are planned. The UbD framework was implemented at the University of Wyoming, in which graduate students were able to transform their original lesson plans into lessons that were more useful, functional, and valuable for both teachers and students (Roth, 2007).

When applying the backward design, Childre et al. (2009) and Whitehouse (2014) explain the key steps in differentiating instruction, more specifically when planning for classrooms with students with disabilities. These key steps include: 1) identifying individual learning needs as well as classrooms needs such as resources and educational background of students, 2) identifying curricular priorities using the standards to drive instruction using essential questions to pique interest, 3) design assessment that is ongoing and frequent that aims to move students beyond the recall of memorized facts to deeper understand of the meaning of content in applied contexts to other concepts, and 4) creating high-quality learning activities that guides students toward accomplishing the desired understanding and assessments while scaffolding information throughout the process. In a study done by Michael & Libarkin (2016) the authors implemented the UbD framework at the university level and found that using these steps, as described by Childre et al. (2009) and Whitehouse (2014), ensues instruction is moving away from lecturing and allowing students the opportunity to take an active role in their own learning. Research suggests there is no real benefit of scripted curriculum when considering student achievement. Studies researching the effectiveness of scripted programs exist in the form of dissertations and other publications, but much of the literature does not show a significant difference in student's achievement between scripted and non-scripted curriculum (Atkeison-Cherry, 2004; Dickson, 2006; Duncan-Owens, 2009; Lyons, 2009; Valencia et al., 2006; Bosen, 2014). Anderson (2011) suggested further research over time to identify patterns of support for scripted reading programs, while Halff (1988) and Hargreaves (1994) recommend a partial implementation of scripted mathematics curriculum. Research studies have been conducted that present the various aspects of the implementation of prescribed reading and mathematics curriculum, but there seems to be a gap in the literature regarding the use of scripted science curriculum. Table 1 shows a comparison between the two curriculum frameworks.

**Table 1**

*Curriculum Framework Comparison*

| STEMscopes | Understanding by Design |
|---|---|
| K-12 digital curriculum that uses exploratory hands-on kits to promote inquiry and allows students to engage in real-world scientific connections (Accelerate Learning, 2021). | Lesson plan framework designed to focus both curriculum and instruction on the development and deepening of student understanding and transfer of learning (Wiggins & McTighe, 2011). |

This study compared the effectiveness of scripted biology curriculum while comparing curriculum developed by the teacher that utilizes the Understanding by Design (UbD) framework. This study explored the following two research questions: (1) What is the difference in science content knowledge between those students receiving UbD curriculum/instruction and those students receiving the district-scripted curriculum/instruction? (2) What is the difference in student participation (constructivist practices) between those students receiving UbD curriculum/instruction and those students receiving the district scripted curriculum/instruction?

## Methods

This study evaluated two curriculum designs among 9th grade Biology students at South Texas Charter School (STCS). STCS is an urban charter school located in south Texas that serves students from kindergarten through twelfth grade. According to the information from the 2017-2018 school year, there were a total of 906 students from grades K-12, with 58.8% (n=533) of those students on free/reduced lunch. Table 2 shows the ethnicity of students within the K-12 school are as follows: 2.6% (n = 24) Asian, 4.2% (n = 38) African-American, 73.8% (n =669) Hispanic, 18.8% (n =170) White, and less than 0.1 % (n =4) identified as Other. This study was conducted using 9th grade Biology curriculum over the course of the second quarter of the 2018-2019 school year.

**Table 2**

*Descriptive Statistics: K-12 School Population*

| | N | % |
|---|---|---|
| Socio-Economic Status | | |
| Free/Reduced Lunch | 533 | 58.8 |
| No Free/Reduced Lunch | 373 | 41.2 |
| Ethnicity | | |
| Asian | 24 | 2.6 |
| African-American | 38 | 4.2 |
| Hispanic | 669 | 73.8 |
| White | 170 | 18.8 |
| Other | 4 | < 0.1 |

The participants consisted of the course instructor and students enrolled in the 9th grade Biology course at STCS during the 2018-2019 school year. Although there were three sections of Biology students, only two sections participated in this study. The third section was not used due to the population of the group consisting of honor students that required the use of a faster paced curriculum. Further assessment to determine which two of the three sections were most similar was unnecessary. The course instructor teaching the Biology course was a Hispanic, female with six years of science teaching experience, three of which were specific to teaching Biology. The two groups proceeded through the curriculum over the course of a nine-week period.

There were a total of thirty-five students, 22 of which experienced STEMscopes as the scripted curriculum framework. Thirteen (13) students experienced the UbD framework, a lesson plan framework designed to focus both curriculum and instruction on the development and deepening of student understanding and transfer of learning (Wiggins & McTighe, 2011).

The course instructor was asked to complete the teacher version of the Constructivist Learning Environment Survey (CLES), (Appendix A) and began teaching the two groups using the designated curriculum, maintaining a daily reflection log for each of the sections. At the end of the nine-week period, the instructor was asked to share a sample lesson plan used for both sections of Biology students, complete the teacher CLES, and submit the daily reflection logs.

The study used a mixed method, concurrent triangulation design. According to Hanson, Creswell, Plano Clark, Petska, and Creswell (2005), concurrent triangulation requires that quantitative and qualitative data are collected and analyzed simultaneously, where priority is equal and data analysis is separate and integrated using the triangulation of data to confirm, cross-validate, and corroborate study findings. The quantitative aspects of the design followed a quasi-experimental, nonequivalent group research design utilizing a content-based pretest/posttest design as well as a survey, while the qualitative aspects followed a case study design that utilized focus groups and teacher reflection logs. Once all data was collected it was triangulated to provide a confirmation measurement to increase the confidence and rigor of the research and build a coherent justification for themes. Member checking was also used to help determine if the participants felt that the themes were accurate.

In quasi-experimental designs, hypotheses are tested regarding the effectiveness of treatments that can be actively manipulated to achieve an outcome (Shadish & Luellen, 2006). The authors go on to explain some threats to internal validity of this design to include: a) ambiguous temporal precedence, b) selection of participants, c) history of events during the treatment, d) maturation over the course of the treatment, e) regression, f) attrition, g) exposure to the test, and h) instrumentation (Shadish & Luellen, 2006, p. 541). According to Creswell (2014) when utilizing a case study design, inquiry can be found through in-depth analysis of a program, event, activity, or individuals. During this process, data analysis must be conducted while still collecting more data in order to allow for various themes to emerge. Data is then coded or organized into chunks allowing the researcher to get a sense of main ideas present. The coding process should be used to generate a description of the topic, setting, and even complex themes for analysis in order to build additional layers (Creswell, 2014).

The first research question of the study focused on the difference in science content knowledge between those students receiving the district-scripted curriculum/instruction and those receiving the UbD curriculum/instruction. This was answered using a triangulation of data based on the pre- post unit tests, teacher reflection logs, and sample lesson plans. The second research question of the study focused on the difference in perception of the learning environment between the classroom receiving district scripted curriculum and UbD curriculum. Data triangulation consisted of student and teacher CLES surveys, student focus groups, and teacher reflection logs.

## Assessment Measure Development

The study began with a content-based pretest administered to all students enrolled in the Biology course to determine which two of the three sections were most similar based on science content knowledge. The content-based pretest consisted of 20 multiple choice questions associated with the Texas Essential Knowledge and Skills (TEKS) that were taught over the nine-week period. The standard that was covered during this time was B.6F. This standard required students to predict possible outcomes of various genetic combinations such as monohybrid crosses, dihybrid crosses, and non-Mendelian inheritance. For purposes of this study, STEMscopes lessons were delivered as the scripted curriculum (control group), since this was the curriculum provided by the school. The treatment group was taught using lessons created by the teacher utilizing the UbD framework. The criteria for the curriculum provided to the groups was randomly selected by the teacher.

Before beginning treatment, the Constructivist Learning Environment Survey (CLES) (Appendix A and B) was administered to both the teacher and students to determine the level of constructivist practices occurring in the classroom. The CLES was originally developed by Peter Taylor, Barry Fraser, and Darrell Fisher at Curtain University of Technology in Perth, Australia (Taylor, Dawson, & Fraser, 1995). According to Johnson and McClure (2003), the Constructivist Learning Environment Survey can be used to determine both teacher and student perceptions of classroom learning environments (p.67). The CLES has been used in many qualitative studies of the nature of science knowledge and learning of science teachers and their students (Lucas & Roth, 1996; Roth & Bowen, 1995; Roth & Roychoudhury, 1993) as well as an investigation of the relationships between classroom environment and student academic efficacy (Dorman, 2001).

## Focus Groups

During the first week, four students from each section were purposefully selected to participate in a focus group meeting. The criteria for purposeful selection included the ability to stay after school for 45 minutes, as described in the consent form, along with students of varying science content knowledge as shown by the pretest scores These students attended a total of two focus group meetings to discuss the level of constructivist practices that occurred. The first focus group meeting occurred during the first week of the nine-week period. An audio recording device was used during focus group meetings along with a list of guiding questions to ensure the students' conversation stayed on track (Appendix C). A final focus group meeting consisting of the same group of students was conducted during the last week of the nine-week period.

## Teacher Reflection Logs

Over the course of the nine-week period, the teacher kept a daily log of each class using a structured reflection questionnaire, (Appendix D) where she analyzed the lesson using a set of questions for each of the lesson designs. One purpose of the reflection logs was to measure the difference in science content knowledge between those students receiving UbD curriculum/instruction and those students receiving the district- scripted curriculum instruction. The other purpose was to measure the difference in perception of the learning environment between the classroom receiving UbD curriculum and the district scripted curriculum.

## Student Work Samples

Student work samples were used to provide an example of the types of materials and activities that were used in each of the classrooms. When comparing these samples, a rubric (Appendix E) was used to determine the depth of science content knowledge between the two frameworks. This rubric was adapted from Constructivist Lesson Rubric (2014) to measure four criteria: 1) evidence of the state standard being taught within the activity, 2) evidence of student expectations taught within the activity, 3) evidence of the essential knowledge assessed within the activity, and 4) evidence of student understanding.

## Sample Lesson Plans

Sample lesson plans were used to provide an example of the types of daily lessons, materials, and activities that were used in each of the classrooms. When comparing these sample lesson plans, a rubric (Appendix F) was used to determine the depth of science content knowledge between the two frameworks. This rubric was adapted from Constructivist Lesson Rubric (2014) to measure five criteria: 1) evidence of instructional design, 2) evidence of standards alignment, 3) evidence that the assessments were used to guide instruction, 4) evidence that the learning activities were aligned to the curriculum and considered the perspective of the learner, and 5) evidence that the lesson was designed to optimize class time for the assignments.

# Findings and Results

Using the mixed method, concurrent triangulation design, the quantitative data analysis consisted of an examination of scores of students based on the type of instruction given over a nine-week period as well as the perception of the learning environment described by the teacher and the students based on the type of instruction conducted in the classroom during the nine weeks. The qualitative data analysis consisted of examining the teacher reflection logs, sample lesson plans, student focus groups, and student work samples.

## Science Content Knowledge

The first research question of the study focused on the difference in science content knowledge between those students receiving UbD curriculum/instruction and those students receiving the district-scripted curriculum/instruction. This was answered using a triangulation of data based on the pre- post unit tests, teacher reflection logs, sample lesson plans, and student work samples. The teacher reflection logs and student focus groups were triangulated and analyzed to identify two themes regarding science content knowledge. The two themes resulting from data analysis were Instructional and Learning Style and Using Discussion Within the Instructional Cycle.

## Content-based Tests

A mixed-design ANOVA was used with time of content test (pretest, posttest) as a within-subjects factor and instructional type (UbD, scripted) as a between-subjects factor revealed a main effect of instructional type. Table 3 shows the results using content tests over time. There was no interaction effect between time and teaching method, $F(1, 33) = 41.81$, $p <$

$.05$, partial $\eta^2 = .56$. Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Huynh-Feldt correction model of sphericity (ε = 1.00). The Mauchly's test of sphericity was used to measure the assumption of sphericity when using repeated-measures ANOVA. The Huynh-Feldt correction model was then used because there was small p-value from the Mauchly's test. This revealed that there was a significant difference between the times the tests were taken showing that the students showed growth from the pretest to the posttest. There was no interaction effect between time and teaching method, F(1, 33) = 41.81, p < .05, partial $\eta^2$ = .56. Based on the type of instruction given to each class, there was no significant difference between the two types of instruction, F (1, 33) = 2.65, p = 0.11. This revealed that both types of instruction increased content knowledge among the students that participated in the study. There was a total of a 15.71point increase over the nine-week period, with a larger gain among the students receiving the district-scripted curriculum.

**Table 3**

*Mixed-Model ANOVA results using Unit Tests over time*

| Predictor | Sum of Squares | d*f* | Mean Square | F | *p* | partial $\eta^2$ |
|---|---|---|---|---|---|---|
| (Intercept) | 193062.38 | 1 | 193062.38 | 462.13 | <.001 | .933 |
| time | 3608.89 | 1 | 3608.86 | 41.81 | <.001 | .559 |
| Instructional type | 1108.10 | 1 | 1108.10 | 2.65 | .113 | .074 |
| time x Instructional type | 180.32 | 1 | 180.32 | 2.09 | .158 | .060 |
| Error | 13786.20 | 33 | 417.76 | | | |

Descriptive statistics was used to determine the mean overall score of the unit tests (pretest and posttest). As shown in Table 4, the mean total score of the participants on the unit pretest was 45.43 with a standard deviation of 16.60. The mean total score of the participants on the unit posttest was 61.14 with a standard deviation of 15.86.

**Table 4**

*Descriptive Statistics: Unit Pretest and Posttest*

| | Instructional Type | N | M | SD |
|---|---|---|---|---|
| Pretest | STEMScopes | 22 | 41.14 | 16.18 |
| | UbD | 13 | 52.69 | 15.22 |
| | Mean Total Score | 35 | 45.43 | 16.60 |
| Posttest | STEMScopes | 22 | 59.32 | 15.61 |
| | UbD | 13 | 64.23 | 16.44 |
| | Mean Total Score | 35 | 61.14 | 15.86 |

### *Teacher Reflection Logs and Student Focus Groups*

The teacher reflection logs and student focus groups were triangulated and analyzed to identify two themes regarding science content knowledge. The two themes resulting from data analysis were instructional and learning style and using discussion within the instructional cycle for both curricula.

***Instructional and Learning Style Using UbD.*** The purpose of the UbD framework is "to 'teach' students that their job is not merely to learn facts and skills, but also to question them for their meaning" (Wiggins & McTighe, 2005, p. 104). The teacher expressed that with this lesson framework, she has "the ability to chunk the information appropriately with [her] students in mind and make time for the detail that will set them up to understand concepts at a deeper level and allow them to build on that understanding with other concepts." During the focus groups, the students explained how the teacher would adapt her lessons to meet their needs but also encourage a productive struggle. One student explained:

> She lets us struggle, but productive struggle. Like if she sees that we really don't get it, she'll help us. When she notices we're really not getting it, she will be a little more elaborate and explain on it and go into more detail.

Another student explained when they would have multiple assignments due in various classes, students knew they could talk to the teacher; "Like I think if we go to her like specifically like one-on-one, she'll give you more time if you ask for it." The student went on to explain that the teacher would also provide different opportunities for them to finish their work or get extra help; "We had a working lunch if we didn't finish [an assignment] or come after school."

In the teacher reflection logs, the teacher explained that she was able to make connections to previous content and lay the foundation for upcoming concepts. As a precursor to labs and other activities, she would ensure the students understood the "how and why" of a concept as well make "direct connections to the TEKS" and allow them to relate it to real world examples.

The teacher further explained, in the reflection logs, that this framework "allowed for some flexibility and differentiation." One specific example of this can be seen when she stated, "I was able to cut out an elaborative assignment for the sake of time and [ensure] that students really focused on the practice assignment where they applied mitosis for the first time. The virtual lab I cut out, while interesting, goes deeper than needed for the curriculum and goals, and so was not necessary."

***Instructional and Learning Style Using Scripted Curriculum***. The district provided curriculum, STEMScopes, as the scripted curriculum for this study. According to a study done by Rice University (2017), this program is designed to have the teacher guide students toward discovery of concepts and skills instead of using direct instruction. The teacher expressed that STEMScopes did not go into the specificity required for each standard. She expressed numerous times that the STEMScopes curriculum did not allow for students to easily make connections between concepts or lay the foundation for new ones. The teacher explained that "STEMScopes focused more on the definitions...rather than effects. [It] seems to lead them through the process of [the various concepts] without going into the 'why' or 'what's happening'." She went on to explain how she would use "quick mini-lessons" to cover the information that STEMScopes did not cover.

***Using Discussion Within the Instructional Cycle for Both Curricula***. During the instructional cycle, the teacher frequently utilized student-led and class wide discussions. As explained in her lesson plans, she would use these discussions in various components in her lesson. During activities, the teacher had the students discuss the overarching concepts and encouraged them to work together to answer the higher order thinking questions asked within the assignment or activity. As explained by the students during the focus group, "Whenever she assigned us group projects, that's when I learned stuff." Another student went on to explain that "helping each other is better than asking the teacher for help...sometimes another student has an easier way."

Another method the teacher used to implement discussion was when students were given written assignments or worksheets. A student explained that the teacher would use them as a guideline of what they were supposed to talk about in their groups or partners. Along with student-led discussion, the teacher mentioned that she would bring the class together as a whole group to check for understanding. If a concept was not covered in the scripted curriculum, the teacher would provide the students with a basic overview of the concept before giving the assignment as written.

The last method the teacher used to implement discussion was as a form of formative assessment to guide instruction and monitor student learning. Group question and answer sessions were held during note taking sessions to make connections to previous content or lay a foundation for upcoming concepts. She would also use small group conferencing during independent work time to work with students that were struggling with a particular concept.

### *Student Work Samples*

A rubric was created and used to analyze the student work for both scripted and UbD assignments. As shown in Table 5, when analyzing the assignments used in the scripted classroom, the state standards were somewhat evident. Neither assignment provided by STEMScopes (Math Connections: Genetic Outcomes and Progress Monitoring Assessment) covered a specific aspect of the standard regarding possible outcomes using non-Mendelian inheritance. A district created Essential Lab was implemented, Paternity by Blood Typing, to cover one type of non-Mendelian genetics called codominance. Student expectations were somewhat evident between the assignments. Only one third of the student expectations were covered within the two work samples. Neither of the assignments required students to show their understanding by inferring genotype of the F1 generation, inferring any phenotypic expression, or predicting genetic combinations using non-Mendelian genetics, specifically, incomplete dominance, using multiple alleles, or sex-linked traits. The essential questions were somewhat answered within the two work samples. The assignments exposed students to two ways to calculate the probability of inheritance in offspring but did offer opportunities for students to explain the limitations of this type of calculation. The student understandings were also somewhat evident within the two assignments.

Math Connections that were used included Genetic Outcomes requiring students to create five monohybrid Punnett squares and determine a specific percentage of the inherited gene, as well as one dihybrid cross to determine the phenotypic ratio of all offspring. Progress Monitoring Assessment consisted of 7 multiple choice questions that required students to use monohybrid and/or dihybrid crosses to answer the questions.

When analyzing the assignments used in the UbD classroom, the state standards were extremely evident. Genetic outcomes were determined *using* a variety of methods among the assignments. Students were required to predict genotypic and phenotypic expression using monohybrid and dihybrid crosses, and use various non-Mendelian combinations (incomplete dominance, using multiple alleles, and sex-linked traits). As shown in Table 6, student expectations were mostly evident between all of the assignments, with only one student expectation not met.

**Table 5**

*Student Work Analysis: Scripted*

| Curriculum | Assignments | Category | Evidence |
|---|---|---|---|
| | Math Connections: Genetic Outcomes | State Standards (TEKS) | State standards were somewhat evident in the scripted curriculum assignments. Genetic outcomes were determined using monohybrid and dihybrid crosses in each assignment. Neither assignment provided by STEMScopes (Math Connections: Genetic Outcomes and Progress. Monitoring Assessments) covered possible outcomes using non-Mendelian inheritance. A district created Essential Lab was implemented. Paternity by Blood Typing to cover one type of non-Mendelian genetics called codominance. |
| Scripted | Progress Monitoring Assessment<br>District Mandated: Paternity by Blood Typing | | Student expectations were somewhat evident between the assignments. Only one third of the student expectations were covered within the two work samples. The assignments from STEMScopes exposed students to monohybrid and dihybrid crosses using Punnett squares, calculating possible outcomes of F2 generation, and predicting combinations with genotypes. The Paternity by Blood Typing assignment required students to predict genetic combinations using codominance. None of the assignments required students to infer genotype of the F1 generation, infer any phenotypic expression, or predict genetic combinations sing non-Mendelian genetics, specifically, incomplete dominance, using multiple alleles, or sex-linked traits. |
| | | Essential Questions | The essential questions were somewhat answered within the two work samples. The assignments exposed students to two ways to calculate the probability of inheritance to offspring but did offer opportunities for students to explain the limitations of this type of calculation. |
| | | Student Understandings | The student understandings were somewhat evident within the two assignments. Math Connections: Genetic Outcomes required students to create five monohybrid Punnett squares and determine a specific percentage of the inherited gene, as well as one dihybrid cross to determine the phenotypic ration of all offspring. Progress Monitoring Assessment consisted of 7 multiple choice questions that required students to use monohybrid and/or dihybrid crosses to determine information necessary to answer the questions. |

**Table 6**

*Student Work Analysis: Understanding by Design*

| Curriculum | Assignments | Category | Evidence |
|---|---|---|---|
| | Monster Genetics<br>Zork Genetics<br>DNA,RNA, Snorks | State Standards (TEKS) | State standards were extremely evident in the UbD assignments. Genetic outcomes were determined using a variety of methods among the assignments. Students were required to predict genotypic and phenotypic expression using monohybrid and dihybrid crosses, and use various non-Mendelian combinations (incomplete dominance, using multiple alleles, and sex-linked traits). A district created Essential Lab was also implemented, Paternity by Blood Typing, to cover one type of non-Mendelian genetics called codominance. |
| Understanding by Design | X-linked Genes<br>Bikini Bottom Incomplete Dominance<br>District Mandated: Paternity by Blood Typing | | Student expectations were mostly evident between all of the assignments, with only one student expectation not met. The Monster Genetics and Zork Genetics assignments utilized by the teacher exposed students to monohybrid and dihybrid crosses using Punnett squares, calculating possible outcomes of F2 generation, and predicting combinations with genotypes. The Bikini Bottom assignment exposed students to incomplete dominance, while the DNA, RNA, Snorks assignment exposed students to gene expression by way of mitochondrial DNA. The X-linked Genes assignment gave students an opportunity to explore, predict genetic combinations with sex-linked traits. The Paternity by Blood Typing assignment required students to predict genetic combinations using codominance. |
| | | Essential Questions | The essential questions were somewhat evident among the work samples. The assignments exposed student to various ways to calculate the 0robability o inheritance in offspring but did offer opportunities for students to explain the limitations of this type of calculation. |
| | | Student Understandings | The student understandings were extremely evident among the assignments. Monster Genetics introduced students to the basics of Mendelian genetics, while Zork Genetics required students to utilize dihybrid crosses and infer phenotypic expression. DNA, RNA, Snorks required students to examine the DNA sequence of an organism and analyze the genes of a DNA sequence to determine what traits the organism has. X-linked Genes gave students an opportunity to predict the combination of eye color in flies as determined by the chromosome. The Bikini Bottom assignment had students explore incomplete dominance of the color of a specific flower, while the Paternity by Blood Typing assignment required students to predict traits using codominance. |

### *Sample Lesson Plans*

A rubric (Appendix F) was created and used to analyze the teacher's lesson plans for both the scripted and UbD classroom. This rubric looked at the instructional design, standards alignment, assessment, learning activities, and instructional pacing. When analyzing the lesson plans used in the scripted classroom, the instructional design used a 5E instructional model (Accelerate Learning, 2021) to cover two related standards. The standards were intertwined to create comprehensive instruction using the 5E model, while incorporating prior science connections, Reading/English Language Arts, and Math concepts. Progress Monitoring Assessments and Math Connections were used as formative assessments during class time. There were a total of three student-friendly essential questions derived from the standards that the teacher reviewed at the beginning of each lesson. Students were given opportunities to work together and have discussions during the engage, explore, and elaborate portions of the 5E instructional model (Accelerate Learning, 2021). According to the teacher's notes, certain aspects of the lesson were modified or shortened due to time constraints and repetition. The teacher also noted that the lessons lacked information required by the standards, Since the scripted curriculum did not contain needed concepts, the teacher incorporated notes and sample problems to ensure students were exposed to this information.

When analyzing the lesson plans used in the Understanding by Design classroom, the lesson also used a 5E instructional model to cover multiple standards. The progression through the standards supported the development and understanding of the concepts. The formative assessments used within this lesson plan included: a) group question and answer sessions held during note-taking; b) small group conferencing during independent work; c) peer dialogue; and d) observation of completion of various hands-on activities to ensure understanding. There were a total of nine student-friendly essential questions derived from the standards. Students were given opportunities to work together and have discussions throughout the learning process. The activities reflected vertical alignment and an appropriate level of rigor. Various instructional tools were used to address the needs of all learners. The sequencing of the lesson within the lesson plan allowed the teacher to think about the aspect of time prior to implementation. Teacher autonomy and the ability to adapt the lesson/time to fit the needs of the student was also a factor in optimizing in class time.

### *Triangulation: Science Content Knowledge*

Although the data collected from the content-based tests revealed that both types of instruction increased content knowledge among the students that participated in the study, other factors should also be considered based on teacher reflection logs, student focus groups, sample lesson plans, and student work samples. Triangulation of data was used to capture different dimensions of each piece of evidence.

Based on the triangulation of the teacher reflection logs and sample lesson plans with the content-based tests, it was evident that the increase in content knowledge was primarily due to the teacher's understanding of the Texas Essential Knowledge and Skills (TEKS) as well as the ability to meet the needs of the students in each class. When looking at the student focus groups and student work samples with the content-based tests, it was evident that the increase in content knowledge was associated with the utilization of discussion during the learning cycle. The teacher utilized discussion at various points within the lessons to review the overarching concepts and encouraged students to work together to answer the higher order thinking questions asked within an assignment or activity.

### *Perception of the Learning Environment*

The second research question of the study focused on the difference in perception of the learning environment between the classroom receiving UbD curriculum and the district scripted curriculum. This was answered using a triangulation of data that consisted of student and teacher CLES surveys, student focus groups, student work samples, and teacher reflection logs. The teacher reflection logs and student focus groups were triangulated and analyzed to identify two themes when looking at the perception of the learning environment. The two themes resulting from data analysis were the Effect of Teacher Relationship On Instruction and the Effect of Time On the Learning Environment.

### *Student CLES*

Descriptive statistics was used to determine the mean overall score of student perception of the learning environment using the CLES (pre- and post-survey). The mean score of the perception of the learning environment at the beginning of the nine-weeks was 72.40 with a standard deviation of 7.60. The mean score of the perception of the learning environment at the end of the nine-weeks was 75.47 with a standard deviation of 10.37. As shown in Table 7, a mixed-design ANOVA was also used to analyze the difference in perception of the learning environments from a student and teacher perspective. When looking at student perception over the nine-week period, time of survey (CLES Pre, CLES Post) was used as the within-subjects factor and instructional type (UbD, scripted) as the between-subjects factor. The data revealed a main effect of time, $F\ (1, 33) = 4.20$, $p < .05$, $\eta p^2 = 0.113$.

Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Huynh-Feldt correction model of sphericity ($\varepsilon = 1.00$). This indicated an increase in student perception of the learning environment over the course of the nine-week period. Based on the type of instruction given to each class, there was no significant difference between the perception of the learning environment between the two instructional types, $F(1, 33) = 0.61$, $p = 0.44$. This revealed that both types of instruction increased student perception of the learning environment among the students that participated in the study. There was a total of a 1.17-point increase over the nine-week period, with a larger gain among the students receiving the UbD curriculum.

**Table 7**

*Mixed-Model ANOVA Results for Student CLES with Instructional Type as Criterion*

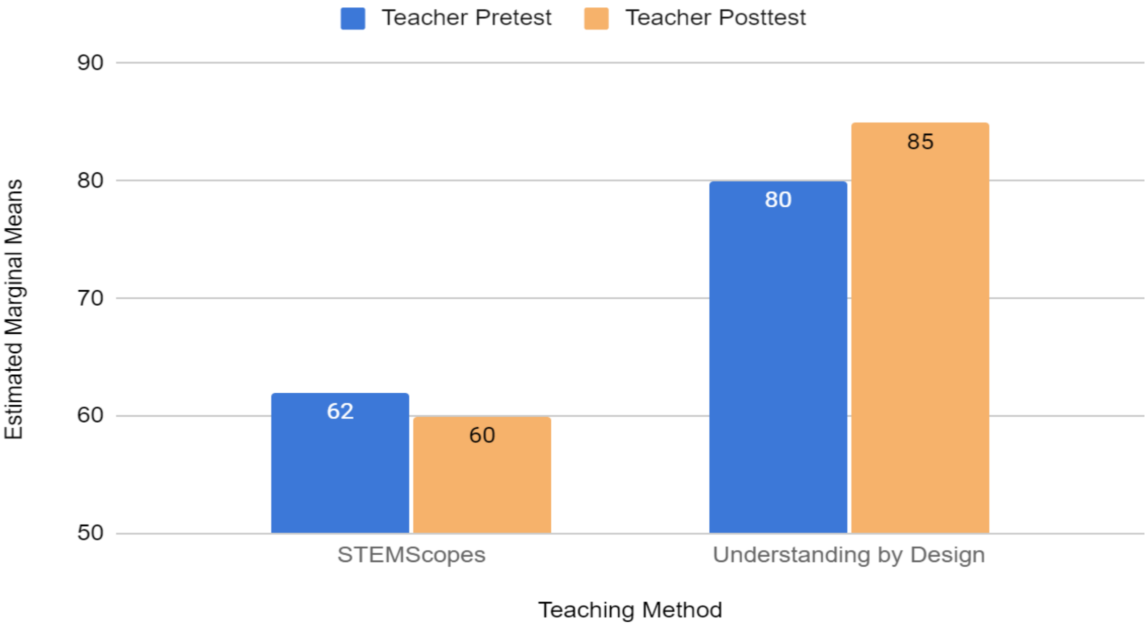
| Predictor | Sum of Squares | d*f* | Mean Square | F | p | partial $\eta^2$ |
|---|---|---|---|---|---|---|
| (Intercept) | 360456.17 | 1 | 360456.17 | 3040.50 | .000 | .989 |
| time | 203.61 | 1 | 203.61 | 4.20 | .049 | .113 |
| instructional type | 72.29 | 1 | 72.29 | .610 | .440 | .018 |
| time x instructional type | 31.73 | 1 | 31.73 | .654 | .424 | .019 |
| Error | 3912.20 | 33 | 118.55 | | | |

### *Teacher CLES*

According to Figure 1 shown below, the teacher CLES score over the course of the nine-week period decreased from 62 to 60 in respect to the scripted STEMScopes curriculum.

**Figure 1**

*CLES: Teacher Pretest and Posttest*



This revealed that the teacher’s perception of constructivist practices decreased in the scripted classroom. In respect to UbD curriculum, the teacher's CLES score over the course of the nine-week period increased from 80 to 85. This revealed that the teacher’s perception of constructivist practices increased in the UbD classroom.

This revealed that the teacher’s perception of constructivist practices decreased in the scripted classroom. In respect to UbD curriculum, the teacher's CLES score over the course of the nine-week period increased from 80 to 85. This revealed that the teacher’s perception of constructivist practices increased in the UbD classroom.

### *Teacher Reflection Logs and Student Focus Groups*

The teacher reflection logs and student focus groups were triangulated and analyzed to identify two themes when looking at the perception of the learning environment. The two themes resulting from data analysis were, (1) Effect of Teacher Relationship On Instruction and the, (2) Effect of Time On the Learning Environment.

***Effect of Teacher Relationships on Instruction***. The teacher utilized various tools, such as differentiation, giving students extensions on assignments, and encouraging productive struggle, as ways to meet the needs of her students. To adapt to the needs of the students, she altered her original plans and “made the additional worksheets extra credit.” In the UbD classroom, the teacher created stations to introduce the students to different concepts, as opposed to the packets utilized in the scripted curriculum. In respect to the scripted curriculum, the teacher explained how she would try to boost engagement when they had to do worksheet-type activities. She stated, "to avoid losing their attention and boring them (and myself) to tears, I offered them a choice. Students could read and work independently, or they could join me...We would read through part 1 (with me expanding on the information and clarifying where necessary) together and many students were making notes as we went on." She went on to explain that she would even "extend the deadline to the next class period" or give them about 30 minutes to work on it during class time. According to the student focus groups, students appreciated the opportunities for extra credit; "Well I did a worksheet where it was like about flies with red eyes and white eyes for extra credit" to help with understanding genetics and inheritance. The students went on to explain how the teacher would let them "struggle, but productive struggle." They went on to explain how she would not give them the answers right away but would give them time to answer questions and give them hints instead. When students had multiple assignments due in various classes, they knew they could talk to the teacher; "Like I think if we go to her like specifically like one-on-one, she'll give you more time if you ask for it."

***Effect of Time on the Learning Environment*.** Each curriculum framework caused issues in respect to time. When using the scripted framework, the teacher explained that "STEMScopes focused more on the definitions...rather than effects. [It] seems to lead them through the process of [the various concepts] without going into the 'why' or 'what's happening'." Since the students were expected to understand these concepts in full, the teacher "[looked] for ways to cover [the topics] without straying from the material." She explained that "STEMScopes only has a couple of practice [problems]" and mentioned that the activities had numerous errors. The teacher went on to explain that there were "excessive short answer questions that ask[ed] similar [information] in different ways" so the "students [were] less likely to complete the assignment." According to the students, they felt they had enough time to complete assignments in class. They explained that the teacher would give plenty of in class time for the assignments, and she would also provide different opportunities for them to finish their work or get extra help; "We had a working lunch if we didn't finish [an assignment] or come after school."

The teacher stated that the UbD framework "allowed for some flexibility and differentiation" when planning and altering lessons to meet the needs of the students. She went on to explain that she would create stations to touch on each concept within a standard "for the sake of time, [allow students to] self-review," and encourage students to make connections between concepts. According to the students in the UbD classroom, they did not feel they were given enough time to complete assignments: "I think like every now and then she like gives us enough time and sometimes she doesn't. She does like a good job at teaching us things, but I feel like it's too much information all at once. I feel like she kind of like piles it on and then it gets to the point where I'm like I just kind of like panic a little bit because so much stuff all together." As a group, the students explained how the teacher would also provide different opportunities for them to finish their work or get extra help; "We had a working lunch if we didn't finish [an assignment] or come after school."

### *Triangulation: Perception of Learning Environment*

Although the data collected from the teacher and student CLES revealed differences in the perception of the learning environment, other factors should also be considered based on teacher reflection logs, student focus groups, sample lesson plans, and student work samples. Triangulation of data was used to capture different dimensions of each piece of evidence. To answer the research question regarding perception of the learning environment between the two types of instruction used in the study, the teacher and student CLES were triangulated with student focus groups, teacher reflection logs, student work samples, and teacher reflection logs.

The student CLES revealed that both types of instruction increased student perception of the learning environment, while the teacher CLES revealed that the teacher's perception of constructivist practices decreased in the scripted classroom over the course of the nine-week period. Based on the triangulation of the teacher reflection logs and sample lesson plans with the teacher and student CLES, it was evident that the differences in the perception of the learning environment was primarily due to the relationship the teacher had with the students.

When looking at the teacher's description of the UbD classroom, she stated that the UbD framework gave the opportunity for flexibility and differentiation when planning and altering lessons to fully cover each TEKS standard. The teacher expressed with this lesson framework, she had "the ability to chunk the information appropriately with [her] students in mind and make time for the detail that will set them up to understand concepts at a deeper level and allow them to build on that understanding with other concepts." Using the triangulation of the student focus groups and student work samples with the teacher and student CLES, it was evident that the differences in the perception of the learning environment was influenced by the amount of time given for each concept within the learning cycle.

## Discussion

The purpose of this study was to analyze the effectiveness of scripted curriculum as a means of providing students with the information required to be successful on standardized assessments, while comparing curriculum developed by the teacher utilizing the Understanding by Design (UbD) framework. Scholarly literature regarding the use of scripted curriculum in the science classroom was not apparent, indicating a need for this study. Several forms of scripted science curriculum have been introduced in Texas and other states over the years, such as CSCOPE, Pearson Interactive Science, and STEMscopes. The above-mentioned curriculum types are often recommended and sold to school districts by Regional Education Service Centers. Once adopted and introduced, it is the responsibility of the superintendents, principals, and teachers to implement the curriculum as intended and with fidelity. Research studies have been conducted that present the various aspects of the implementation of prescribed reading and mathematics curriculum, but there seems to be a gap in the literature regarding the use of scripted science curriculum. Thus, the findings of this study are unique and contribute to the body of literature for the effectiveness of scripted curriculum and add to the research on alternative curriculum and instruction methods for teaching science, such as the use of the Understanding by Design (UbD) framework. The following sections contain the existing literature and the implications of this study regarding science curriculum and content knowledge, the constructivist learning environment, and Understanding by Design in the science classroom.

### ***Science Content Knowledge***

Curriculum materials can be defined as resources to guide teacher instruction that can include textbooks and supplementary units or modules (Remillard et al., 2014). Many studies show that science curriculum materials can have positive effects on student learning, including an increase in students' attitudes and motivation toward science (e.g., Häussler & Hoffmann, 2002; Roblin, et al., 2017; White & Frederiksen, 1998), an increase in student understanding of science concepts (e.g., Harris et al., 2015; Sadler, et al., 2015), and an increase in their abilities to engage in science practices. In a study done by Sudduth (2020), strict implementation of scripted curriculum leaves educators feeling constrained by what to teach, the amount of time they have for lessons, and how students should be assessed. The author explains that scripted curriculum limits teachers and hinders their ability to tailor lessons to each of the different learning styles in the classroom. Curriculum materials have also shown to have an influence on teachers' beliefs about science teaching and learning, the nature of science, and about themselves as knowers of science (Dias et al., 2011; Wyner, 2013).

According to the data collected from the content-based tests, there was a significant difference between the times the content tests were taken. This showed student growth from the pretest to the posttest. Although the data collected from the content-based tests revealed that both types of instruction increased content knowledge among the students that participated in the study, other factors should also be considered based on teacher reflection logs, student focus groups, sample lesson plans, and student work samples.

Based on the triangulation of the teacher reflection logs and sample lesson plans with the content-based tests, it was evident that the increase in content knowledge was primarily due to the teacher's understanding of the Texas Essential Knowledge and Skills (TEKS) as well as the ability to meet the needs of the students in each class. The teacher expressed that the scripted curriculum did not go into the specificity required for each standard. She explained that "STEMScopes focused more on the definitions...rather than effects. [It] seems to lead them through the process of [the various concepts] without going into the 'why' or 'what's happening'." She went on to explain how she would use "quick mini-lessons" to cover the information that STEMScopes did not cover. She went on to explain that it did not allow for students to easily make connections between concepts or lay the foundation for new ones. As a precursor to labs and other activities, the teacher would ensure the students understood the "how and why" of a concept as well make "direct connections to the TEKS" and allow them to relate it to real world examples. One way to provide the students with the content specified in the TEKS, the teacher would use mini-lessons to cover the information that the scripted curriculum did not cover.

Based on the triangulation of the student focus groups and student work samples with the content-based tests, it was evident that the increase in content knowledge was associated with the utilization of discussion during the learning cycle. Discussion was implemented at various points within the lessons to discuss the overarching concepts and encouraged students to work together to answer the higher order thinking questions asked within an assignment or activity.

### *Constructivist Learning Environment and the Use of the Understanding By Design Framework the Science Classroom*

According to Kumar and Gupta (2009), a constructivist classroom provides opportunities to observe, work, explore, interact, raise question enquiry, and share their expectation to all. One way to implement the constructivist model in the science classroom is through the use of Roger Bybee's 5E model, which was developed under the Biological Science Curriculum Study (BSCS) project (Singh & Yaduvanshi, 2015). Singh and Yaduvanashi (2015) further explain that the 5E constructivist-based model encourages learners to "reflect and question their own understanding via active meaning making process". According to Taber (2019), constructivist teaching is a process of personal knowledge construction that occurs within the minds of individual learners and is contingent upon the way the learner constructs his/her thinking. Devetak & Glazar (2014) explain that teaching involves activities that require students to identify and activate relevant prior knowledge, includes 'active' learning, encourages students to reflect on their thinking and ongoing learning, and pushes students to discuss their work.

Rubrica (2018) states that the Understanding by Design (UbD) framework has enhanced the delivery of instruction through curriculum mapping, construction of unit assessment matrices, revision of the learning module components, the integration of values in lesson, effective management of instructional time, and enriched student learning. Wiggins and McTighe (2005) explain that the teachers are coaches of understanding, that focus on ensuring learning, not just teaching. They further explain that the goal is to check for successful meaning-making and transfer of the information by the learner. Schiller (2015) conducted a study using UbD to design unit lesson plans for the Next

Generation Science Standards (NGSS) for the topic of evolution and correlated it to the NGSS performance expectations. The author went on to explain that the findings showed the UbD unit lessons increased student achievement in the unit, using the NGSS assessment, as well as an increase in student interest in learning the science content.

Student and teacher Constructivist Learning Environment Surveys (CLES), student focus groups, student work samples, and teacher reflection logs were used to explore the perception of the learning environment when utilizing each curriculum. The student CLES revealed that both types of instruction increased student perception of the learning environment, while the teacher CLES revealed that the teacher's perception of constructivist practices decreased in the scripted classroom over the course of the nine-week period. Although the data collected from the teacher and student CLES revealed differences in the perception of the learning environment, other factors should also be considered based on teacher reflection logs, student focus groups, sample lesson plans, and student work samples.

Based on the triangulation of the teacher reflection logs and sample lesson plans with the teacher and student CLES, it was evident that the differences in the perception of the learning environment was primarily due to the relationship the teacher had with the students. The teacher utilized various tools, such as differentiation, giving students extensions on assignments, and encouraging productive struggle, as ways to meet the needs of her students. When examining the student focus group data, the students felt comfortable to ask questions in the classroom, ask for more individualized help, and appreciated opportunities for extra credit as well as productive struggle. A student was quoted as saying:

> She lets us struggle, but productive struggle. Like if she sees that we really don't get it, she'll help us. When she notices we're really not getting it, she will be a little more elaborate and explain on it and go into more detail.

Based on the triangulation of the student focus groups and student work samples with the teacher and student CLES, it was evident that the differences in the perception of the learning environment was influenced by the amount of time given for each concept within the learning cycle. When looking at the teacher's description of the scripted classroom curriculum, the students in this classroom did not always engage in the same hands-on activities as the students in the UbD classroom. The teacher did not feel the assignments were being completed due to the excessive number of short answer questions that were asked in different ways. According to the students in the scripted classroom, there was a lot of paperwork.

When looking at the teacher's description of the UbD classroom, she stated that the UbD framework gave the opportunity for flexibility and differentiation when planning and altering lessons to fully cover each TEKS. The teacher expressed that with this lesson framework, she had "the ability to chunk the information appropriately with [her] students in mind and make time for the detail that will set them up to understand concepts at a deeper level and allow them to build on that understanding with other concepts." According to the students in the UbD classroom, they felt there was a lot of work and information presented during class time, but they appreciated that the teacher provided different opportunities for them to finish their work or get extra help. One student explained when students would have multiple assignments due in various classes, they knew they could talk to the teacher; "Like I think if we go to her like specifically like one-on-one, she'll give you more time if you ask for it."

## Limitations

The present study has several limitations. Firstly, the sample size was small, which may not reflect the larger population. This sample size was also limited, as it was only utilizing one school within a district and would be more comprehensive if comparing across an entire district. Secondly, there was only one teacher, which may present a limited point of view when comparing the two classes taught. If multiple teachers were used in the study, it would also allow for a more comprehensive look at the curriculum from various perspectives, while utilizing the same curriculum.

The two curriculum frameworks in this study were used by a single teacher, and the increase in student content-based test scores over the course of the nine-week period could have been influenced by the teaching strategies used in each classroom, such as the *quick mini-lessons* within the scripted classroom. These mini-lessons were used to meet the needs of the students to cover the information that the scripted curriculum did not cover. When looking at the perception of the learning environment, the overall increase in student perception of the constructivist learning environment, other factors could have influenced these outcomes since the teacher differentiated instruction and adapted to the needs of the students, therefore not fully using a true scripted curriculum. These factors need to be considered when making generalizations from these results.

## Recommendations for Future Research

According to Alwahaibi et al., (2019), science curriculum is often described as “unrelated, difficult, and boring to learn in comparison with other topics”. Therefore, it is important for teachers to actively engage students in the learning process and have the ability to differentiate instruction to meet the needs of students in the classroom. Helldén (2005) explains that without students’ interest in science, they may not make the effort to learn and understand the concepts that they are taught.

The results of this study have implications for designers of science curriculum, however other factors than the curriculum could have influenced the outcomes since only one teacher was used to teach both classes of students. It is important to look at teacher and student efficacy when scripted programs are implemented in the science classroom. Using scripted programs may cause teachers to feel that their professionalism has been devalued which may impact their teaching and consequently affect the students and their learning process. According to Costigan (2008), curricular mandates hinder four basic areas teachers need to thrive professionally: a) autobiographically based teaching, b) personal teacher theory is limited or extinguished, c) teaching is narrowed to assessment outcomes, and d) mandated curriculum does not promote understanding of student's lives or communities. Another factor to consider when implementing a scripted curriculum is the price per student. According to the Accelerate Learning (2021), the pricing per student for digital access to materials in Kindergarten – Grade 5 is $5.25, while Grades 6 – High School is $5.95. This does not include the hands-on and consumable kits that are required for Kindergarten through Grade 8. When looking at a district like STCS with a total of about 10,000 students in Kindergarten through Grade 12, the cost of STEMscopes reaches about $300,000 worth of school funds paid by the public.

It is important to look beyond the numbers and raw data when choosing curriculum. As shown using only the quantitative measures in this study, there was no significant difference between the two instructional methods, leaving room for curriculum decision makers to want to choose the pre-packaged curriculum to ensure success. Although the number showed little difference, the triangulation of data made it evident that the increase in content knowledge was primarily due to the teacher’s understanding of the Texas Essential Knowledge and Skills (TEKS) as well as her ability to meet the needs of the students in each class. When looking at the Constructivist Learning Environment Surveys (CLES), there were differences in the perceptions of the learning environment. This was primarily due to the relationship the teacher had with the students. This study shows that it is important to look beyond the numbers to create a positive and engaging classroom environment. The use of a curriculum framework like Understanding by Design (Wiggins & McTighe, 2005), would be the better curriculum option.

The findings of this study have the potential to change current thinking about implementing scripted curriculum in the science classroom. Although the number of students in each of the classes was limited, the students involved in the study were the average students and show that the use of constructivist practices allows students to have a greater understanding of content and overall learning success. Additionally, as a result of the study, the teacher was able to reflect on the daily lessons and adapt the teaching style to meet the needs of the students in the classroom, as well as time constraints.

When utilizing the UbD framework, the teacher was able to choose activities and direct instruction to engage the students in the learning process. Additionally, the students retained more information from meaningfully planned activities created and/or utilized by the teacher in the UbD classroom. From the data gathered using the CLES, both types of instruction increased student perception of the learning environment, while the teacher CLES revealed that the teacher's perception of constructivist practices decreased in the scripted classroom over the course of the nine-week period. A topic that is relatively underexplored is the influence constructivist practices have on teacher efficacy when using the Understanding by Design framework in the classroom. It may be advantageous to explore how teachers with a strong sense of efficacy impact student efficacy and perception of the learning environment.

The length of time of this study was a nine-week period. Providing a study over the course of an entire school year and using several classrooms across a school district would provide a richer understanding of the importance of implementing a curriculum that allows for teacher autonomy. While these results should be taken into account when considering implementing a new science curriculum, further investigation into teacher training programs regarding the implementation of a constructivist learning environment while utilizing the UbD framework merits examination. It may be advantageous to do a follow-up measure during the students' senior year of high school to examine the level of Biology content knowledge that was retained. This data can provide evidence to determine which of the two curriculum frameworks, instructional styles, and activities helped the students retain the content learned during that school year.

When implementing a new curriculum, there are several factors to consider, such as the depth, rigor, and alignment of standards, differentiation tools provided, implementation requirements, professional development offered, resources necessary for hands-on instruction, budgetary constraints, and teacher buy-in. District curriculum decision makers can utilize curriculum adoption committees to provide teachers an opportunity to examine various curriculum resources before they are implemented in the classroom. This would include providing teachers and administrators an opportunity to use the state provided rubrics to review resources and discuss the benefits and disadvantages of each. Along with reviewing the resources, this would also give the committee time to create a budget for the hands-on equipment and supplies needed to implement these resources effectively in the classrooms. In my role as science curriculum coordinator, I plan to use the results of this study to promote a more inclusive method for adopting curriculum. With new science standards being adopted and implemented within the next year, I would like to utilize curriculum adoption committees to provide science teachers an opportunity to examine various curriculum resources before they are implemented in the classroom. This will allow teachers an opportunity to see how curriculum resources are aligned to the standards and choose one that will fit the needs of the students in our district.

## Summary

In this study, participants were exposed to two curriculum frameworks over the course of a nine-week period. The use of content-based tests, Constructivist Learning Environment Surveys, student focus groups, teacher reflection logs, sample lesson plans, and student work samples were utilized to identify differences in science content knowledge and gain an understanding of the differences in the perception of the learning environment.

Each component of the study plays an integral role when implementing curriculum in the classroom. The teacher's awareness of student perception of the learning environment has influenced her teaching style and use of various strategies to keep students engaged during the lesson cycle. Additionally, the teacher was able to make note of gaps in the scripted curriculum and relay this information to the person at the district-level in charge of assessing curriculum.
Implementing constructivist practices along with a curriculum framework that allows for more teacher autonomy has a great potential for positively impacting teacher and student efficacy in the science classroom, thus creating a positive learning environment.

*The authors received no financial support for the research, authorship, and/or publication of this manuscript.*

**Masomeh Mahzoon-Hagheghi** (masomeh.mahzoon@gmail.com) is a graduate from Texas A&M Corpus Christi, receiving a PhD in Curriculum and Instruction. She received a bachelor's degree in biology with a minor in chemistry from The University of Texas at San Antonio, and a mater's degree in elementary education from Texas A&M- Corpus Christi. She is currently the district science curriculum coordinator for The Schools of Science and Technology. She has passion for science education and is dedicated to making science fun for students of all ages.

**Faye Bruun** (faye.bruun@tamucc.edu) is Professor of Education in the Department of Curriculum, Instruction, and Learning at Texas A&M Corpus Christi. She is Program Coordinator of the Ph.D. and Masters in C&I. Her research interests are in STEM teacher education.

## References

Accelerate Learning. (2021). [The 5E + IA Instructional Model- Underlying principles of the 5E].

Alwahaibi, S.M.H., Lasharı, S.A., Saoula, O., Lasharı, T.A., Benlahcene, A. & Lubana, A. (2019). Determining Students' Intention: The Role of Students' Attitude and Science Curriculum. *Journal of Turkish Science Education*,16(3), 314-324.

Amrein, A. L., & Berliner, D. C. (2002). High-stakes testing, uncertainty, and student learning. *Education Policy Analysis Archives*, 10(18).

Anderson, C. G. (2011). A study of the impact of scripted reading on student fluency, comprehension, and vocabulary. (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI 3461716)

Apple, M.W. (2006). Markets, standards, god and inequality. In Blair, E. (2011). *Thinking about schools: a foundations of education reader* (p. 129-155). Boulder, CO: Westview Press.

Atkeison-Cherry, N. K. (2004). A comparative study of mathematics learning of third-grade children using a scripted curriculum and third-grade children using a non-scripted curriculum. (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI 3149291)

Bosen, P. K. (2014). Scripted or non-scripted: A comparative analysis of two reading programs. (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI 3623269)

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A, & Landes, N. (2006). *The BSCS 5E instructional model: Origins, effectiveness, and applications*. Colorado Springs, CO: Biological Sciences Curriculum Study.

Carl, N. M. (2014). Reacting to the script: Teach for America teachers' experiences with scripted curricula. *Teacher Education Quarterly*, 41(2), 29-50.

Childre, A., Sands, J. R., & Pope, S. T. (2009). *Backward Design. Teaching Exceptional Children*, 41 (5), 6-14.

Cilliers, J., Fleisch, B., Prinsloo, C., & Taylor, S. (2019). How to improve teaching practice? An experimental comparison of centralized training and in-classroom coaching. *Journal of Human Resources*, 55(3), 926–962.

Costigan, A. T. (2008). Canaries in the coal mine: Urban rookies learning to teach language arts in " high priority" schools. *Teacher Education Quarterly*, Spring, 85-103.

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

Crocco, M. S., & Costigan, A. T. (2007). The narrowing of curriculum and pedagogy in the age of accountability: Urban educators speak out. *Urban Education*, 42, 512-535.

Cunningham, A.E., Zibulsky, J., Stanovich, K. E., & Stanovich, P. J. (2009). How teachers would spend their time teaching language arts: The mismatch between self-reported and best practices. *Journal of Learning Disabilities*, 42: 418-30.

Demko, M. (2010). Teachers become zombies: The ugly side of scripted reading curriculum. *Voices from the Middle*, 17(3), 62-64.

Devetak, I., & Glažar, S.A. (Eds.). (2014*). Learning with Understanding in the Chemistry Classroom.* Dordrecht: Springer.

Dias, M., Eick, C., & Brantley-Dias, L. (2011). Practicing what we teach: A self-study in implementing an inquiry-based curriculum in a middle grades classroom. *Journal of Science Teacher Education*, 22(1), 53-78.

Dickson, R. A. (2006). The effect on student achievement of research-based versus non-research based reading programs. (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI 3232104)

Dorman, J. (2001). Associations between classroom environment and academic efficacy. *Learning Environments Research*, 4, 243-257.

Doyle, W. (1992). Curriculum and pedagogy. In P.W. Jackson (Ed.), *The handbook of research on curriculum: A project of the American Educational Research Association* (pp. 486-516). New York: Macmillan.

Duncan-Owens, D. D. (2009). Commercial reading programmes as the solution for children living in poverty. *Literacy*, 44(3), 112-121.

Ede, A. (2006). Scripted curriculum: Is it a prescription for success? *Childhood Education*, 83(1), 29-32.

Eisenbach, B. B. (2012). Teacher belief and practice in a scripted curriculum. *The Clearing House*, 85, 153-156.

Elkind, D. (1986). Formal education and early childhood education: An essential difference. *Phi Delta Kappan*, May, 631-633.

Firestone,W. A., Winter, J., & Fitz, J. (2000). Different assessments, common practice? Mathematics testing and teaching in USA and England and Wales. *Assessment in Education*, 7(1), 13-37.

Flipo, R. (1999). *What do the experts say?* Portsmouth, NH: Heinemann.

Freire, P. (1970). *Pedagogy of the oppressed*. New York: Continuum.

Freire, P. (1993). *Pedagogy of the oppressed*. New rev. 20th-Anniversary ed. New York: Continuum.

Freire, P. (2005). *Teachers as cultural workers: Letters to those who dare teach*. Boulder, CO: Westview Press.

Giroux, H. A. (1988). *Teachers as intellectuals: Toward a critical pedagogy of learning*. Granby, MA: Bergin & Garvey.

Gunter, P. & Reed, T. (1997). Academic instruction of children with emotional and behavioral disorders using scripted lessons. *Preventing School Failure*, 42(1), 33.

Halff, H. M. (1988). Curriculum and instruction in automated tutors. In M. C. Polson and J. J. Richardson (Eds) *Foundation of intelligent tutoring systems*, (pp. 77-108). Hillside, NJ: Lawrence Erlbaum Associated.

Hanson, W. E., Creswell, J. W., Plano Clark, V. L., Petska, K. S., & Creswell, J. D. (2005). *Mixed methods research designs in counseling psychology*. Faculty Publications, Department of Psychology. 373.

Hargreaves, A. (1994). *Changing teacher, changing times*. New York: Teachers College Press.

Harris, C., Penuel, W., D'Angelo, C., DeBarger, A., Gallagher, L., Kennedy, C. .Krajcik, J. (2015). Impact of project-based curriculum materials on student learning in science: Results of a randomized controlled trial. *Journal of Research in Science Teaching*, 52(10), 1362-1385.

Helldén, G. (2005). Exploring understandings and responses to science: A program of longitudinal studies. *Research in Science Education*, 35(1), 99-122.

Herr, K. & Arms, E. (2004). Accountability and single sex-schooling: A collision of reform agendas. *American Educational Research Journal*, 41(3), 527-555.

Hiralall, A. & Martens, B. (1998). Teaching classroom management skills to preschool staff: The effects of scripted instructional sequences on teacher and student behavior. *School Psychology Quarterly*, 13(2), 94.

Häussler, P., & Hoffman, L. (2002). An intervention student to enhance girls' interest, self-concept, and achievement in physics classes. *Journal of Research in Science Teaching*, 39(9), 870-888.

Helldén, G. (2005). Exploring understandings and responses to science: A program of longitudinal studies. *Research in Science Education*,35(1), 99-122.

Hos, R. & Kaplan-Wolff, B. (2020). On and off script: A teacher's adaptation of mandated curriculum for refugee newcomers in an era of standardization. *Journal of Curriculum and Teaching*, 9(1), 40-54.

Jerald, C.D. (2006). School culture: The hidden curriculum. *Issue Brief*, December, 1-8.

Johnson, B. & McClure, R. (2004). Validity and reliability of a shortened, revised version of the constructivist learning environment survey (CLES). *Learning Environments Research*, 7(1), 65-80.

Kang, G. (2016). Advocacy for autonomy: Complicating the use of scripted curriculum in unscripted spaces. *Language Arts Journal of Michigan*, 32 (1), 43-50.

Kohl, H. (2009). The educational panopticon. *Teachers College Record*, Date Published: January 08, 2009, http://www.tcrecord.org, ID Number 15477, Date Accessed: 11/6/ 2016.

King, K. V., & Zucker, S. (2005). *Curriculum Narrowing*. San Antonio: Pearson Education.

Kumar, R. & Gupta, V.K. (2009). An introduction to cognitive Constructivism in Education. *Journal of Indian Education*. 35(3) 39-45.

Lucas, K. & Roth, W.M. (1996). The nature of scientific knowledge and student learning: Two longitudinal case studies. *Research in Science Education*, 26, 103-127.

Lyons, M. T. (2009). Comparing the effectiveness of scripted and non-scripted language arts programs in low-performing schools. (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI 3411179)

MacGillivray, L., Ardell, A.L., Curwen, M.S., & Palma, J. (2004). Colonized teachers: Examining the implementation of a scripted reading program. *Teaching Education*, 15(2),131-144.

Marchand-Martella, T. A. Slocum, & R. C. Martella (Eds.), *Introduction to Direct Instruction* (pp 28-65). Boston: Allyn & Bacon.

McLaren, P. (2007). *Life in schools: An introduction to critical pedagogy in the foundations of education.* Boston: Pearson/Allyn and Bacon.

Michael, N. A., & Libarkin, J. C. (2016). Understanding by design: Mentored implementation of backward design methodology at the university *level. New Waves Educational Research & Development,* 42 (2) 44-52.

Mills, C. (2008). Reproduction and transformation of inequalities in schooling. *British Journal of Sociology of Education,* 29(1), 79-89.

Milner, H. R. (2013). Scripted and narrowed curriculum reform in urban schools. *Urban Education*, 48 (2), 163-170.

Milosovic, S. (2007). Building a case against scripted reading programs: A look at the NCLB reading first initiative's impact on curriculum choice. *Education Digest*, 73 (1), 27-30.

Moustafa, M. & Land, R. E. (2002). The reading achievement of economically disadvantaged children in urban schools using Open Court vs comparably disadvantaged children using non-scripted reading programs. *In 2002 yearbook of the urban learning, teaching, and research special interest group of the American Educational Research Association* (pp. 44- 53). Washington, DC: AERA.

O'Loughlin, M. (1992). Rethinking science education: Beyond Piagetian constructivism toward a sociocultural model of teaching and learning. *Journal of Research in Science Teaching*, 29(8), 791-820.

Pestalozzi, H. (1951). *Education of man*. New York: Philosophical Library.

Piaget, J. (1973). *To understand is to invent: The future of education*. New York: Grossman.

Powell, R., Cantrell, S. C., & Correll, P. (2017). Power and agency in a high poverty elementary school: How teachers experienced a scripted reading program. *Journal of Language & Literacy Education*, 13 (1), 93-112.

Ravitch, D. (2010). *The death and life of the great American school system: How testing and choice are undermining education*. New York: Basic Books.

Remillard, J., Harris, B., & Agodini, R. (2014). The influence of curriculum materials design on opportunities for student learning. *ZDM Mathematics Education*, 46(5), 735-749.

Resnick, L. B. (1989). Introduction in L.B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 1-24). Hillsdale, NJ: Erlbaum.

Rice University. Houston, Texas https:// www.acceleratelearning.com Date Accessed: 26 April 2017.

Roblin, N.P., Schunn, C., & McKenny, S. (2017). What are critical features of science curriculum materials that impact student and teacher outcomes? *Science Education*, 2017: 1-23.

Roth, D. (2007). Understanding by Design: A Framework for Effecting Curricular Development and Assessment. *CBE-Life Science Education*, 6(2), 95-97.

Roth, W.M., & Bowen, G. (1995). Knowing and interacting: A study of culture, practices, and resources in a grade 8 open-ended science classroom guided by a cognitive apprenticeship model. *Cognition and Instruction*, 13, 73-128.

Roth, W.M., & Roychoudhury, A. (1993). The nature of scientific knowledge, knowing, and learning: The perspectives of four physics students. *International Journal of Science Education*, 15, 27-44.

Rubrica, R.D. (2018). *An Action Research on Project-Based Learning and Understanding by Design and Their Effects on the Science Achievement and Attitude of Science Students.*

Sadler, T., Romine, W., Menson, D., Ferdig, R., & Annetta, L. (2015). Learning biology through innovative curricula: A comparison of game-and nongame-based approaches. *Science Education*, 99(4), 696-720.

Schiller A. (2015). Understanding by design unit lesson plans for the next generation science standards: Life science. *Graduate Research Papers.* 73.http://scholarwork.uni.edu/grp/73

Shadish, W. R., & Luellen, J. K. (2006). Quasi-experimental design. In J. L. Green, G. Camilli, & P. B. Elmore (Ed.), *Handbook of Complementary methods in education research* (pp. 539-550). New York, NY: Routledge.

Singh, S., & Yaduvanshi, S. (2015). Constructivism in science classroom: Why and how. *International Journal of Scientific and Research Publications*, 5(3), 1-5.

Smagmorinsky, P., Lakly, A., & Johnson, T.S. (2002). Acquiescence, accommodation, and resistance in learning to teach within a prescribed curriculum. *English Education*, 34, 187-211.

Smith, M.L., Edelsky, C., Draper, K., Rottenberg, C., & Cherland, M. (1989). *The role of testing in elementary schools* (Monograph). Tempe, AZ: Arizona State University, Center for Research on Evaluation, Standards, and Student Testing (Grant No. OERI-G-86-0003).

Spring, J. (2014). *American Education*. New York: Mc Graw Hill Companies, Inc.

Srikantaiah, D. (2009). *How state and federal accountability policies have influenced curriculum and instruction in three states: Common findings from Rhode Island, Illinois, and Washington.* Washington DC: Center on Education Policy.

Sudduth, K. (2020). Teachers' perceptions of enhancing student achievement through scripted and teacher-developed curriculums. (Publication No. 28155999) [Doctoral dissertation, Walden University]. ProQuest Dissertations and Theses Global.

Taber, K. S. (2019). Constructivism in education: Interpretations and criticisms from science education. In Information Resources Management Association (Ed.), *Early Childhood Development: Concepts, Methodologies, Tools, and Applications* (pp. 312-342). Hershey, Pennsylvania: IGI Global.

Taylor, P., Dawson, V., & Fraser, B. (1995). A constructivist perspective on monitoring classroom learning environments under transformation. Paper presented at the annual meeting of the American Educational Research Association, San Francisco.

Twyman, J. S., & Heward, W. L. (2018). How to improve student learning in every classroom now. I*nternational Journal of Educational Research*, 87, 78-90.

Valencia, S.W., Place, N. A., Martin, S. D., & Grossman, P. L. (2006). Curriculum materials for elementary reading: Shackles and scaffolds for four beginning teachers. *The Elementary School Journal,* 107(1), 93-120.

Valli, L., & Buese, D. (2007). The changing roles of teachers in a high-stakes era accountability. *American Educational Research Journal*, 44, 519-558.

Vasquez Helig, J., & Jez, S. J. (2014). *Teach for America: A return to the evidence*. Boulder, CO: National Education Policy Center. https://nepc.colorado.edu/publication/teach-for-america-return

Walsh, D. J. (1986). The trouble with program-directed curricula. *Principal*, 66(1), 68-70

Watkins, C. L., & Slocum, T. A. (2004). *The components of direct instruction.* In N.E.

White, B., & Frederiksen, J. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, 16(1), 3-118.

Whitehouse, M. (2014). Using a backward design approach to embed assessment in teaching. *School Science Review,* 95(352), 99-104.

Wiggins, G., & McTighe, I. (2005). *Understanding by Design* (2nd ed.). Alexandria, VA: ASCD.

Wiggins, G., & McTighe, J. (2011). *The Understanding by Design guide to creating high-quality units.* Alexandria, VA: ASCD.

Wineburg, S. S. (2001). *Historical thinking and other unnatural acts: Charting the future of teaching the past.* Philadelphia: Temple University Press.

Wyner, Y. (2013). The impact of a novel curriculum on secondary biology teachers' dispositions toward using authentic data and media in their human impact and ecology lessons. *Journal of Science Teacher Education*, 24(5), 833-857.

Zhao, Y., Wehmeyer, M., Basham, J., & Hansen, D. (2019). Tackling the wicked problem of measuring what matters: Framing the questions. *ECNU Review of Education*, 2(3), 262-278.

## APPENDIX A: CONSTRUCTIVIST LEARNING ENVIRONMENT SURVEY: TEACHER

### Constructivist Learning Environment Survey
### Teacher Version

This questionnaire contains 20 statements about teaching and learning that could take place in a science classroom.

You will be asked how often each practice occurs: almost never, not very often, sometimes, often, or almost always. There are no "right" or "wrong" answers. Your opinion is what is wanted. Think about how well each statement determines your science classroom. Indicate the best response for each item.

Be sure to give an answer for each question. If you change your mind about an answer, just cross it out and circle another. Some statements in this questionnaire are fairly similar to other statements. Don't worry about it. Simple give your opinion about each statement. *Your identity will be kept strictly confidential.*

Today's date:___________________________

Your Name_____________________________Campus Name_________________________

Grade Taught____________________________Science Subject________________________

| What Happens in My Science Classroom | Almost Always | Often | Some times | Not very often | Almost never |
|---|---|---|---|---|---|
| 1. I teach about the world in and outside of school. | | | | | |
| 2. Things I teach about connects to things about the world in and outside of school. | | | | | |
| 3. I teach how science is part of in and outside of school life. | | | | | |
| 4. I teach interesting things about the world inside and outside of school. | | | | | |
| 5. I teach that science cannot always provide answers to problems. | | | | | |
| 6. I teach that scientific explanations have changed over time. | | | | | |
| 7. I teach that science is influenced by people's different cultural values and opinions. | | | | | |
| 8. I teach that science is a way to raise questions and seek answers. | | | | | |
| 9. It's okay for students to question the way that they are being taught. | | | | | |
| 10. I feel I teach better when students are allowed to question what or how they're learning. | | | | | |
| 11. It's okay for students to ask questions about activities that are confusing. | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 12. It's okay for students to say they are concerned about anything that gets in the way of their learning. | | | | | |
| 13. In this class, students help plan what they are going to learn. | | | | | |
| 14. In this class, students help decide how well they are learning. | | | | | |
| 15. In this class, students help decide which activities work best for them. | | | | | |
| 16. In this class, students let the teacher know if they need more class time to complete an activity. | | | | | |
| 17. In this class, students talk with other students about how to solve problems. | | | | | |
| 18. In this class, students explain their ideas to other students. | | | | | |
| 19. In this class, students ask other students to explain their ideas. | | | | | |
| 20. In this class, students ask me to explain my ideas. | | | | | |

Source: Johnson & McClure, 2004.

## APPENDIX B: CONSTRUCTIVIST LEARNING ENVIRONMENT SURVEY: STUDENT

### Constructivist Learning Environment Survey
### Student Version

This questionnaire contains 20 statements about teaching and learning that could take place in a science classroom.
You will be asked how often each practice occurs: almost never, not very often, sometimes, often, or almost always. There are no "right" or "wrong" answers. Your opinion is what is wanted. Think about how well each statement determines your science classroom. Indicate the best response for each item.
Be sure to give an answer for each question. If you change your mind about an answer, just cross it out and circle another. Some statements in this questionnaire are fairly similar to other statements. Don't worry about it. Simple give your opinion about each statement. *Your identity will be kept strictly confidential.*

Today's date:___________________________
Your Name_____________________________Campus Name_________________________
Grade _________________________________Science Subject________________________

| What Happens in My Science Classroom | Almost always | Often | Some-times | Not very often | Almost never |
|---|---|---|---|---|---|
| 1. I learn about the world in and outside of school. | | | | | |
| 2. Things I learn about connects to things about the world in and outside of school. | | | | | |
| 3. I learn how science is part of in and outside of school life. | | | | | |
| 4. I learn interesting things about the world inside and outside of school. | | | | | |
| 5. I learn that science cannot always provide answers to problems. | | | | | |
| 6. I learn that scientific explanations have changed over time. | | | | | |
| 7. I learn that science is influenced by people's different cultural values and opinions. | | | | | |
| 8. I know that science is a way to raise questions and seek answers. | | | | | |
| 9. It's okay for students to question the way that they are being taught. | | | | | |
| 10. I feel I learn better when students are allowed to question what or how they're learning. | | | | | |
| 11. It's okay for students to ask questions about activities that are confusing. | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 12. It’s okay for students to say they are concerned about anything that gets in the way of their learning. | | | | | |
| 13. In this class, students help plan what they are going to learn. | | | | | |
| 14. In this class, students help decide how well they are learning. | | | | | |
| 15. In this class, students help decide which activities work best for them. | | | | | |
| 16. In this class, students let the teacher know if they need more class time to complete an activity. | | | | | |
| 17. In this class, students talk with other students about how to solve problems. | | | | | |
| 18. In this class, students explain their ideas to other students. | | | | | |
| 19. In this class, students ask other students to explain their ideas. | | | | | |
| 20. In this class, students ask me to explain my ideas. | | | | | |

Source: Johnson & McClure, 2004.

# APPENDIX C: FOCUS GROUP GUIDING QUESTIONS

1. Looking back at this week's lesson, what do you feel you have learned?

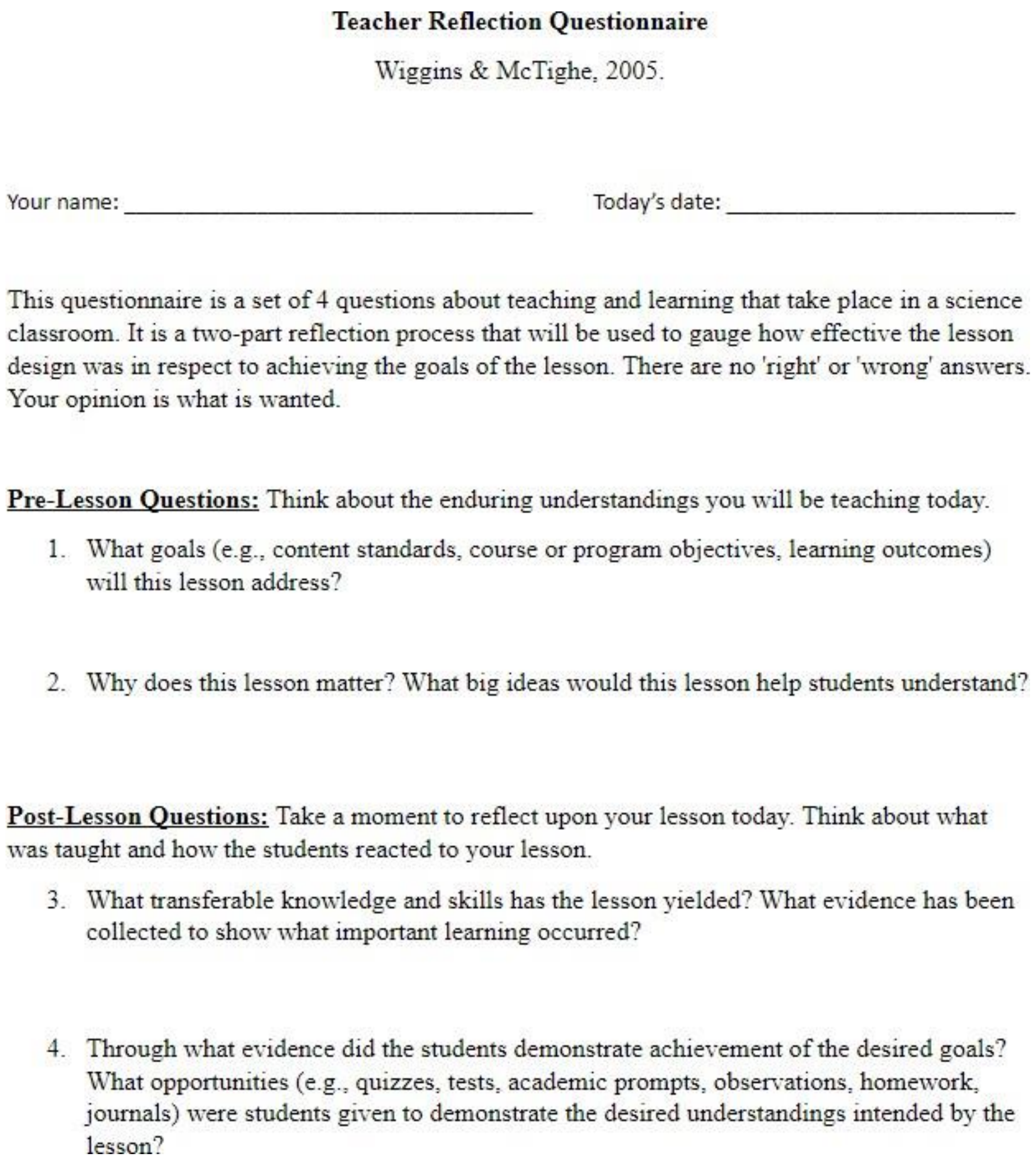
2. How do you think the activities you have done this week helped you truly understand what you were supposed to learn- the objectives written on the board?

3. Do you feel that you had enough time to complete the activities chosen for you to do in class? Give specific examples.

4. Were you given an opportunity to discuss what you learned from each activity? What are some things you discussed during these sessions? Did the teacher give you specific things to discuss, or were you able to choose?

5. How do you feel that your teacher gave you opportunities to ask questions and apply what you learned?

# APPENDIX D: TEACHER REFLECTION LOG QUESTIONNAIRE



**Teacher Reflection Questionnaire**

Wiggins & McTighe, 2005.

Your name: ______________________________ Today's date: ______________________

This questionnaire is a set of 4 questions about teaching and learning that take place in a science classroom. It is a two-part reflection process that will be used to gauge how effective the lesson design was in respect to achieving the goals of the lesson. There are no 'right' or 'wrong' answers. Your opinion is what is wanted.

**Pre-Lesson Questions:** Think about the enduring understandings you will be teaching today.

1. What goals (e.g., content standards, course or program objectives, learning outcomes) will this lesson address?
2. Why does this lesson matter? What big ideas would this lesson help students understand?

**Post-Lesson Questions:** Take a moment to reflect upon your lesson today. Think about what was taught and how the students reacted to your lesson.

3. What transferable knowledge and skills has the lesson yielded? What evidence has been collected to show what important learning occurred?
4. Through what evidence did the students demonstrate achievement of the desired goals? What opportunities (e.g., quizzes, tests, academic prompts, observations, homework, journals) were students given to demonstrate the desired understandings intended by the lesson?

## APPENDIX E: STUDENT WORK ANALYSIS RUBRIC

| | | | | |
|---|---|---|---|---|
| Rubric | | Student Work Analysis | | |
| Score each item as follows: 1. Not evident 2. Somewhat evident 3. Mostly evident 4. Extremely evident | | | | |
| Category | Indicators | Score | Assignment Name | Evidence |
| State Standards (TEKS) | Predict possible outcomes of various genetic combinations such as monohybrid crosses, dihybrid crosses, and non-Mendelian inheritance. | | | |
| Student Expectations | The student will be able to:<br>● Use Punnett squares or other methods to calculate possible outcomes of the $F_2$ generation based on genotype information about the $F_1$ generation<br>● Infer genotype information of the $F_1$ generation based on genotype or phenotype information about the $F_2$ generation<br>● Predict genetic combination with single gene trait on autosomal chromosomes with one dominant allele and one recessive allele using Mendelian genetics.<br>● Predict genetic combinations with genotypes including homozygous dominant (GG), homozygous recessive (gg), or heterozygous (Gg) using Mendelian genetics.<br>● Predict genetic combinations with two traits caused by two separate genes on the same or different autosomal chromosome using Mendelian genetics.<br>● Predict genetic combination with each gene following the dominant, recessive, homozygous, and heterozygous conventions independent of the other gene using Mendelian genetics.<br>● Predict genetic combinations with incomplete dominance (one allele does not completely mask the action of the other allele, so a completely dominant allele does not occur) using Non-Mendelian genetics.<br>● Predict genetic combinations with codominance (both alleles are expressed | | | |

| | | | | |
|---|---|---|---|---|
| | equally in a heterozygous genotype) using Non-Mendelian genetics.<br>● Predict genetic combinations with multiple alleles (more than 2 alleles affect the trait) using Non-Mendelian genetics.<br>● Predict genetic combinations with sex-linked traits (genes that are located on the sex chromosome, usually the X chromosome) using Non-Mendelian genetics.<br>● Recognize that phenotypic expression is often the result of a complex interaction of many genes, gene products (proteins), and environmental factors using Non-Mendelian genetics.<br>● Recognize that some traits can be a result of mitochondrial DNA gene expression (e.g., Leber's hereditary optic neuropathy) using Non-Mendelian genetics. | | | |
| Essential Questions | Essential knowledge assessed by the assignment:<br>● In what ways can the probability of offspring inheritance be calculated?<br>● What are the limitations of calculating the probability of offspring inheritance? | | | |
| Student Understanding | ● Does the student's work demonstrate his/her understanding of the task?<br>● Does the student's work demonstrate the depth of his/her understanding of the topic?<br>● Does the student's work demonstrate his/her proficiency with the requirements of the targeted standards? | | | |
| | Total | /16 | | |

## APPENDIX F : SAMPLE TEACHER LESSON PLAN RUBRIC

<table>
<tr><td colspan="4">Lesson Plan Rubric</td></tr>
<tr><td colspan="4">Score each item as follows: 1. Not evident 2. Somewhat evident 3. Mostly evident 4. Extremely evident</td></tr>
<tr><td>Category</td><td>Indicators</td><td>Score</td><td>Evidence</td></tr>
<tr><td>Instructional Design</td><td>● The lesson design is clear, coherent, and presented in a developmentally appropriate way.<br>● Concepts and skills build logically and purposefully with transitions to support development and understanding.<br>● The lesson teaches and uses active learning strategies to engage students and foster deep understanding.<br>● The lesson uses a variety of media to give students multiple and varied experiences with a single concept or skill, inviting students to explore a concept or skill from different angles.<br>● The lesson is differentiated and accommodates unique learning styles and various ability levels using scaffolding.</td><td></td><td></td></tr>
<tr><td>Standards Alignment</td><td>● The lesson aligns with the current Texas Essential Knowledge and Skills for Biology.</td><td></td><td></td></tr>
<tr><td>Assessment</td><td>● Assessments reflect types of questions students may see on future high stakes assessments.<br>● Formative assessments are used to guide instruction and monitor student learning.</td><td></td><td></td></tr>
<tr><td>Learning Activities</td><td>● The lesson contains student-friendly essential questions derived from the academic standards.<br>● The activities reflect vertical alignment and appropriate level of rigor (Standard + Instructional Strategy + Verb + Product + Assessment = Rigorous Lesson).<br>● The activities actively engage and promote higher order thinking and problem solving.</td><td></td><td></td></tr>
</table>

| | | | |
|---|---|---|---|
| | ● The activities address learner needs and considers the perspective of the learner (learning style, interest, developmental stages, and possible gaps).<br>● The activities provide students opportunities for student collaboration.<br>● The activities provide opportunities for students to have discussions (student-led, group, or class-wide).<br>● Exemplars are used within the lesson to demonstrate/model performance expectations | | |
| Instructional Pacing | ● Lesson is designed to optimize in class time for assignments. | | |
| | Total | /20 | |

* Adapted from Constructivist lesson rubric (2014).

ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 27, NO. 4, 59-76

# Pathways to Science Careers: Exploring Perceptions of Science Educators and Professionals on Being a Scientist

Sarah L. Ferguson
*Rowan University*

Lesa DeShield Givens
*Rowan University*

**ABSTRACT**

One function of modern education has been to prepare students for future college and/or career pathways. Particular attention in the US is given to preparation in STEM career fields. However, we may not be effective in advising students towards some STEM careers. This qualitative interview study evaluates the perspectives of stakeholders in science career preparation, including high school teachers and counselors, community college and university faculty, and science industry professionals. Interviews were conducted to explore participant perceptions on skills and dispositions students need to be successful in science careers. Results presented focus on areas of agreement and areas of difference between the stakeholder groups, and specific recommendations for practical change in science career development are discussed.

*Keywords:* science education, student skills and dispositions, qualitative interview study

## Introduction

It has been argued that one purpose of education is to prepare students for their future college and/or career plans. Particular attention in education research has been given to *college and career readiness*, where students leaving high school should be prepared to enter college and/or the workforce without needing further developmental training (U.S. Department of Education, n.d.a). Additionally, the areas of science, technology, engineering, and mathematics (STEM) continue to receive particular attention due to projected advances in these career fields and the belief that STEM advances are important for the protection and development of the country as a whole (U.S. Department of Education, n.d.b). However, science careers continue to be pursued and staffed by primarily white males from middle to high social status families (Byars-Winston, 2014; Tyson et al., 2007). Underrepresentation by women, minoritized groups, and students with lower socio-economic status has been studied and addressed for years with little improvement (Falco, 2017; Swafford & Anderson, 2020). Additionally, we may not be as effective in advising students towards STEM careers outside of the most common science areas such as biology, engineering, chemistry, and physics (Byars-Winston, 2014; Falco, 2017; Rottinghaus et al., 2018). At a foundational level, one piece of this problem may be a disconnect between what our education system prepares students for in science, how we advise students around science careers, and what scientists need to be effective in their careers.

## Theoretical Framework

While this is an exploratory study, a theoretical foundation is used to provide understanding. Social cognitive career theory (SCCT) provides a foundation of understanding for the career development process (Lent et al., 1994; 2002). SCCT provides a complex theory of career development for the individual where learning experiences impact self-efficacy and outcome expectations, which subsequently impact career interests, goals, and choices. Self-efficacy is the belief in one's ability to complete tasks toward a goal, and outcome expectations focus on the perceived outcomes, positive or negative, one connects with a specific career path. Career interests are the likes, dislikes, and indifferences an individual has about occupation activities and are key determinants in choosing a career (Lent et al., 2002).

SCCT also particularly highlights the role of person inputs, background affordances, and proximal supports and barriers in the overall career choice process, resulting in a more comprehensive framework for understanding career development. Person inputs in SCCT refer to components of the self that impact the career process, elements of identity such as age, gender, disability status, etc. (Lent et al., 1994, 2002). Background affordances such as family history, culture, ethnicity, and socio-economic status are also understood to impact career decisions and outcomes. Finally, SCCT breaks proximal contextual influences into two components: barriers to career decisions such as social stereotypes, or a lack of job opportunities, and supports to career decisions such as mentoring networks and internship opportunities (Lent et al., 2002).

Specific to STEM careers, Byars-Winston (2014) argues the need for a Multicultural STEM Career Development framework, specifically highlighting the ongoing barriers for students in minoritized and traditionally underrepresented identities accessing STEM opportunities and careers. Research has consistently shown the impact of lack of opportunity, decreased self-efficacy in STEM related content and courses, and lack of support as barriers for these students, regardless of actual ability (Byars-Winston, 2014; Rottinghaus et al., 2018; Tyson et al., 2007). Connecting this argument back to SCCT, Falco (2017) presents a synthesis of STEM career development research within the SCCT framework, and also highlights the need Byars-Winston (2014) had previously presented for targeted interventions with historically underrepresented groups. We therefore extend this argument with empirical evidence from across the STEM career development pathway, building on the foundation of SCCT and the extensions by Byars-Winston (2014) and Falco (2017) on the need to better understand the decision-making process and needed supports for students potentially pursuing STEM careers.

For the present study, educational experiences are addressed through the interviews of high school and college/university science faculty, and proximal supports and barriers are addressed through discussions with high school administrators in addition to science educators. Finally, the science professionals represent the culminating example of an individual who chose a science career, so theoretically they can be seen as an example of the successful completion of science career development. Understanding their experiences may help us better understand areas for change throughout the career development process.

## Literature Review

Previous work has examined student perceptions of science and scientists at different levels of education (Farland-Smith, 2009; Finson, 2002; Fralick et al., 2009; Schibeci, 2006; Shin et al., 2015) and science educator perceptions (Akerson et al., 2012; Milford & Tippett, 2013; Ucar, 2012). Marked increase in such studies is noted since 1957, when researchers began examining students' impressions of scientists - the majority substantiating previous findings that students' representations of scientists are based on stereotypes (Finson, 2002; Farland-Smith, 2009; Schibeci, 2006). Many of these studies employed drawings (i.e., Draw-A-Scientist Test and related measures) and interviews as data generating methods (Milford & Tippett, 2013; Schibeci, 2006; Shin et al., 2015; Ucar, 2012). This data was used to evaluate pre- and post-perceptions about science dispositions, scientists, applicability, and ambitions.

## Student Perceptions of Science and Scientists

While the present study is not focused on student perceptions, the distal outcome of the STEM career pathway is student interest and choices about STEM careers. Therefore, a discussion of the stakeholders and direction of the STEM career pathway must include a discussion on the issues we are seeing at the end of the pathway, namely the perceptions of students about these careers. Meta-summaries and analyses of multiple studies about students' drawings of scientists have been conducted to look at the collective patterns of beliefs about these careers (Ferguson & Lezotte, 2020; Finson, 2002; Miller et al., 2018). The common stereotypical impressions were scientists as glasses-wearing males of European descent with beards and mustaches, in a lab coat, and working in a room or chemistry lab (Ferguson & Lezotte, 2020; Finson, 2002; Fralick et al., 2009; Miller et al., 2018). There are multiple ways of interpretation and researchers have cautioned against taking students' visual representations as fact, as many drawings may portray whimsical or unrelated images, or may be impacted by the available materials and instructions given for the task (Ferguson & Lezotte, 2020; Finson, 2002).

However, these results support other findings that students' perceptions of scientists are associated with their own feelings about science, as well as perceptions about their own abilities, capabilities, and control (Finson, 2002; Fralick et al., 2009). For those with a stronger sense of self-perception in these areas, fewer aspects of stereotype were displayed in their drawings (Finson, 2002). On the other hand, scientists drawn by students of different races, gender, grade levels, and in different countries were all consistent in their stereotypical representations (Finson, 2002; Ucar, 2012). Self-efficacy has been consistently shown as the primary predictor of STEM career interest and choices (Aschbacher et al., 2012; Chemers et al., 2011).

Farland-Smith (2009) extended the work and findings of existing studies to specifically address the significance of culture as an influencer in the way students viewed scientists and their roles. From the position that schools are sites of cultural development, educational systems in schools across different nations provide the cultural factors that foster the formation of students' worldview. Therefore, their impressions of what scientists do is directly related to the predominant culture of the classroom and this includes the way in which science is taught (Farland-Smith, 2009; Finson, 2002). The societal influences of their cultural mores, including that of their school rooms, impacted learning and perceptions (Farland-Smith, 2009). A recurring implication of the literature on this topic is that the less stereotypical the image one holds, the more probable it is that one will opt to take more science classes and subsequently consider entering a profession in the sciences (Farland-Smith, 2009; Finson, 2002; Ucar, 2012).

## Teacher Perceptions of Science and Scientists

Research on student perceptions of science and scientists continue to emphasize the importance of foundational experiences and exposure through education, explaining that positive perceptions of science can begin in elementary school (Farland-Smith, 2009; Shin et al., 2015). Science teachers need to be cognizant of the fact that many of their students have stereotypical impressions of scientists (Finson, 2002), and examine their own perceptions, as the way teachers teach influences the way students learn, and how they view science and scientists (Anderson, 2015; Mansour, 2009). Previous studies have supported that classrooms are a chief site for engagements with science, and teachers are critical authorities in students' conceptions of science (Anderson, 2015; Mansour, 2009; Milford & Tippett, 2013).

However, studies have illustrated pre-service teachers believe their own traditions, values, and beliefs are not the same as those of scientists, and this can impact how teachers provide science instruction (Akerson et al., 2012; Farland-Smith, 2009). Studies evaluating drawings by preservice teachers mostly demonstrated that they held stereotypical views of a male scientist with unkempt hair and glasses, wearing a lab coat in a lab (Finson, 2002; Fralick et al., 2009; Milford & Tippett, 2013). Teachers' perceptions and dispositions about science directly impact the content and instructional delivery of science, and the teacher preparation programs are a catalyst in the conception and reinforcement of these perceptions (Milford & Tippett, 2013; Ucar, 2012).

## Changing Perceptions of Science

Finson (2002) suggested more research utilizing interventions to alter stereotypes to determine what the impacts were, rather than doing research focused only on the consistency of stereotypes. The researcher called for an examination of underlying assumptions and root causes behind stereotypical perceptions of scientists, moving past studies that basically confirm that students have stereotypical perceptions, and rather describe how interventions have impacted them (Finson, 2002). Both Finson (2002) and Schibeci (2006) suggested that stereotypical representations should not always be viewed negatively, because they do also encompass positive elements associated with scientists, and which may be necessary for identification purposes. But Schibeci (2006) also points to researchers who assert that in order for students to gravitate more to studying the sciences and select scientific careers, stereotypes are harmful.

Research has supported the impact of critical education interventions on students' views of scientists (Fralick et al., 2009; Schibeci, 2006; Shin et al., 2015; Zuo et al., 2019). Specifically, studies have highlighted the benefits of giving students opportunities to engage with working scientists as especially useful in cultivating practical impressions about scientists and the jobs they do (Fralick et al., 2009; Shin et al., 2015). Exposing students purposefully to not only realistic and practical science curricula, but also meaningful and realistic interactions with scientists can help prevent and change stereotypes (Schibeci, 2006; Shin et al., 2015).

University and college science professors could impact teacher candidates and those already teaching in differentiating between negative and positive elements in stereotypical images of scientists and effective ways of changing them (Finson, 2002). Changing the views of pre-service teachers so they see themselves as having similar traditions, values, and beliefs as scientists could positively influence the way they think about and teach science (Akerson et al., 2012). Future teachers should be exposed to courses that will build their self-efficacy as capable teachers of active and applied science, allowing them to be more successful and effective in communicating this to the diverse students with which they engage (Milford & Tippett, 2013).

## Present Study

The purpose of this study is to gain a better understanding of the perceptions of science for key stakeholders along the science career pathway, looking specifically at places where there is perceived disagreement. While substantial research has been conducted on student and teacher perspectives of science and scientists, less work has been done in the research literature to understand school counselors' perspectives of science and scientists (Ferguson et al., 2019; Hall et al., 2011; Moore, 2006; Schmidt et al., 2012), and little was found focused on the perspectives of faculty members in college and university programs on scientists and science careers outside of academia (Knezek et al., 2011). The perspectives of scientists themselves are also rarely studied, possibly due to the broad nature of science careers and the difficulty in recruiting participants for research of this type (Makarem & Wang, 2020; Yore et al., 2006). Furthermore, no prior study was located that compares and contrasts the beliefs and perceptions of all stakeholders along the science career pathway, missing the opportunity to view this issue from the perspective of the career development process. Therefore, in the present study, data was collected from high school teachers, counselors, and administrators, from local community college and university faculty in science areas, and from industry professionals working in various science fields in the region. This exploratory qualitative study is guided broadly by SCCT (Lent et al., 1994; 2002) as a theoretical framework, and seeks to understand what these stakeholders believe about the skills and dispositions students need if they seek to pursue a science career. There are two specific research questions guiding the inquiry process in this study:

1. What are the perspectives of stakeholders along the science career pathway on what skills and dispositions students need if they want to pursue a career in science?
2. What differences, if any, exist between these stakeholders on these components of science and science career understanding?

## Methods

The present study is an exploratory qualitative interview study focused on understanding the perceptions of the stakeholders along the science career pathway. The context of this study is localized to one state in the Northeastern United States to gain a focused view of the science career pathway for students in one state. This allows for a discussion of the interconnections between the educational entities but may also limit the application of these findings to this region. An early portion of this manuscript was presented at the American Education Research Association conference as a poster (Ferguson & Givens, 2020).

### Participants

After IRB approval was gained, participants were recruited from local high school science and math teachers, high school counselors, high school principals and/or vice-principals, community college faculty, university faculty, and science professionals working in the region. A target of four participants per category (total $n = 24$) was set to allow for maximum variation sampling (Johnson & Christensen, 2018), looking for participants within each category that represent a different perspective or aspect of the science career pathway within their role. For instance, when recruiting high school teachers, school counselors, and principals, attention was given to recruiting participants from a variety of high school sizes, locations (urban, suburban, rural), and levels of experience. This is a useful approach to recruitment with a study that attempts to understand a broad perspective on a specific issue (Johnson & Christensen, 2018).

### Data Collection

Participants were interviewed in one, one-hour session each by the primary researcher, at a location convenient for the participant. The interviews were semi-structured around three key questions: (a) *What do you believe science is, if you had to define it or describe the nature of it?*, (b) *In your opinion, what is a scientist? What does it mean to be a scientist?*, and (c) *In your opinion and based on your experience, what skills and/or dispositions do students need to be successful in science careers?* Follow up and probing questions were asked throughout to capture the experiences and perceptions of each participant as it relates to the focus of this study, including their perspective on the education and career development pathway for students in science related fields. All interviews were conducted by the primary researcher on this project. Additionally, participants and other educators were invited to a follow up discussion group to review the major study findings and discuss further. This served as a form of member checking and expansion of the data collected. These conversations are also considered in the data analyzed for this study.

### Data Analysis

All interviews were recorded and transcribed verbatim by a professional transcriptionist. Both researchers coded the interview transcripts following a thematic analysis procedure as detailed by Braun and Clarke (2006). First, researchers independently coded participant responses to identify meaningful concepts in initial codes. Then, the team met to compare the resulting codes and refine or clarify codes collaboratively, discussing any discrepancies and creating a shared coding structure through consensus. Next, the participants' responses were evaluated again with the new coding structure, and each researcher identified broad themes across the codes in connection with the study research questions. Specifically, for this study, themes were identified within the study participant groups individually to facilitate cross-group comparison. Then, the themes from each participant group were compared against other participant groups to look for similarities and differences in beliefs and perceptions. Next, the researchers met to finalize the identified themes within and between groups, and any areas of disagreement were resolved collaboratively to reach consensus. Finally, the preliminary findings from the study analysis were disseminated back to the participants and other community stakeholders that did not participate in the original interviews through a workshop discussion group. A total of 10 professionals attended the follow-up session in the spring where the researchers shared the results of the study, and the group collectively discussed implications for students and educators and recommend practical changes. These discussions also informed the results reported here.

## Results

A total of 24 participants were interviewed for the present study. The goal of four participants from each of the six role categories was almost fulfilled, except that there were only three participants for the community college faculty category and five participants for the high school administrator category. Descriptive information for the participants can be found in Table 1. The outcomes from this study focus on what students need to be successful in science, from the viewpoint of a cross-section of stakeholders in the science career pathway. Findings are organized first around what was found to be common between the different stakeholders along the pathway in relation to the three research questions. See Figure 1 for this information. Then, key differences in responses between the stakeholder groups are presented and supported, as shown in Figure 2.

**Figure 1**

*Shared Themes From Key Study Variables*

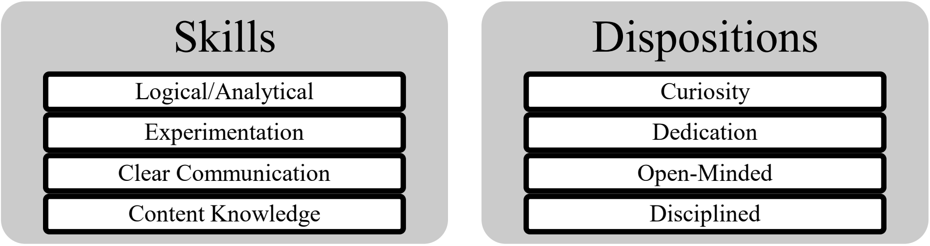


**Figure 2**

*Notable Differences Between Stakeholder Groups on Key Study Variables*

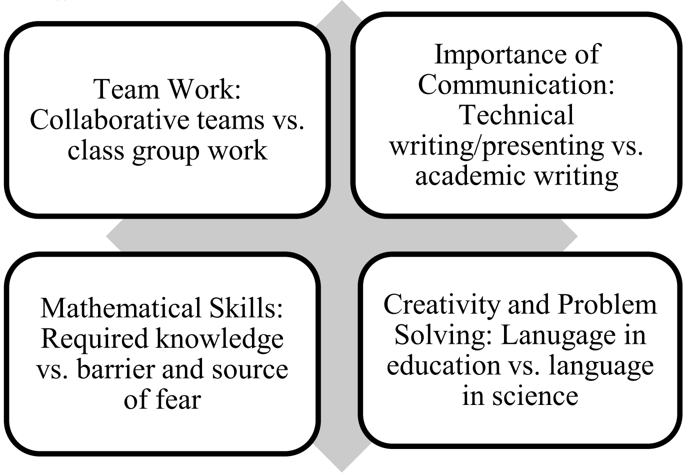


**Table 1**

*Descriptive Information About Interview Participants*

| Role | Professional Title | Gender | Experience | Science Focus |
|---|---|---|---|---|
| High School Administrator | Assistant Principal, Supervisor | Female | 2 years | |
| | Assistant Principal | Female | 9 years | |
| | Principal | Male | 1.5 years | |
| | Principal | Male | 5 years | |
| | Principal | Male | 18 years | |
| High School Counselor | School Counselor | Male | 8 years | |
| | Guidance Counselor | Female | 8 years | |
| | Director of Student Personnel Services | Female | 10 years | |
| | Guidance Counselor | Female | 22 years | |
| High School Science Teacher | Teacher | Male | 1 year | Physics, Forensics |
| | Teacher, Science Club Advisor | Male | 11 years | Biology |
| | Supervisor | Female | 13.5 years | STEM, Instructional Tech |
| | Teacher, Science Club Advisor | Male | 35 years | Physics |
| Community College Science Faculty | Dean, Professor | Male | 11 years | Biology, STEM Division |
| | Assistant Professor | Male | 16 years | Physical & Earth Science |
| | Professor | Male | 28 years | Engineering |
| University Science Faculty | Associate Professor | Female | 7 years | Physics |
| | Associate Professor | Female | 18 years | Biology |
| | Professor | Male | 10 years | Chemistry |
| | Professor, Director | Male | 23.5 years | Ecology, Biology |
| Scientist / Industry Professional | Chemist | Female | 7.5 years | Chemistry |
| | Lubricant Formulator | Female | 15 years | Chemical Engineering |
| | Chemist | Male | 8 years | Chemistry |
| | Pharmacist | Male | 20 years | Pharmacy |

## Shared Perspectives

Participants had shared perspectives themed as four skills and two broad dispositions for students interested in science as a field. Areas of agreement were found in students' needing scientific skills such as logical and analytical methods, an understanding of experimentation as a method, the ability to communicate clearly, and foundational content knowledge. A principal with 18 years of experience suggested requisite skills to be a scientist would include "…reading, writing for sure, problem solving, critical thinking, being able to do an analysis of something, comparing and contrasting…and sort of problem solving." Math or analytical skills were mentioned repeatedly, but not always consistently as explained further in the next section. Communication, both written and spoken, was also discussed consistently, as one university professor noted:

> I think one that is underrated at least for students coming in is the communication skills. The verbal communication and the written communication is absolutely critical to be a successful scientist…Students need to be quantitative but they have to be able to communicate.

Content knowledge was also presented as a foundational need, but likely not the most important component of effective science preparation. A high school principal expounded on this idea, saying:

> If you're going to have that kind of understanding…that's going to lead to the next breakthrough, you need to understand what the rules are for those things and how those things interact…you do need to have a fundamental understanding of that content to keep progressing.

On the topic of dispositions, stakeholders generally agreed that students in science should be curious/open-minded and dedicated/disciplined. A university chemistry professor noted that students "…need to be able to learn, take in, and master new techniques…This is a constantly evolving and developing world…so they can't just go into industry with a knowledge set and expect that to carry them for 30 years." The importance of dedication and openness to failure in the process was repeated regularly. As one assistant principal said, it is important to help students see failure as an opportunity to learn, "And that's kind of like our mantra, that we don't want you to fail per se, but understand that without taking risks you're not going to grow." A high school counselor participant shared an anecdote from her school that highlights the role of failure and dedication in science clearly:

> I remember the one girl in this advanced topic biology class that Dr. A taught, she was doing something with mosquitos…and her mosquitos kept dying in her project, so she had to keep starting over. Then he was like, 'Alright well why do your mosquitos keep dying? What's going on?' And then she found out it was the temperature in the lab room, so we had to move her lab room. But she was getting so frustrated, and he's like, 'This is research. This is what happens…' And I think perseverance is one of the big things that is important.

## Group Differences

There were also four notable differences in the themes of stakeholder beliefs about what students need to be successful in science careers: (a) importance of communication, (b) mathematical skills and knowledge, (c) understandings of creativity and problem solving, and (d) experience of teamwork.

### *Communication*

First, the importance of communication was discussed throughout the participant groups, and a need for clear communication skills was noted as a shared theme. However, science professionals noted that the communication they typically engage in is in the form of marketing presentations for clients or company administrators, or brief communications and presentations to share results across teams. One scientist in chemical engineering expounded on the role of communication and technical writing in her work, commenting that receiving long emails with blocks of text was perceived as a waste of her time, but "if you have, you know, three or four headers with two or three bullet points each, then I'm definitely going to invest a few minutes to try and understand what you are telling me." More formal writing does happen in science professions as well, but this scientist noted that, "In 15 years, [I] have written five or six things that I might call an actual report, where I use page numbers and citations and references."

The communication taught and emphasized in educational settings may not always align with this need, suggesting additions may be needed in the science curriculum. A university professor in biology noted that in her high school experience:

> Those skills weren't as emphasized for scientists. If you wanted to major in English, you need to be good at writing. But if you want to be a scientist, you just need to be good in math. And I think that's a disservice.

A community college professor also noted the importance of communication in both technical and non-technical forms, arguing "And it comes down to not only reading and writing technical scientific papers, but it also comes down to just simple communication…how to convey that scientific information whether it's to a peer or whether it's to somebody that's a non-scientist." While verbal and written communication are foundational content areas in K-12 and higher education, we may not be effectively preparing students for the types of technical writing and presentations most common in the industrial and academic space.

### *Mathematics*

Second, the role of mathematical skills and knowledge in science careers was highlighted throughout the interviews, and the analytical process of problem solving was noted as a shared theme. However, the differing perspectives on the importance of mathematical knowledge present a complex picture. On one side, mathematical knowledge is important for both linear and analytic thinking processes, and for the ability to use data to investigate and solve problems. However, math also appears to serve as a barrier for students interested in science, potentially a false barrier derived from fear or low self-efficacy towards math, instead of a true lack of ability to use math in applied contexts. One scientist working as a pharmacist noted that math does not play a major role in all science careers, noting that,

> If you can do basic algebra, basic calculus, I would even say differentiation. If you have that skillset, that is sufficient. You don't need to be able to write your own equations to solve a pharmaceutical problem. Is it beneficial? People majored in undergrad math, of course it's beneficial. Is it necessary? No.

Differences in mathematical skill requirements by fields of science were also noted a few times, as one high school counselor reflected, "There is a difference between…physics, that's a lot of calculus. Environmental science is a lot of statistics, and so *that* math is actually wildly different." The community college Dean participant noted essentially the same pattern, saying, "Chemistry…you know you've got to have that strong math background. Go into biology…you're going to use some statistics." However, he then went on to argue for advanced math preparation for all science students, saying,

> Everybody in science should get up through at least Calculus I if not Calculus II. And not necessarily because they'll use it, but specifically because it's going to open your mind to how you're going to manipulate and solve this math problem.

There is a noted lack of consensus in belief about the role and application of mathematical knowledge and skills in science careers, and one that cannot be resolved in the scope of this work. But consideration should be given to what level of mathematics training is really needed for students pursuing these different types of science careers.

### ***Creativity and Problem-Solving***

The third key concept noted by participants related to skills and dispositions needed for science was the idea of creativity and imagination. Multiple educators in the study mentioned this as a key disposition for science careers, but no scientists mentioned the concept of creativity specifically in their discussions. For educators, the idea of creativity is an important one throughout the interviews, as one biology professor making the claim that students "…might be very good at organizing their thoughts and all that, but without that creative drive, they're not going to become research scientists." This term not being used in the interviews with the scientist participants was noted in early analysis by the research team. However, further discourse during the discussion group held following the interviews highlighted a possible difference in language. Specifically, it was discussed that scientists may not use the term "creativity" to discuss their work, and instead refer to this skill as "problem solving" or identifying unique solutions.

A second look at the interviews of the four scientist participants revealed mention of solving problems, like the chemical engineer noting, "Being a scientist and solving problems, you're going to be coming up with ideas." Though her focus was largely on issues of compliance and marketability, she explained,

> If I have a product, I need to create that product in a way that complies with all local, state, federal, and global regulations…I will need to document the way that it complies, and I will have to sometimes manage and steward a budget in which I am applying for those confirmation…It has to be accurate. I need to think about all the people who need to know what my product is about so that they can sell it, market it, commercialize it, manufacture it, package it, and label it.

While not traditionally how educators might think of creativity, this kind of critical thinking and development is key to her work as a scientist. Other scientists noted similar thoughts, with the male chemist noting the importance of:

> …curiosity, analytical skills, being able to look at data and draw conclusions, being able to parse out from the data what really is important and what is just chaff, and being able to think a problem through, think of possible solutions and how you're going to get to those solutions.

Additionally, the female chemist participant noted the limitations of education in developing this kind of thinking, saying, "Sometimes we get recent grads with their B.S. in Chemistry, and they're not prepared. They have just gone through the motions. They haven't been taught all the soft skills that they need." This finding is multifaceted, as creativity is an area of focus in education that we may not be effectively supporting for those seeking science careers. But this is also a potential example of the need for clarity around language and meaning. This is so that stakeholders in education contexts are clear on what they mean by concepts like creativity, and design their programs to build on important elements of this skill related to problem solving and application.

### *Teamwork and Collaboration*

Finally, the concept of teamwork came up as a key concept for science professionals and educators. Across the stakeholder groups, collaboration and teamwork was noted as an important skill in science. However, science professionals highlighted that the type of collaboration they engage in is more individual responsibility with results shared across team members who are working on other components. As one scientist in chemical engineering explained,

> Part of being on a team is learning about people on your team. There are going to be people who will not speak unless you ask them a question, and that doesn't mean that their ideas are any less valuable…But there are going to be other people who are more forceful and who will trample on your idea, so you have to be able to engage them as well...

The scientist participants consistently highlighted the importance of interpersonal skills, finding balance in collaboration between ideas for different members of the group, and working independently on tasks and then sharing results with the group. However, collaboration or teamwork in education contexts is often very different, with more direct group work and shared responsibility for the same tasks, like a group project in a course. A couple of the scientists directly addressed this perceived misalignment between education and science as a profession. Here, one chemist shares her experience with teachers of her own children:

> I've heard some of my son's teachers, 'Oh yeah, we're doing group work!' That's really great, but that's not balanced… I'm thinking in the back of my mind, 'It's like you have no clue of how real life actually works, because yes group work is important, but I do the majority of my work by myself.' That's how we all are. We do have group sessions, but the majority of the time we're working on our own laptop on our own deliverables.

This appears to be an area where educational stakeholders may not be using collaboration and group work in the same way as it is used in science. While we say we are doing these things in classrooms, it is not clear that we are really preparing students for professional expectations.

## Discussion

The purpose of this study was to gain a better understanding of the perceptions of science for key stakeholders along the science career pathway, speaking with high school teachers, counselors, and administrators, from local community college and university faculty in science areas, and from industry professionals. Analysis focused on comparing and contrasting the beliefs and perceptions of these various stakeholders along the pathway to explore this issue from the perspective of science career as a developmental process (Lent, et al., 1994; 2002). The two research questions guiding this study were:

1. What are the perspectives of stakeholders along the science career pathway on what skills and dispositions students need if they want to pursue a career in science?
2. What differences, if any, exist between these stakeholders on these components of science and science career understanding?

Answering research question one, there was also a great deal of consistency in how stakeholders discussed skills and dispositions needed for success in science careers, including analytical methods, the ability to communicate clearly, foundational content knowledge, and an understanding of experimentation as a method. These findings are also generally in line with prior research, especially on the soft skills sometimes referred to as 21st century skills such as public speaking and problem solving (National Education Association, 2020; National Research Council, 2012), and science content standards emphasized in education through the Next Generation Science Standards (2013).

Research question two addressed differences between the stakeholder groups, and four key areas of inconsistency were noted: (a) the role and form of communication, (b) the need for mathematical skills, (c) creativity in science, and (d) group work and collaboration in education versus in careers.

## Role and Form of Communication

Participants highlighted the role of communication in science careers, arguing both verbal and written communication play important roles in these professions. However, this appears to be an area where education and industry are not addressing these skills in the same way. We know the importance of written and verbal communication in science and other areas, and NGSS (n.d.) supports this specifically in relation to science content. However, results from this study suggest educators should continue to consider ways to increase technical writing beyond the traditional lab report format common in classrooms and look at ways to expand assignments to model more closely industry expectations (Elliott et al., 2016; Moon et al., 2018). This could be a key space to collaborate with industry, bringing in science professionals to classroom spaces to share their knowledge and experiences on cross-cutting topics like communication (Yore et al., 2006). Additionally, cross-disciplinary collaborations in schools between science and English writing teachers could be meaningful in addressing this perceived area of need in science education.

## Need for Mathematical Skills

Participants in the study presented two opposing perspectives on mathematical knowledge requirements for science careers. On one side, participants supported the need for advanced mathematical skill and thinking to support students interested in science careers. Conversely, an alternative perspective was presented with math serving as a barrier for many students, and participants pointed out that in many science professions advanced calculus type mathematical skills are not necessary. Science career development and STEM education as a whole need to continue this discussion on the role of mathematical skills in science career development.

We know some science careers require higher levels of math to be effective (Schroeder et al., 2007; Young et al., 2018), but participants in the present study were clear this is not the case across all science careers. And we have extensive research on the barrier that mathematical knowledge and course performance has played in blocking students from science or STEM pursuits as a result of tracking in education (Ozer & Perc, 2020; Spade et al., 1997), advising against advanced course taking for women or students of color (Vijil et al., 2016), and limited opportunities for advanced course work in mathematics or science for students in urban and rural communities (Flowers & Banda, 2019; LeBeau et al., 2020). If students are interested in a science or STEM career that does not require advanced calculus, and we are barring these students from access to advanced coursework or opportunities because of a lack of this mathematical skill, we are directly contributing to the lack of participation in science and STEM we consistently see for women, students of color, students from rural communities, and those with other underrepresented identities. Further research is needed to clarify the requirement of advanced mathematical knowledge in specific science and STEM careers, with particular focus on helping students make the connections between mathematical knowledge and their career interests.

## Creativity in Science

Participants in the present study also differ in their understanding of creativity and problem-solving in science careers. Creativity is a complex concept in education, with a consistent lack of agreement on how we should define creativity (Kaufman & Baer, 2012; Martin & Wilson, 2017) and how we can best support students in developing creativity (Glăveanu, 2018). While educators in the present study mentioned creativity repeatedly, scientists did not, though they did discuss problem-solving and finding solutions to practical problems in their comments.

Inconsistency in language on its own is arguably not a problem, but potential inconsistency in how we support and develop creative thinking and problem-solving is worth noting. Educators should consider how they are supporting creativity in science content courses and explore ways in which they can help students develop divergent thinking and unique solutions to problems (Hong & Song, 2020). Integrating science curriculum with the arts has recently regained attention (science technology engineering arts and math, STEAM), and consideration could be given on how to integrate creative and improvisation practices from the arts into science content, which could support student development of this kind of creative thought (Sousa & Pilecki, 2013; Wilson, 2018).

## Group Work and Collaboration

Participants in the present study highlighted the perceived disconnect between how group work is often formulated in schools and how it is used in practical application in science professions. Scientists in the present study specifically highlighted their frustration with K-12 education group work and how it is not applicable to the "real world" of their profession. Research on science teaching supports the importance of group/collaborative work for learning (Freeman et al., 2014; Fung & Lui, 2016), but maybe we need to consider more authentic group experiences like team-based learning (Espey, 2017; Jeno et al., 2017) or project-based learning (Beier et al., 2018; Merritt et al., 2017) with clearly delineated group roles and responsibilities (Chang & Brickman, 2018). Educators should examine whether we are effectively teaching collaboration in the ways we currently organize and require group work.

## Social Cognitive Career Theory

While this was an exploratory study, SCCT is used as a general framework to provide further understanding to the findings (Lent et al., 1994; 2002). For students to effectively develop interest and career goals in science fields, SCCT posits they must have learning experiences related to science that develop science career self-efficacy and positive outcome expectations. Additionally, students should receive positive proximal supports as they pursue their interest in science careers and have the ability to overcome barriers presented along the process.

The present study findings align with this theoretical conception of career development as participants highlighted the need for positive and varied learning experiences to develop self-efficacy in relation to skills and dispositions connected to science careers. They also discussed the potential barriers and supports that could be provided as students pursue these interests, another key element of SCCT career development. Byars-Winston (2014) and Falco (2017) have expanded on this particular element of career development and can be seen as an extension of SCCT with considerations for career development professionals in STEM specifically. The findings in the present study confirm prior research using SCCT to explore STEM career development (e.g. Fouad & Santana, 2017; Sasson, 2020), and future explorations of the science career development process may benefit from this theoretical perspective (Brown & Lent, 2019; Byars-Winston, 2014; Falco, 2017). Connections between study findings, theoretical considerations, and practical recommendations are presented in Table 2.

**Table 2**

*Summarizing Study Findings, Connections to Theory, and Practical Recommendations*

| Key Study Findings | Practical Recommendations | Theoretical Connections |
|---|---|---|
| Role and Form of Communication | Integrate assignments to practice technical writing in science courses (memos, emails, etc.), and collaborate with industry partners to share their experiences with writing and speaking in their work | SCCT argues learning experiences impact self-efficacy about career skills, such as both communication and mathematics, and students need these experiences to develop interest in science careers |
| Need for Mathematical Skills | Be clear with students on the different roles math plays in different science careers; acknowledge student fears and the barriers to mathematical skills, and create opportunities for learning | SCCT, Byars-Winston (2014), and Falco (2017) all argue that individuals need support to overcome stigma and barriers, such as reinforced anxiety and the lack of access to advanced math |
| Creativity in Science | Develop assignments and experiences to build divergent thinking in science courses, and integrate arts activities such as improvisation and free drawing to practice these skills | SCCT presents that students must be able to see themselves in a career to develop career goals, and experiencing the types of problems real scientists work with can encourage this development |
| Group Work and Collaboration | Utilize authentic Team-Based Learning and/or Problem-Based Learning, with clearly defined group roles and responsibilities to model real-world collaboration | SCCT supports positive learning experiences as key to development of career interest, and teamwork is a key component of science careers students should experience |

## Conclusion

This project serves as a foundational exploration of the science career pathway in one northeastern state in the US to develop a deeper understanding of the perceptions and beliefs of stakeholders on how we can best support students interested in science as a career. The results of this study provide a foundation for future studies and interventions along the science career pathway to better support students. Targeted interventions supported by this work could be focused on helping educators improve collaboration and group projects in their classes to better model professional collaborations, increasing educational support for the types of communication used regularly in science careers, addressing the disagreement in the field on the role of mathematics in science career development, supporting different forms of creativity in the science classroom, and continuing to increase opportunities for science career exploration.

While this study is limited to a single state in one region of the US, the findings from the present study align with prior research on these issues, supporting the application of these results to a broader audience. The regional nature of the study and the small sample in each stakeholder category did impact representation of science areas, with a higher percentage of chemistry professionals in the study matching the industry type common in the region. Additionally, this study is uniquely positioned as a cross-sectional exploration along the career development pathway, with identified areas of agreement and areas of inconsistency that expand our understanding of science education and career development. If we posit education as a space for the development of skills and dispositions for future college and career pathways, then professionals along this pathway will benefit from time and space to evaluate their practice against these findings and explore ways to better support their students in their career development.

*This work was partially supported by a Seed Grant Award from Rowan University.*

**Sarah L. Ferguson** (fergusons@rowan.edu) is an applied methodologist in education research, focusing on the application of advanced research methods and statistics approaches to issues in education. Prior to coming to Rowan University, Dr. Ferguson was a certified teacher in the state of Texas with certifications in Elementary Education, Middle School Science, and High School Science. Her current research focuses on two areas: the education and utilization of quality research methods and analyses, and supporting the career development pathway for individuals from high school to career in STEM fields.

**Lesa DeShield Givens** (givens13@rowan.edu) is a Ph.D. candidate and adjunct professor, whose work in education and research focuses on interdisciplinary and inclusive policies and practices, as well as the internal and external impacts of life circumstances on teachers and students. Presently, her dissertation research is centered in Liberia, West Africa, examining the impact of prolonged devastating life experiences on the wellbeing of teachers and subsequent impacts on their professional work. Mrs. DeShield Givens was previously a certified teacher (elementary, music, and special education) in the states of Maryland, New Jersey, and Virginia, serving grades K – 12.

## References

Akerson, V., Buzzelli, C., & Eastwood, J. (2012). Bridging the gap between preservice early childhood teachers' cultural values, perceptions of values held by scientists, and the relationships of these values to conceptions of nature of science. *Journal of Science Teacher Education*, 23(2), 133-157.

Anderson, D. (2015). The nature and influence of teacher beliefs and knowledge on the science teaching practice of three generalist New Zealand primary teachers. *Research in Science Education*, *45*(3), 395-423.

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

Beier, M. E., Kim, M. H., Saterbak, A., Leautaud, V., Bishnoi, S., & Gilberto, J. M. (2019). The effect of authentic project-based learning on attitudes and career aspirations in STEM. *Journal of Research in Science Teaching*, *56*(1), 3-23. https://doi.org/10.1002/tea.21465

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101.

Brown, S. D., & Lent, R. W. (2019). A social cognitive view of career development and guidance. In J. A. Athanasou & R. Esbroeck (Eds.), *International Handbook of Career Guidance* (pp. 147-166). Springer.

Byars-Winston, A. (2014). Toward a framework for multicultural STEM-focused career interventions. *The Career Development Quarterly*, *62*(4), 340-357. https://doi.org/10.1002/j.2161-0045.2014.00087.x

Chang, Y., & Brickman, P. (2018). When group work doesn’t work: Insights from students. *CBE—Life Sciences Education, 17*(3), 1-17. https://doi.org/10.1187/cbe.17-09-0199

Chemers, M. M., Zurbriggen, E. L., Syed, M., Goza, B. K., & Bearman, S. (2011). The role of efficacy and identity in science career commitment among underrepresented minority students. *Journal of Social Issues, 67*, 469–491.

Elliott, L. A., Jaxon, K., & Salter, I. (2016). *Composing science: A facilitator's guide to writing in the science classroom*. Teachers College Press.

Espey, M. (2018). Enhancing critical thinking using team-based learning. *Higher Education Research & Development*, *37*(1), 15-29. https://doi.org/10.1080/07294360.2017.1344196

Falco, L. D. (2017). The school counselor and STEM career development. *Journal of Career Development*, *44*(4), 359-374. https://doi.org/10.1177/0894845316656445

Farland-Smith, D. (2009). How does culture shape students' perceptions of scientists? Cross-national comparative study of American and Chinese elementary students. *Journal of Elementary Science Education, 21*(4), 23-42. https://doi.org/10.1007/bf03182355

Ferguson, S.L. & Lezotte, S. (2020). Exploring the state of science stereotypes: Systematic review and meta-analysis of the Draw-A-Scientist Checklist. *School Science and Mathematics, 120*(2), 55-65. https://doi.org/10.1111/ssm.12382

Ferguson, S.L., Klutz-Drye, B., & Hovey, K.A. (2019). Preparing students for a bright outlook: Survey of high school career advising in technician fields. *Journal of Research in Technical Careers, 3(1),* 66-82. https://doi.org/10.9741/2578-2118.1046

Ferguson, S.L. & Givens, L. (2020). Pathways to science careers: Exploring perceptions of science educators and professionals toward being a scientist. Poster presentation at the *American Education Research Association* conference, San Francisco, California.

Finson, K. D. (2002). Drawing a scientist: What we do and do not know after fifty years of drawings. *School Science and Mathematics, 102*(7), 335-345. https://doi.org/10.1111/j.1949-8594.2002.tb18217.x

Flowers III, A. M., & Banda, R. M. (2019). An investigation of black males in advanced placement math and science courses and their perceptions of identity related to STEM possibilities. *Gifted Child Today*, *42*(3), 129-139. https://doi.org/10.1177%2F1076217519842213

Fouad, N. A., & Santana, M. C. (2017). SCCT and underrepresented populations in STEM fields: Moving the needle. *Journal of Career Assessment, 25*(1), 24-39. https://doi.org/10.1177%2F1069072716658324

Fralick, B., Kearn, J., Thompson, S., & Lyons, J. (2009). How middle schoolers draw engineers and scientists. *Journal of Science Education and Technology, 18*(1), 60-73.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences USA, *111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Fung, D., & Lui, W. M. (2016). Individual to collaborative: Guided group work and the role of teachers in junior secondary science classrooms. *International Journal of Science Education*, *38*(7), 1057-1076. https://doi.org/10.1080/09500693.2016.1177777

Glăveanu, V. P. (2018). Educating which creativity? *Thinking Skills and Creativity*, *27*, 25-32. https://doi.org/10.1016/j.tsc.2017.11.006

Hall, C., Dickerson, J., Batts, D., Kauffmann, P., & Bosse, M. (2011). Are we missing opportunities to encourage interest in STEM fields? *Journal of Technology Education, 23*(1), https://doi.org/10.21061/jte.v23i1.a.4

Hong, O., & Song, J. (2020). A componential model of Science Classroom Creativity (SCC) for understanding collective creativity in the science classroom. *Thinking Skills and Creativity, 37*. https://doi.org/10.1016/j.tsc.2020.100698

Jeno, L. M., Raaheim, A., Kristensen, S. M., Kristensen, K. D., Hole, T. N., Haugland, M. J., & Mæland, S. (2017). The relative effect of team-based learning on motivation and learning: A self-determination theory perspective. *CBE—Life Sciences Education*, *16*(4), 1-16. https://doi.org/10.1187/cbe.17-03-0055

Johnson, R.B. & Christensen, L. (2018). *Education research: Quantitative, qualitative, and mixed approaches.* Sage Publications.

Kaufman, J. C., & Baer, J. (2012). Beyond new and appropriate: Who decides what is creative? *Creativity Research Journal, 24*(1), 83–91. https://doi.org/10.1080/10400419.2012.649237

Knezek, G., Christensen, R., & Tyler-Wood, T. (2011). Contrasting perceptions of STEM content and careers. *Contemporary Issues in Technology and Teacher Education*, *11*(1), 92-117.

LeBeau, B., Assouline, S. G., Lupkowski-Shoplik, A., & Mahatmya, D. (2020). The Advanced Placement program in rural schools: Equalizing opportunity. *Roeper Review, 42*(3), 192-205. https://doi.org/10.1080/02783193.2020.1765923

Lent, R. W., Brown, S. D., & Hackett, G. (1994). Toward a unifying social cognitive theory of career and academic interest, choice, and performance. *Journal of Vocational Behavior, 45*, 79-122.

Lent, R. W., Brown, S. D., & Hackett, G. (2002). Social cognitive career theory. In D. Brown (Ed.), *Career choice and development* (p. 255-311). Jossey-Bass.

Makarem, Y., & Wang, J. (2020). Career experiences of women in science, technology, engineering, and mathematics fields: A systematic literature review. *Human Resource Development Quarterly*, *31*(1), 91-111.

Mansour, N. (2009). Science teachers' beliefs and practices: Issues, implications and research agenda. *International Journal of Environmental and Science Education*, *4*(1), 25-48.

Martin, L., & Wilson, N. (2017). Defining creativity with discovery. *Creativity Research Journal, 29*(4), 417-425. https://doi.org/10.1080/10400419.2017.1376543

Merritt, J., Lee, M. Y., Rillero, P., & Kinach, B. M. (2017). Problem-based learning in K–8 mathematics and science education: A literature review. *Interdisciplinary Journal of Problem-Based Learning, 11*(2). https://doi.org/10.7771/1541-5015.1674

Milford, T. T., & Tippett, C. C. (2013). Preservice teachers' images of scientists: Do prior science experiences make a difference? *Journal of Science Teacher Education*, *24*(4), 745-762.

Miller, D. I., Nolla, K. M., Eagly, A. H., & Uttal, D. H. (2018). The development of children's gender-science stereotypes: A meta-analysis of 5 decades of U.S. Draw-A-Scientist studies. *Child Development*, *89*(6), 1943-1955. https://doi.org/10.1111/cdev.13039

Moon, A., Gere, A. R., & Shultz, G. V. (2018). Writing in the STEM classroom: Faculty conceptions of writing and its role in the undergraduate classroom. *Science Education*, *102*(5), 1007-1028. https://doi.org/10.1002/sce.21454

Moore, J. L. (2006). A qualitative investigation of African American males' career trajectory in engineering: Implications for teachers, school counselors, and parents. *Teachers College Record*, *108*(2), 246-266.

National Education Association. (2020). *Partnership for 21st century skills.* http://www.nea.org/home/34888.htm

National Research Council. (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. The National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By State*s. The National Academies Press.

Ozer, M., & Perc, M. (2020). Dreams and realities of school tracking and vocational education. *Palgrave Communications*, *6*(1), 1-7. https://doi.org/10.1057/s41599-020-0409-4

Rottinghaus, P. J., Falk, N. A., & Park, C. J. (2018). Career assessment and counseling for STEM: A critical review. *The Career Development Quarterly*, *66*(1), 2-34.

Sasson, I. (2020). Becoming a scientist: Career choice characteristics. *International Journal of Science and Mathematics Education*, 1-15. https://doi.org/10.1007/s10763-020-10059-9

Schibeci, R. (2006). Student images of scientists: What are they? Do they matter? *Teaching Science: The Journal of The Australian Science Teachers Association*, 52(2), 12-16.

Schmidt, C. D., Hardinge, G. B., & Rokutani, L. J. (2012). Expanding the school counselor repertoire through STEM-focused career development. *The Career Development Quarterly*, *60*(1), 25-35.

Schroeder, C. M., Scott, T. P., Tolson, H., Huang, T. Y., & Lee, Y. H. (2007). A meta-analysis of national research: Effects of teaching strategies on student achievement in science in the United States. *Journal of Research in Science Teaching, 44*(10), 1436-1460. https://doi.org/10.1002/tea.20212

Shin, S. Y., Parker, L. C., Adedokun, O., Mennonno, A., Wackerly, A., & Miguel, S. S. (2015). Changes in elementary student perceptions of science, scientists, and science careers after participating in a curricular module on health and veterinary science. *School Science and Mathematics, 115*(6), 271-280. https://doi.org/10.1111/ssm.12129

Sousa, D. A., & Pilecki, T. (2013). *From STEAM to STEAM: Using brain-compatible strategies to integrate the arts*. Corwin.

Spade, J. Z., Columba, L., & Vanfossen, B. E. (1997). Tracking in mathematics and science: Courses and course-selection procedures. *Sociology of Education*, *70*(2), 108-127. https://doi.org/10.2307/2673159

Swafford, M., & Anderson, R. (2020). Addressing the gender gap: Women's perceived barriers to pursuing STEM careers. *Journal of Research in Technical Careers, 4*(1), 61-74.

Tyson, W., Lee, R., Borman, K. M., & Hanson, M. A. (2007). Science, technology, engineering, and mathematics (STEM) pathways: High school science and math coursework and postsecondary degree attainment. *Journal of Education for Students Placed at Risk*, *12*(3), 243-270. https://doi.org/10.1080/10824660701601266

Ucar, S. (2012). How do pre-service science teachers' views on science, scientists, and science teaching change over time in a science teacher training program? *Journal of Science Education and Technology*, 21(2), 255-266. https://doi.org/10.1007/s10956-011-9311-6

U.S. Department of Education (n.d.a). *College and career-ready standards.* Available online https://www.ed.gov/k-12reforms/standards

U.S. Department of Education (n.d.b). *Science, technology, engineering, and math: Education for global leadership*. https://www.ed.gov/stem

Vijil, V., Combs, J. P., & Bustamante, R. M. (2016). Barriers to pursuing STEM-related careers: Perceptions of Hispanic girls enrolled in advanced high school STEM courses. *School Leadership Review*, *11*(2), 1-13. https://scholarworks.sfasu.edu/slr/vol11/iss2/8

Wilson, H. E. (2018). Integrating the arts and STEM for gifted learners. *Roeper Review, 40*(2), 108-120. https://doi.org/10.1080/02783193.2018.1434712

Yore, L.D., Florence, M.K., Pearson, T.W. & Weaver, A.J. (2006) Written discourse in scientific communities: A conversation with two scientists about their views of science, use of language, role of writing in doing science, and compatibility between their epistemic views and language, *International Journal of Science Education, 28*(2-3), 109-141, https://doi.org/10.1080/09500690500336601

Young, C. J., Levine, S. C., & Mix, K. S. (2018). The connection between spatial and mathematical ability across development. *Frontiers in Psychology, 9*(755). https://doi.org/10.3389/fpsyg.2018.00755

Zuo, H., Ferris, K. A., & LaForce, M. (2019). Reducing racial and gender gaps in mathematics attitudes: Investigating the use of instructional strategies in inclusive STEM high schools. *Journal for STEM Education Research*, *3*, 125-146.

ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 27, NO. 4, 77-106

International Consortium for Research in
Science & Mathematics Education

# Facilitating Emergent Bilinguals' Participation in Mathematics: An Examination of a Teacher's Positioning Acts

Erin Smith
*University of Nevada Las Vegas*

**ABSTRACT**

This study examined the mathematical learning opportunities provided to emergent bilinguals (EBs) through their participation in whole class discussions in an elementary classroom. Positioning theory (Harré & van Langenhove, 1999) was used to examine a third-grade monolingual teacher's positioning acts and related storylines across two years. An examination of the data revealed the teacher utilized three prevalent positioning acts with EBs (i.e., inviting EBs to share mathematical thinking, valuing EBs' mathematical contributions, and inviting peers to consider EBs' mathematical contributions) that provided multiple and varied opportunities to participate in whole class mathematical discussions while circulating two storylines: EBs are mathematically competent and EBs can explain their mathematical reasoning to others. Findings suggest that positioning acts can be used in similar ways by other teachers across contexts to strive for equitable mathematics education.

*Keywords:* positioning theory, elementary mathematics teaching, emergent bilinguals, language learners

## Introduction

Emergent bilinguals[1] (EBs) are a diverse group of students who represent an increasing demographic within U.S. public schools (National Center for Educational Statistics [NCES], 2016). Given EBs' unique educational goals of simultaneously learning mathematics and the English language, teachers must enhance instruction to increase access and create opportunities to learn (Harper & De Jong, 2004; Lucas et al., 2008). Yet, EBs continue to underachieve in mathematics in comparison to their peers (National Assessment of Educational Progress, 2022) despite knowledge of research-based strategies specifically for teaching mathematics to EBs (e.g., de Araujo et al., 2018).

Engagement in discourse is critical to learn mathematics (National Council of Teachers of Mathematics [NCTM], 2014) and the English language (Lightbrown & Spada, 2013). Yet, classroom discourse is a powerful tool that can either empower or repress students (Turner et al., 2013). Therefore, those who control the classroom discourse also control opportunities to learn (Gee, 2008). Thus, teachers must not only understand the importance and influence of their own discourse in the mathematics classroom, but also have ways to use their discourse strategically to facilitate mathematics and language learning for every student.

---

[1] I use the term emergent bilingual in alignment with translanguaging literature (García, 2009) to indicate students are in the process of acquiring English and are not fully bilingual. I also use this term to highlight the linguistic competencies students possess, as opposed to what they lack.

Stereotypes, narratives, and storylines of mathematical competence permeate U.S. culture (Nasir, 2016). Stereotypes, narratives, and storylines related to EBs have historically been deficit-oriented, focusing solely on their English language deficiencies and the added challenges they pose to over-worked teachers (de Araujo et al., 2016; Gandara et al., 2005; Pettit, 2011). Such storylines can be circulated in classrooms and determine ways in which teachers and students interact with EBs (de Araujo et al., 2016; Smith, 2022; Turner et al., 2013; Wood, 2013; Yamakawa et al., 2009; Yoon, 2008). For instance, if teachers position EBs in deficit storylines—as has historically happened (Brenner, 1998; Gutiérrez, 2008)—EBs' opportunities to access, learn, and achieve in mathematics are diminished. Thus, it is critical for teachers to establish and foster storylines of mathematical competence for EBs in the classroom through strategic uses of their discourse.

Positioning theory (Harré & van Langenhove, 1999) provides a useful theoretical lens to examine classroom discourse. Positioning theory foregrounds discourse and proffers a way to analyze the dynamic nature of classroom interactions. More specifically, positioning theory provides a framework to guide the examination of teachers' positioning acts and the ways they facilitate EBs' participation in whole class mathematical discussions and circulate storylines for EBs across time.

## Positioning Theory

Positioning theory assumes social phenomena exist in, and are a product of, discursive practices (Harré & van Langenhove, 1999). Moreover, it assumes all social interactions occur in distinct, sequential, and historically situated episodes, which are "defined by their participants, but at the same time they shape what participants do and say" (Harré & van Langenhove, 1999, p. 5). In this study, I used positioning theory (van Langenhove & Harré, 1999) as a conceptual and methodological framework to examine the discursive practices of an elementary mathematics teacher.

Positioning theory is composed of three central components: acts, storylines, and positions (Harré & van Langenhove, 1999). *Acts* refer to the social meaning(s) of people's intended actions, which, in any situation, may have multiple social meanings (Harré, et al., 2009; Moghaddam, et al., 2007). *Storylines* are "strips of life [that] unfold according to local narrative conventions" (Harré, 2012, p. 198) that are constituted and reconstituted through social interactions. Storylines can be used to refer to the multiple categories, stereotypes, or cultural values people draw on in social situations to define the expectations and conventions of interactions in that setting (Herbel-Eisenmann et al., 2015). For example, a mathematics teacher may draw on the storylines of reform/traditional instruction and right/wrong answers simultaneously to motivate their interactions with students. Moreover, individuals never enter a social interaction with a *clean slate*, since fragments of prior experiences and storylines exist that shape current and future interactions. Thus, within each interaction multiple storylines may be at play that are all drawn on participants' cultural, historical, and political backgrounds and experiences.

The ways individuals enact storylines are, or become, socially recognizable. For instance, if a teacher employs a storyline that contradicts historical or culturally shared storylines (e.g., incorrect answers are just as valuable as correct answers), the *new* storyline may not initially be conceived as socially recognizable; however, over time, through various acts, new storylines can be shaped and become socially recognizable in the local moral order.

*Positions* refer to one's "moral and personal attributes as a speaker" (Harré & van Langenhove, 1991, p. 395) and the "momentary clusters of rights and duties to speak and act in a certain way" (van Langenhove, 2011, p. 67) in social interactions. Said another way, one's position determines the social expectations and range of available acts of participants/people. Individuals continually engage in *positioning acts*—either they are assigning themselves a position, called *reflexive positioning*, or assigning positions to others, called *interactive positioning* (Green et al., 2020; Kayi-Aydar, 2019; McVee, 2011). In this way, positions are relational (Harré & Slocum, 2003), dynamic, and contingent upon the unfolding storyline and the competencies of the participants. Thus, positions can shift at any one time along a continuum rather than a binary (e.g., competent/incompetent; Anderson, 2009; Pinnow & Chval, 2015).

Interactive positioning can impact one's position and the availability of acts. To illustrate this, consider a medical emergency where a bystander points and states, "They're a doctor." The bystander's interactive positioning serves to position the doctor as someone who may have the skills and training to offer medical advice and whose contributions should be considered valid. Alternatively, in that same situation, a person begins to offer medical advice, and another exclaims, "They're just a chef." This interactive positioning results in the chef being positioned as one whose medical recommendations should be considered invalid given the knowledge and social standing of their job.

The setting of social interactions can also affect the positions available and the resulting rights and duties of participants. For example, in the institutional setting of a school, teachers' conferred rights and duties are socially prescribed (given their position) and evidenced in their performance of specific actions (e.g., assign grades, discipline students) and various discursive practices (e.g., give directions, provide instructions). Thus, classroom interactions are shaped by the local moral order and the "cluster of collectively located beliefs about what it is right and good to do and say" (Moghaddam & Harré, 2010, p. 10).

## Positioning Theory and Emergent Bilinguals

Positioning theory has been used in mathematics education to examine social interactions (i.e., student-to-student and teacher-to-student) in classroom settings. This body of research has identified that positioning can influence students' mathematical identities (Esmonde, 2009; Ju & Kwon, 2007; Turner et al., 2013; Wood, 2013; Yamakawa et al., 2009), development of competencies (Enyedy et al., 2008; Pinnow & Chval, 2015), and opportunities to participate and learn (Anderson, 2009; Esmonde & Langer-Osuna, 2013; Mesa & Chang, 2010; Tait-McCutcheon & Loveridge, 2016). However, much of this research did not specifically focus on or include EBs. This raises questions of the applicability of the findings to teachers of EBs, particularly when many teachers continue to report a lack of preparation and confidence in their capabilities to teach a diverse range of learners (Banilower et al., 2018; Banilower et al., 2013), the prominence of deficit-oriented storylines for EBs—and immigrants in general—in the U.S. (Battey & Leyva, 2016; de Araujo et al., 2016; de Araujo & Smith, 2022), and prior research indicating EBs have been marginalized and positioned inequitably in classroom contexts (Gutiérrez, 2008; Pappamihiel, 2002; Yoon, 2008). Therefore, in this section I draw from research across educational disciplines where EBs were a specific focus of study when examining teachers' positioning and student participation.

Researchers have examined, to a limited extent, teachers' positionings of EBs in English language (Martin-Beltrán, 2010), English Language Arts (ELA; Yoon, 2008), and social studies classrooms (Duff, 2002). The earliest of these studies, Duff (2002), identified that not all teacher positioning is equivalent and that a desire to create an equitable learning environment, where every student contributes to discussions in meaningful ways, is insufficient to ensure productive EB positionings. Extending this work, Yoon (2008) and Martin-Beltrán (2010) also examined teachers' positioning and EBs' participation. Their findings illustrated teachers' positioning affected EBs' participation, not EBs' English language competencies or teachers' pedagogical approaches (e.g., student-centered). These collective findings highlight the significance of teachers' positioning on EBs' participation and identified a need to determine *what kinds* of interactive positionings teachers can use to facilitate EBs' participation and, in turn, content and language learning.

To identify specific interactive positioning acts teachers can use to facilitate EBs' participation in mathematics discussions, Enyedy and colleagues (2008) and Turner and colleagues (2013) examined bilingual teacher positioning. In Enyedy and colleagues' (2008) study, the authors examined a bilingual high school mathematics teacher's use of revoicing in a multilingual classroom. Their findings indicated the teacher often used revoicing to translate EBs ideas between Spanish and English; thereby positioning EBs at the center of the idea or discussion while making the idea accessible to non-Spanish speakers and potentially advancing storylines of mathematical competence. In a similar vein, Turner and colleagues (2013), examined a bilingual teacher-researcher's positioning acts of EBs in an after-school program and identified three prevalent acts that facilitated EBs participation in small and whole group discussions. These positioning acts were (a) validating an EB's ideas and/or ways of communicating the idea, (b) asking EBs to share mathematical thinking, and (c) inviting peers to consider an EB's idea. Both study's findings show promise for bilingual teachers and bilingual teacher-researchers but raise questions as to how monolingual teachers (or other bilingual teachers) can utilize these positionings when they lack fluency in EBs' first language. Moreover, the findings from Turner and colleagues (2013) raise additional questions of whether teachers in traditional school settings, constrained by large class sizes and educational demands (e.g., curriculum, policy, standardized assessments), implement similar positionings. Thus, more research is needed to determine the interactive positionings of monolingual teachers in traditional classroom settings that facilitate EBs' participation in mathematical discussions and whether these positionings reoccur longitudinally across different academic years with different students. Therefore, this study sought to answer the following question:

*What positioning acts did an elementary teacher employ to facilitate the participation of EBs during whole class mathematics instructional episodes and what storylines were circulated as a result of these positioning acts?*

## Methodology

Data for the present study was drawn from a large, longitudinal professional development intervention study that spanned three years. The professional development focused on supporting EBs' development of mathematics and language, enhancing mathematics curriculum materials, and orchestrating productive classroom interactions (Chval et al., 2014). For more information about the features of the professional development, please see Chval et al. (2021).

This study focused on one teacher, Courtney[2], who was selected because she was a common, yet unique case (Stake, 1995). As white, female, and monolingual, Courtney characteristically represented many elementary teachers in the U.S. (Grissom et al., 2015; Sleeter, 2001). Moreover, she taught in an area of changing demographics and saw EBs in schools that these students had historically been absent in (NCES, 2016). However, Courtney is unique because she developed (over the course of the intervention) specialized knowledge for teaching EBs. This included an increase in her abilities to: interpret EBs' mathematical thinking as opposed to simply describing it (Estapa et al., 2016); enhance mathematics curriculum to facilitate EBs' learning *about* and *through* language (Chval et al., 2014); and provide opportunities for EBs to participate in classroom discourse (Pinnow & Chval, 2015). Although these prior studies show evidence of Courtney's ability to facilitate mathematical and language learning for EBs, to date a more in-depth analysis has not examined the extent of Courtney's acts. Thus, more research was needed to identify how she interactively positioned EBs and how these positions facilitated EBs participation in whole-class mathematical interactions.

### Context

Courtney taught in a Midwestern city with an approximate population of 115,000 in a school that was predominately white (>70%), with less than 10% of the student population Latinx. In

---

[2] All names are pseudonyms.

addition, over half of students received free and reduced lunch. At the start of the intervention, Courtney had two years of elementary teaching experience with no prior education in pedagogy for EBs or experience teaching EBs. Thus, the first year of the study coincided with her first opportunity to teach EBs. In the first two years of the intervention, Courtney had three Latinx EBs. In the last year, Courtney had one Latinx EB who moved away partway through the school year. As a result, data from the third year of the study was excluded.

I selected four students from the first two years of the intervention to focus my examination of Courtney's interactive positionings of EBs. I selected one student, Alonzo, from the first year and three students, Lea, Bryce, and Samuel, from the second year. These students were selected because they provided a robust range of interactions that occurred across the two years and represented an array of mathematical and language competencies. See Table 1 for this information.

**Table 1**

*Demographic Information for the Emergent Bilinguals*

| EB | Year in Study | Birthplace | ACCESS Composite Score^ | ACCESS Listening Score^ | ACCESS Speaking Score^ | ACCESS Writing Score^ | ACCESS Reading Score^ |
|---|---|---|---|---|---|---|---|
| Alonzo | 1 | Mexico | 4.6* | 5* | 5.4* | 4.2* | 5* |
| Lea | 2 | USA | NA | NA | NA | NA | NA |
| Bryce | 2 | USA | 3.8 | 3.8 | 2.9 | 3.7 | 5 |
| Samuel | 2 | USA | 4 | 5 | 3.5 | 4.2 | 3.6 |

*Note.* NA = not available.
^ Based on a 6-point scale.
* ACCESS scores were only available in the year following the study.

Furthermore, I excluded the other two students in year one because they represented duplications in the mathematical and language competencies represented by the other students. I also selected the four focal students to capture the interactive positionings Courtney initially implemented (in year one) and continued to hone (as evidenced by their presence in year two). Therefore, by including a greater number of students in year two, I had increased opportunities to examine Courtney's positionings. The school district classified each focal student as an English language learner based on their scores on the Assessing Comprehension and Communication in English State-to-State for English Language Learners (ACCESS) assessment.

### ***Alonzo***

Alonzo's ACCESS composite scores in fourth grade placed him at the "expanding" performance level. Students at this level generally can understand and may use some technical mathematical language, speak, or write in varied sentence lengths of various linguistic complexity, and communicate given various kinds of support (e.g., sentence frame) with some errors that do not affect the overall meaning[3]. Although it is unknown what Alonzo's ACCESS scores were in third grade, Courtney did describe some of Alonzo's language competencies. Courtney reported that he read close to grade level and was "pretty good at expressing himself through writing." Additionally, Alonzo was "pretty willing to participate in other areas [outside of mathematics] like writing or reading." Courtney hypothesized that this was based on his reading comprehension, "I think he can read the directions and understand them and so he is not hung up on some of the things." Lastly, Courtney identified Alonzo as a "pretty strong student in all academic areas" who was uncomfortable sharing publicly in mathematics unless "he knows the right answer."

### *Lea*

Lea's ACCESS scores were not available from the school district. However, Courtney described Lea as a student who had different comfort levels with public speaking and writing, stating "there's some disconnect between what she's willing to say and what she's willing to put on paper." Courtney also described Lea as a "pretty strong math student" who possessed some mathematical "misconceptions." Courtney provided no other information about Lea at the beginning of the school year, stating, "I don't know her [Lea] as well as I feel like I know [Samuel and Bryce]" because she had been gone for two of the first five weeks of the school year.

### *Bryce*

Bryce's ACCESS composite score placed him at the "developing" performance level. Students at this level generally can understand and may use some specific mathematical language, speak, or write in expanded sentences or paragraphs, and communicate given various kinds of support (e.g., sentence frame) in narrative or expository forms with errors that may affect communication, but retain the overall meaning. Courtney described Bryce as a student who "[did] a lot of mental math," possessed "some number sense," and "[needed] to be assured that he's right." In addition, Bryce was a student Courtney was academically concerned about. Courtney explained that Bryce did not appear confident in his mathematical work and was often seen erasing work when approached (by Courtney). Moreover, Bryce was not comfortable and faced challenges sharing his mathematical reasoning publicly, stating "he has a tough time really like communicating how he's thinking about things."

### *Samuel*

Like Alonzo, Samuel's ACCESS composite scores placed him at the "expanding" performance level described above. In contrast to the other students, Courtney did not discuss Samuel's language competencies with the researcher. She did, however, discuss his mathematical competencies. Specifically, Courtney reported that Samuel "has a lack of confidence" in his mathematical thinking, was "very reluctant to share his thinking with anybody," and "like[d] to be in the background."

## Data

Data for this study was composed of classroom video and audio recordings from the teacher and student perspectives, and audio recordings of professional development interventions (nine to 12 debrief and nine to 12 planning sessions each year per teacher). Each class was generally recorded biweekly in the first 12 weeks of the school year and for two more weeks at the end of the school year.

---

[3] For a more thorough description of student performance at each level, contact World Class Instructional Design and Assessment (WIDA).

Across the two years, a total of 45 lessons were video and audio recorded, each approximately one hour long. In year one, 27 lessons were recorded, and 22 had a whole class interaction with Alonzo. In year two, 18 lessons were recorded, and each had at least one whole class interaction with Lea, Bryce, or Samuel.

### Data Refinement and Analysis

I refined the data of whole class interactions to interactional episodes focused on mathematics. An interactional episode occurred when an EB participated, were asked to participate, or were interactively positioned by Courtney or a peer. Interactional episodes began at the initial turn when an EB participated, was asked to participate, or was interactively positioned and ended when the discussion switched focus or topic (e.g., when the discussion moved to another student's strategy). The frequencies of interactional episodes for each EB across the school year are shown in Table 2.

**Table 2**

*Frequency of Interactional Episodes for Each Emergent Bilingual*

| Emergent Bilingual | Number of lessons present | Number of interactional episodes | Number of teacher positioning acts |
|---|---|---|---|
| Alonzo | 22 | 43 | 156 |
| Lea | 12 | 32 | 117 |
| Bryce | 12 | 27 | 111 |
| Samuel | 13 | 20 | 72 |
| | **Totals** | 122 | 456 |

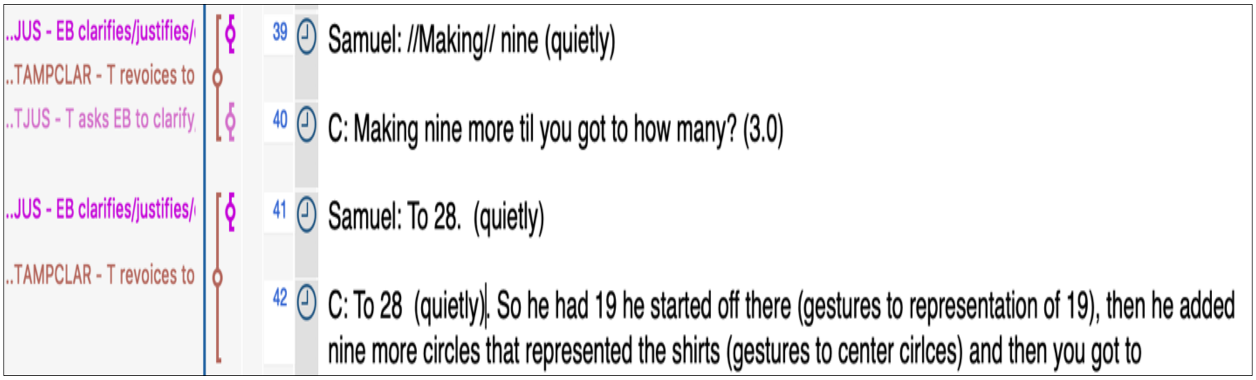
Since Courtney's lessons were typically structured with an initial whole class discussion at the carpet, individual, or group seat work, and a closing whole class discussion, frequent opportunities to engage students in whole class mathematical discussions were provided.

To analyze the data, I first transcribed all interactional episodes. Transcripts reflected the intonation, volume, pause, and pronunciation used in speech (see Appendix A for listed conventions used) and included images of written acts when relevant (e.g., instances when an EB's idea was publicly documented). Then, I coded transcripts iteratively at the utterance and turn taking levels using the constant comparative method (Patton, 2015). To do this, I began with an initial coding scheme based on teacher positioning acts found to be used by bilingual teachers to facilitate EBs' participation in mathematical discussions. These positioning acts were used even though Courtney was monolingual, because no other positioning acts had been identified in the literature. Moreover, any positioning acts that restricted EBs' participation was excluded from the coding scheme because they fell outside the scope of the research question.

I initially coded a subset of the data to solidify the coding scheme given the sheer size of the data set. After this first iteration, the coding scheme was refined, and some codes were collapsed. For example, the three positioning acts (1) the teacher solicits EB's math thinking, noticing, or observation, (2) the teacher invites EB to provide a solution strategy, and (3) the teacher invites EB to comment on a peer's idea were collapsed to the single act of *teacher invites EB to share mathematical ideas*. This was done since the three positioning acts served the same purpose (of inviting EBs to share their mathematical thinking that was deemed unique or relevant). The refined coding scheme (see Appendix B) was then used by a colleague and I to independently re-code a subset of the data. We met to discuss our analysis and all disagreements were notated and resolved through discussion and refinement of the coding scheme. Afterwards, the remaining data was coded in MAXQDA while I maintained an audit trail. See Figure 1 for an example. The number of acts identified were shown in Table 2.

**Figure 1**

*An Example of a Coded Transcript in MAXQDA*



Samuel: //Making// nine (quietly)

C: Making nine more til you got to how many? (3.0)

Samuel: To 28. (quietly)

C: To 28 (quietly). So he had 19 he started off there (gestures to representation of 19), then he added nine more circles that represented the shirts (gestures to center cirlces) and then you got to

In order to make sense of the data, I chose to narrow my focus to positioning acts that were recursive across the two years in order to identify what interactive positions and storylines were prevalent for EBs in Courtney's classroom. In this process, I simultaneously sought to identify how Courtney positioned EBs across multiple interactions, lessons, and years, and how these positions were related to classroom circulated storylines. After preliminary findings were identified, I employed investigator triangulation and had colleagues in and outside of mathematics education examine the data, analyses, and findings (Stake, 1995). In each of these conversations, assumptions and alternative interpretations were discussed.

## Findings

The findings are presented in three parts. First, I describe the three prevalent positioning acts I identified in my analysis that facilitated EBs participation in whole class mathematical interactional episodes. Second, I present a vignette to reflect how the three prevalent interactive positioning acts were typically seen across the data. Then, I describe two prominent storylines that were circulated across the two years via Courtney's positioning acts.

### Teacher Positioning Acts

The three prevalent positioning acts evidenced across the two years were: invites EB to share mathematical thinking, values EB mathematical contributions, and invites peers to consider EBs' mathematical contributions. These positioning acts occurred at least 30 times across the two years and were present in both years. To illustrate the positionings acts, multiple classroom interactional episodes are presented (see Appendix A for transcript conventions). These episodes were selected because they epitomized and demonstrated the nuances of each respective interactive positioning act. Table 3 displays a summary of the positioning acts used.

**Table 3**

*Summary of Courtney’s Positioning Acts Used with Emergent Bilinguals*

| **Teacher Positioning Acts** | **Selected Data** | **Frequency of Positioning Acts with Focal Students** | | |
|---|---|---|---|---|
| | | Year 1 | Year 2 | Total |
| Invites EB to share mathematical thinking | “Why would that be 24?”<br>“How did you figure that out?”<br>Invited to present problem-solving strategy to class (e.g., “Can you [Samuel] go on up and explain how you solved number two”) | 45 | 94 | 139 |
| Values EBs’ mathematical contributions | “Really cool idea”<br>“Really smart thinking Bryce” | 11 | 26 | 37 |
| Invites peers to consider EB’**s** mathematical contribution: | “Any comments about Lea’s strategy?”<br>“So any questions for Jake, Samuel (EB), Keri about their strategy? | 16 | 15 | 31 |

*Note*. EB = emergent bilingual

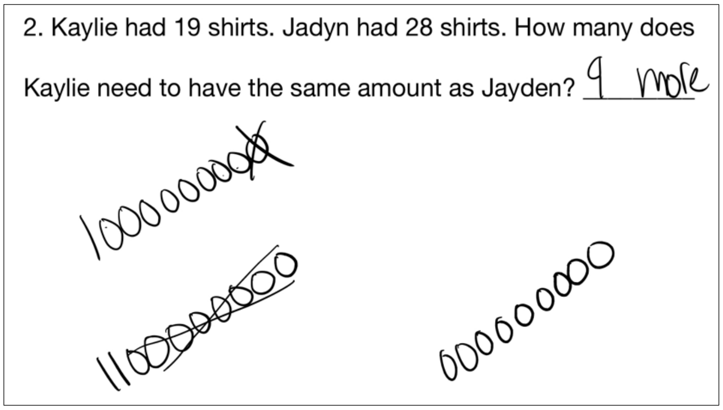
### *Invites EBs to Share Mathematical Thinking*

The EBs in Courtney’s class were most often invited to participate in a mathematical discussion by sharing their mathematical ideas. When inviting EB participation, Courtney used a range of invitations that typically required language use beyond simple or short answers (i.e., asking “What’d you do?” or “What is it representing?” as opposed to “What was your answer?”). To illustrate Courtney’s use of this interactive positioning act, I present two classroom episodes.

**Episode 1*.*** On October 6 (Year 2 [Y2]), after students had worked individually, the class sat at the carpet to discuss three student strategies Courtney had selected for the problem shown in Figure 2. Samuel was the first student to share his scanned and projected work.

**Figure 2**

*Samuel’s Scanned Mathematical Work*



2. Kaylie had 19 shirts. Jadyn had 28 shirts. How many does Kaylie need to have the same amount as Jayden? 9 more

Courtney (C): I've got three friends who are going to share a strategy that they figured um—that they used to figure out number two. [Administrative talk] Ok the first person I'd like to share (pulls up scanned work on board) is uh Samuel. [Administrative talk] Can you go on up and explain how you solved number two. Shh.
Samuel: (gets up to come to board, then stands at edge of board)
C: I need your um papers on the ground and your eyes up at Samuel. What'd you do?
Samuel: Well, I thought um 19 and 28 and I took 9 away. (8.0)
C: Ok so hold on, you've got 19 here and 28 down here?
Samuel: (nods) Uh-huh
C: Ok. And then what did you do to figure it out how much difference there was between the amount of shirts Kaylie had and Jadyn had?
Samuel: (20.0)
C: (moves to board) What it looked like to me, was when you had 19 (points to top left representation) and 28 (points to bottom left representation). It looked (points to center representation) to me like you took the 19 and you were, (gestures drawing circles in center representation) //maybe//
Samuel: //Making// nine (quietly)
C: Making nine more til you got to how many? (3.0)
Samuel: To 28 (quietly)
C: To 28 (quietly). So he had 19 he started off there (gestures to representation of 19), then he added nine more circles that represented the shirts (gestures to center circles) and then you got to
Samuel: nine—28 (quietly)
C: 28. So the difference he found between Kaylie's shirts and Jadyn's shirts was what?
Samuel: Nine
C: Nine shirts. Nice job Samuel. (claps)
Students: (clapping)
C: Drawing a picture can sometimes really help you. Thank you very much for sharing.

Before inviting Samuel to the board, Courtney had scanned and projected his work. This act benefited Samuel because he could connect his written and oral language with his mathematical representations and use the image as a visual referent while he spoke—an instructional strategy recommended for EBs (Chval et al., 2009) and discussed during the professional development. Courtney invited Samuel to take up the physical and metaphorical position of the teacher whose rights included explaining a problem-solving strategy to the class with her act to "go on up and explain" (line 4). In addition, her invitation interactively positioned Samuel as a student who had successfully solved the problem since he had a strategy "to figure out number two." In this way, Courtney positioned Samuel at the start of his presentation as a student who was mathematically competent. In lieu of inviting Samuel to explain, Courtney could have explained his work entirely herself or only asked Samuel to share the answer. However, her acts indicated she expected students to be explainers.

At the board, Courtney questioned Samuel about his mathematical representation and how he determined the value of nine (lines 8, 10-11). This act provided extended talk time, reinforced Samuel's position and storyline as a student who could explain his reasoning to others, signaled his idea was worthy of further consideration, and that he still controlled the conversational floor. Samuel, however, did not respond (line 12). After waiting 20 seconds, Courtney moved to the front of the room to explain her interpretation of Samuel's strategy (lines 13-16). Courtney's act positioned the understanding of a peer's strategy as important, even if the student did not articulate it themselves. Courtney did not let Samuel "off the hook" even though he was hesitant to speak publicly as evidenced by his quiet and limited responses, but continued to probe (lines 18, 24) amid extended wait time. As a result, Courtney did not take over the explanation or allow Samuel to "give up," instead she continued to provide Samuel multiple opportunities to share his reasoning.

**Episode 2.** In some cases, when invited to share mathematical ideas an EB did not always speak. For example, on October 28 (Y1), the class sat at the carpet with Courtney in a circle and discussed how many "rolls" (of ten) should be in a "box"—a conversation built off the story *Grandma Eudora's T-Shirt Factory* (Fosnot, 2007).

C: How many rolls do you think I should put into a big box? Alonzo, what do you think?
Alonzo: I think 10.
C: Why do you think 10 big rolls–10 of these rolls would be good? (1.0) Not sure, ok. But he thinks 10 might be a good number. Why do you think 10 might be a decent number to choose? Why do you think 10 would be a good number to choose to put into the box? Ian, what do you think?
… [Courtney solicits other student ideas for 3 minutes]
C (standing in front of board): Ok. Alright. Well you know what I think we've got ten shirts in one roll and, you know, we—our place value blocks, if we're going to use those because we don't have enough of these (holds up rolls of ten shirts). I mean I don't have enough shirts for all of us to have ten rolls of ten, do I? I don't have enough shirts at home and if we're going to use the place value blocks. I'm kind of thinking, you know we've got the, the rolls represented by the rods that have 10 and then the flats, they have a hundred on them, those flat ones, they have 10 groups of 10, so that's a hundred and so if, if you guys are going to work with those I kind of like Alonzo's idea that there's gonna be a hundred shirts in a box because then, if we wanted to, we could just pretend that that was one box, if we wanted to. So, I think that I, I like Alonzo's idea, and your other ideas were great, but I think we'll go with Alonzo's idea about having a hundred in a box, a hundred shirts in a box.

As the class talked, Courtney invited Alonzo to share how many rolls of t-shirts he thought should go in a big box (lines 1-2). This act positioned Alonzo as possessing an idea worth sharing. After Alonzo shared his idea, Courtney invited him to justify why "10 of these rolls would be good" (line 3), which indicated he still held the floor. This occurred regardless of the limited wait time provided for Alonzo to respond (1.0 second pause). Courtney then provided Alonzo an out, "Not sure, ok. But he thinks 10 might be a good number" (lines 3-4). This act allowed Alonzo to retain his position in the class as a student with an idea worth discussing and signaled it was acceptable to be unable to articulate a justification. As a result, Courtney facilitated a space in the classroom where taking mathematical risks was acceptable and moved to normalize "not knowing." Next, Courtney turned the request for a mathematical justification for Alonzo's idea to the class (lines 5-6). This act signaled Alonzo's idea was worthy of further consideration by positioning it at the heart of the class discussion (i.e., Courtney used footing to create this link; Goffman, 1981). After Courtney fielded different student responses, she revisited Alonzo's idea (lines 15-16) with a hedged evaluation, "I *kind of like* Alonzo's idea," which placed ownership of the idea with Alonzo. Courtney then re-asserted her value judgment of Alonzo's idea without the hedge (lines 18-19) and positioned his idea as the one the class will use, "I *like* Alonzo's idea, and your other ideas were great, but *I think we'll go with Alonzo's idea*." This combination of statements (lines 15-16, 18-19) further reinforced Alonzo's interactive position as a student with a (valuable) mathematical idea worth sharing and using. Moreover, it signaled that even though Alonzo was unable to fully justify his mathematical idea, it did not invalidate it.

**Summary.** Across the two years, this interactive positioning act was the most prevalent used by Courtney with the focal students, which may be tied to the professional development's focus on facilitating EBs participation. Overall, the prevalence of this positioning act contrasts with other research that has found teachers infrequently invite EBs into mathematical discussions in substantial ways (e.g., Iddings, 2005; Planas & Gorgorió, 2004; Weiss et al., 2003) and further demonstrates that EBs can participate in mathematics discussions as they develop their language proficiencies (Moschkovich, 2002; Setati, 2005; Turner et al., 2013).

Some may see this interactive positioning as just "good teaching", however, for the EBs in Courtney's class it supported them in multiple ways. First, Courtney's positioning of EBs as active participants who possess mathematical ideas worth sharing and contrasts common positionings of EBs as periphery participants documented in the literature across content classrooms (e.g., Brenner, 1998; Yoon, 2008). Second, by positioning EBs in agentive ways (e.g., mathematical explainers, students with valid mathematical strategies), the potential to positively impact their mathematical identities became available. Third, multiple storylines were circulated for EBs, including EBs are mathematically competent and EBs can explain their reasoning to peers. Lastly, the invitations provided varied and extensive opportunities for EBs to develop their English language competencies—a necessity for second language acquisition (Gibbons, 1992; Lightbrown & Spada, 2013).

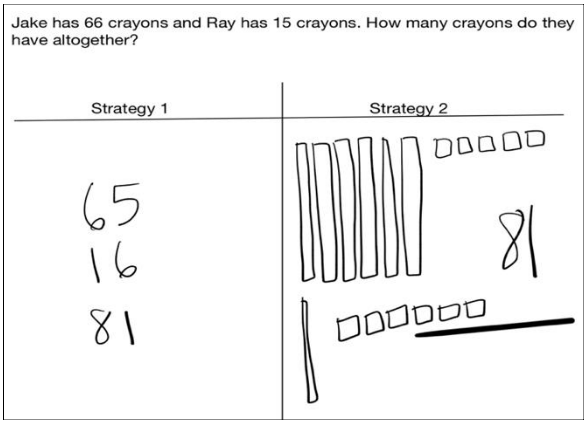
### *Value EBs' Mathematical Contributions*

Through her interactive positionings, Courtney indicated valued ways of being and acting mathematically in the classroom. One way this occurred was through explicit statements, such as value judgments or evaluations, that called attention to aspects of an EB's mathematical contribution and varied in specificity from general (e.g., "Ok, so, Lea had a really cool idea, can you explain your idea?") to particular (e.g., "[Alonzo] did a nice job of explaining this a few different ways"). In some cases, albeit less often, direct evaluations were stated (e.g., "that's right").

**Episode 3.** On September 13 (Y2) while students worked to solve multi-digit addition word problems using multiple strategies, Bryce asked Courtney if he could share his strategy with the class for solving the problem. The problem and Bryce's strategy are provided in Figure 3. This represented a unique situation since Bryce often appeared uncomfortable speaking in front of the class. Courtney capitalized on this moment and invited Bryce to share during the whole-class discussion at the close of class.

**Figure 3**

*Bryce's Written Work*



Jake has 66 crayons and Ray has 15 crayons. How many crayons do they have altogether?

C: Alright. We have a couple different strategies we're going to share. Bryce um wanted to share a strategy he did with drawing a picture. Do you want to come up and show us what you did? So I saw really smart strategies on problem number one. [administrative talk] Ok so Bryce can you explain kind of what you did?
Bryce: This one (very quietly; gestures to rods in picture)
C: So, yeah, so the problem was Jake has 66 crayons, Ray has 15 crayons, how many crayons did they have altogether? So what did you do?
Bryce: (looks at paper in hands as he faces the board diagonally with back to majority of class) I forgot how I did it (4.0). There's si—six tens and…five because…I switch, the five to…66 I switch the (5.0) (looks at paper and board)
C: It looks like you switched it to=
Bryce: =switched the last, the last six of the 66
C: 66 to 65, right?
Bryce: Six and I took the, the 16 off 15 switched it (gestures to algorithm)…and…then I add one more ten and it's seven tens…equals…seventy (10.0; looking at paper) and I (10.0; looking at work on board and gestures between the two representations) and I—no I added the six and that made it to 81.
C: Wonderful. (clapping) Ok so I…well how do we show respect to Bryce? (class claps) Yeah. So Bryce thank you so much for sharing. It looked like Bryce said you know 66 is a, is a not so kind number, I'm going to change that to 65 and I'm just going to add 16 crayons to it and so he counted up by tens and then counted the ones and got 81. Did anyone else get 81 too?
Students: (raise hands)
C: Really smart thinking Bryce.

Courtney introduced Bryce to the class as someone who "wanted to share a strategy" (line 1), which interactively positioned him as a student who believed his mathematical ideas were worth sharing. This differed from Courtney's typical approach of selecting speakers based on aspects of their mathematical thinking *she* wanted to highlight. After inviting Bryce to the front, Courtney stated, "So I saw some really smart strategies on problem number one" (lines 3-4). Given its situated context, this act simultaneously validated Bryce's desire to share as legitimate and evaluated Bryce's strategy as "really smart," which was not superficial considering Bryce's use of an invented algorithm. This act may have also been used to further bolster Bryce's confidence in his own mathematical thinking—an area Courtney identified in need of improvement in a conversation with the researcher on September 2, "Bryce definitely needs to be assured that he's right and, like, he needs to know, 'You're right, and so tell me why you're right,' type of situation […] [otherwise] he's very…reluctant [to share his thinking]." Consequently, Courtney's act set the stage for Bryce to explain his strategy and contributed to Bryce's storyline of a mathematically competent student. After Bryce explained his strategy, Courtney concluded the interactional episode by publicly evaluating Bryce's thinking again, stating "really smart thinking" (line 27). This act reinforced her initial interactive positioning of Bryce as competent and continued to foster a similar storyline. Moreover, it served to promote Bryce's own self-confidence in his mathematical thinking and reiterated his desire to share was valid. Thus, Courtney's use of this interactive positioning appears to be intentional and strategic, not flippant.

**Summary.** Across the two years, the positioning act of valuing EBs' mathematical contributions occurred more frequently in year two (potentially due to the number of EBs) and preceded or followed opportunities to participate. The findings confirm what other research has identified in different contexts, that evaluating student contributions is a common type of discursive practice used by teachers and even more so for novice teachers (Cazden, 2001; Kawanaka et al., 1999; McHoul, 1978; Sinclair & Coulthard, 1975). Although others may assert teachers use of this practice can limit student participation, preserve teacher rights and duties, and restrict student ownership of mathematics, I contend Courtney's use of this discursive practice served to productively position EBs in her classroom as students who possessed valued ways of thinking mathematically (e.g., "that's a smart way of thinking about it [Bryce]"), signaled their mathematical ideas or strategies were worthy of public consideration (e.g., "So I saw some really smart strategies on problem number one"), and indicated EBs were students who could explain their reasoning to others in intelligible ways while they developed their language competencies (e.g., "I thought that [Alonzo] did a nice job of explaining this a few different ways"). At this same time, Courtney's use of this positioning act simultaneously fostered the storyline that EBs were mathematically competent students. Consequently, this interactive positioning allowed Courtney to leverage her rights as a teacher to call attention to EBs mathematical thinking in front of peers and acted to counter deficit-oriented storylines of EBs in mathematics.

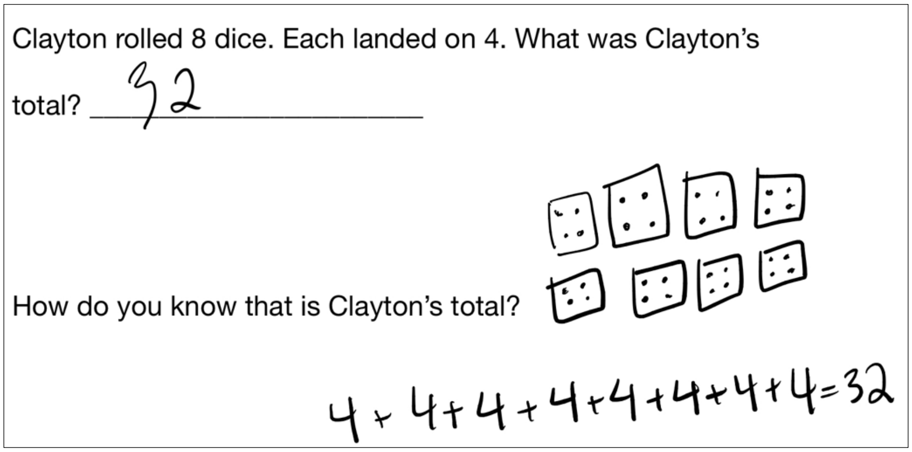
### *Invites Peers to Consider EBs' Mathematical Contributions*

Courtney expected every student to attend to the mathematical contributions of others. This expectation was reinforced through Courtney's requests for students to respond to the mathematical contributions of others, such as asking peers to respond to or restate the mathematical contribution of an EB.

**Episode 4.** Courtney often requested peers to explain, comment, question, or compliment on an EB's mathematical contribution after they had shared a problem-solving strategy. For example, at the close of the lesson on October 22 (Y2) Courtney selected three students to share their strategy to solve the problem, Lea was the second student to share her work shown on board. Her work and the problem are provided in Figure 4.

**Figure 4**

*Lea's Written Mathematical Work*



Clayton rolled 8 dice. Each landed on 4. What was Clayton's total? 32

How do you know that is Clayton's total?

4 + 4+4 + 4+4+4+4+4=32

C: Alright the next person to share is Lea. Lea will you get up.
Lea: (gets up and comes to board)
C: [administrative talk]
Lea: First um I added four and then um I added four plus four plus four plus four. First I drew a picture of eight dice and then added four plus four plus four plus four plus four plus four plus four plus four equals 32.
C: So why did you—how many four—how many times did you need to count up by four?

Lea: Well I needed to count um I needed to count eight times so I could get (inaudible)
C: Ok so when she—when she—what'd um—any comments about Lea's strategy?
Lea: Janie.
Janie: Nice work an:d I like your strategy.
Lea: Carl
Carl: I like the way how you like, drew a picture of this stuff (gestures across work)—numbers.
Lea: Ok. Laura
Laura: Um I think the way that you drew your picture of the four plus four plus four is kind of confusing but I still think you did a great job.
C: Alright so she wrote a number sentence and she wrote up a picture to go along with that. I like—I like your strategy a lot. Nice job Lea. (clapping and cheers)

After Lea presented, Courtney asked if there were any comments on her strategy (line 10). Courtney's act reinforced the expectation students would attend to and think about each other's mathematical reasoning, signaled Lea's ideas were worthy of further consideration, and kept Lea's mathematical thinking at the center of the discussion. Lea took on a typical right of a teacher (Lemke, 1990; McHoul, 1978; Mehan, 1979) to call on Janie, Carl, and Laura and field their comments. Lea's peers had many comments they could make. Each comment referenced Lea's mathematical work and included praise (e.g., "I like your strategy")—although Laura's was back-handed ("but I still think you did a great job" line 20). After Laura's comment, Courtney stepped in to re-state Lea's strategy (line 21) and positively evaluate it, stating "I like your strategy a lot. Nice job" (line 22). Thus, Courtney's final act in this episode amplified Lea's strategy, signaled the strategy represented valued mathematical thinking that contradicted Laura's assessment, and reinforced Lea's mathematical competence.

**Episode 4.** Another way Courtney implemented this positioning act was by aligning an EB's strategy to peers, asking if peers used the strategy, and then stating explicit connections between the peer(s) and EB. An example of this occurred on May 13 (Y2) immediately after Jake, Samuel, and Keri had collectively shared their problem-solving strategy to an equal sharing problem of seven brownies and four people. Courtney stated:

> Ok so any questions for Jake, Samuel, or Keri about their strategy? Did anyone else try this strategy? (some students raise hands) Caleb did this strategy, Laurence did this strategy. I think it's a really effective way of doing it because you always know you're going to have a fair share if you're cutting it into one-fourth pieces and you know that there's four people, you know you're going to be able to share it fairly. Nice job guys.

In this act, Courtney placed ownership of the strategy on the three students when inviting peer feedback on the problem-solving strategy, which reinforced Samuel's interactive positions as a problem solver like Jake, Keri, and a community member. Next, Courtney moved to create connections between the three presenters and peers when she asked if others had used the strategy (lines 1-2). Courtney publicly named two students who also used the strategy (lines 2-3), thereby expanding the mathematical connections in the classroom and creating a large group of students who all shared similar mathematical reasoning as Samuel (and Jake and Keri). Courtney capitalized on this moment further with her evaluation of the group's strategy, stating "I think it's a really effective way of doing it" (line 3). In this way, she publicly validated the strategy, positioned it as valuable, and interactively positioned Samuel as using an effective strategy—a characteristic of mathematical competence in Courtney's class. Moreover, positioning acts like this may have been used by Courtney with Samuel and other EBs who may be resistant, hesitant, or uncomfortable with public speaking to proffer peer support and an out if they chose not to speak when in front of the class.

**Summary.** Across the data this interactive positioning act occurred in both years, was seen throughout each year, either preceded or followed opportunities for EBs to participate, and was predominately split between each year regardless of the number of EBs in year two. The reduction of this interactive positioning in the second year (based on total EBs) may have been a result of Courtney's increased ability to deftly use it to: set and uphold the classroom expectation peers would attend to and think about EBs' mathematical contributions (e.g., "any comments about Lea's strategy"), support the development of a dialogic classroom environment where students interacted *with* each other and took on greater rights and duties typically reserved for teachers, interactively position EBs' mathematical contributions as valuable as advocated by research (e.g., "I think it's a really effective way of doing it"; Gorgorió & Planas, 2001; Secada & De La Cruz, 1996), and foster the storyline that EBs can explain theirs or others mathematical reasoning (e.g., "Lea, can you go up there and explain what Emily did?"). Importantly, Courtney's use of this positioning act challenged stereotypes of who can do mathematics (Battey & Leyva, 2016; de Araujo et al., 2016) and advanced counter-stories of who can do and be successful in mathematics.

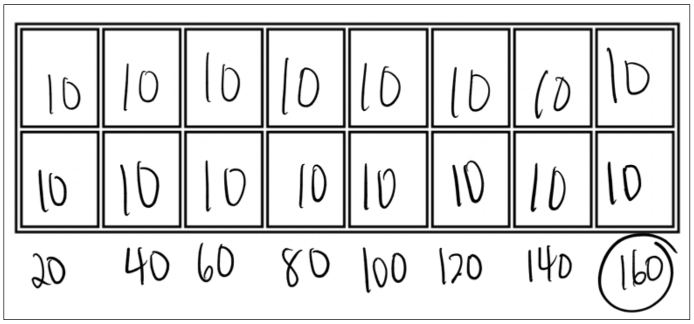
## The Reality of Implementing the Positioning Acts*:* A Vignette

Up to this point, I have presented the prevalent interactive positioning acts Courtney employed across two years to facilitate EBs participation in whole class mathematical discussions independently. However, these positioning acts did not occur in isolation, but in conjunction with one another. Thus, I present a vignette to illustrate the reality of the interactional episodes that occurred in Courtney's classroom and elucidate how her interactive positioning acts worked in conjunction with one another.

In the lesson on October 27 (Y2), students created a book of stamps in an array, selected a stamp value, and calculated the total cost of the book of stamps. To conclude the lesson, Courtney selected some students to share their strategies for calculating the total cost of the book. Bryce was the first student selected to share his book of stamps shown in Figure 5.

**Figure 5**

*Bryce's Book of Stamps and His Written Work*



C: Bryce, you're my first fellow to share. Why don't you go on up. [Administrative talk] Ok Bryce is going to share how he figured this problem out. [Administrative talk].
Student: Hey, that's the same thing I did.
C: Shh.
Student: He did the same thing I did.
C: Alright, make sure your voices and eyes are showing respect for your presenter
Bryce: I //counted down by twos// (gestures down the columns)

C: //Shh. Carl//
Bryce: I got 20, 40, 60, 80, 100, 120, 140, 160. A 160 is my answer.
C: Ok, so um questions, comments for Bryce about his strategy for figuring out the value of his book?
Bryce: (looks at students on carpet) (4.0)
C: You can call on
Bryce: What's up (looking at student)
Student: Um you did—you had a great strategy and great work.
C: Ok, //any other// of comments on his strategy?
Bryce: //Janie//
Janie: Um instead of putting 10, 20, 30, 40 all the way to um the answer he just did it like, added the, you know 10 plus 10 is 20 so he said 20, 40, 60, 80, 100, 120, 40, 60 and then he.
C: Yeah so he was being very efficient, right? So he was doing a quick way of counting. Greg something else?
Greg: Nice job.
C: Alright well we are all pleased with your work. Thank you very much for showing us how you figured out the value of your stamps. (class claps)

In this interactional episode, Courtney employed each of the positioning acts previously described and some other notable acts.

### *Invited Bryce to Share His Mathematical Thinking*

In Courtney's introduction for Bryce, "Bryce, you're my first fellow to share. Why don't you go on up. [Administrative talk] Bryce is going to share how he figured this problem out" (lines 1-2), multiple things occurred. First, Courtney invited Bryce to share his problem-solving strategy with the class, which shifted the duty to explain onto him and thereby allowed him to participate in the discussion. Second, Courtney's invitation enabled Bryce to take up the physical space typically reserved for the teacher at the front of the room, which shifted *some* of the rights and duties of a teacher onto Bryce. Third, Courtney called attention to Bryce's mathematical competency when she stated he had "figured this problem out" (line 2). Courtney may have chosen to interactively position Bryce in this way to bolster his self-confidence given his historical hesitancy in presenting to the class and a perceived need "to be assured that he's right."

### *Invited Peers to Consider Bryce's Mathematical Contributions*

After Bryce's explanation, Courtney asked, "Ok, so um questions, comments for Bryce about his strategy for figuring out the value of his book?" (lines 10-11). In this act, four things happened. First, Courtney exercised her duty (as a teacher) to facilitate mathematical discussions. Second, Courtney's act indicated an expectation peers would listen and respond to Bryce's explanation and that he was a part of the classroom community. Third, Bryce's position as participant and explainer was reinforced since his explanation was considered valid and Courtney as the "expert" did not restate it or offer an alternative explanation. Fourth, Courtney reinforced Bryce's position as mathematically competent since he had a valid strategy for "figuring out" the problem. Courtney then paused for 4.0 seconds and stated to Bryce, "You can call on" (line 13), which indicated Bryce could control the conversation and shifted the duty to mediate discussions onto him. Bryce took up this duty (lines 14 and 17) and fielded comments. After the first peer positively evaluated Bryce's work (line 15) Courtney asked if there were other comments, but Bryce had already begun to call on another student (line 17).

It is unclear why Courtney took over the conversation at this point, however, it marked a shift in the interaction where she reclaimed the duty to facilitate interactions between Bryce and his peers.

### *Evaluated Bryce's Mathematical Reasoning*

After Janie—a peer—had restated Bryce's explanation, Courtney evaluated the strategy, "Yeah so he was being very efficient, right? So he was doing a quick way of counting" (line 21). This act positioned Bryce's strategy as valued since it was efficient and reinforced his prior position as a mathematically competent student. In addition, it served to further advance Bryce's storyline of mathematical competence.

### *Other Notable Acts*

In addition to the positioning acts described above, Courtney employed four additional acts that influenced Bryce's position and opportunity to participate in this interactional episode. First, Courtney scanned Bryce's written work (Figure 5) to serve as a visual referent he could gesture to (line 7) to support his explanation—an instructional strategy recommended for EBs (Khisty & Chval, 2002; Moschkovich, 2002; Raborn, 1995). Second, Courtney reinforced Bryce's duty as a teacher to present mathematical information to the class when she referred to him as "a presenter" (line 6). This is an important position for Bryce since EBs are infrequently asked to present in content classrooms or referred to as "presenters" in front of native speaking peers publicly (Brenner, 1998; Gibbons, 2008). Third, as Bryce described his strategy he stated, "I counted down by twos" (line 7), which was not an accurate reflection of his strategy. However, Courtney did not call attention to this error and allowed him to maintain face in front of peers. Courtney's decision to remain silent may have been a result of their overlapping speech, a prior discussion she had had with Bryce, or she may have found an interruption unnecessary since Bryce continued to accurately describe his strategy of counting by twenties (line 9). Lastly, Courtney concluded this episode by stating, "*We* are all pleased with your work. Thank you very much for showing *us* how you figured out the value of your stamps" (line 26). This final act is important in multiple ways. First, the use of "we" and "us" indicated the class was a community and Bryce a member of it (Ju & Kwon, 2007). Second, Courtney reflexively positioned herself as a speaker for the community, which is not unusual given her rights and duties as a teacher. Third, the *community* was satisfied with Bryce's mathematical reasoning and respective explanation (as opposed to only Courtney being satisfied). This is notable since teachers usually reserve the duty to evaluate student thinking (Lemke, 1990; McHoul, 1978; Mehan, 1979), however, Courtney's statement reinforced Bryce's peers' evaluation of his thinking. Fourth, Courtney reinforced Bryce's position as presenter, explainer, and participant when she thanked him for sharing his strategy with the class. Lastly, Courtney called attention to Bryce's mathematical competence when she reiterated his success in "figuring out" the problem for the third time. In this way, she chose to conclude the episode by reinforcing his position and storyline as a mathematically competent student.

## **Storylines**

Since storylines can occur at multiple scales, I limited my focus to the storylines Courtney fostered for EBs collectively through her interactive positionings across the two years. In this way, I centered on the storylines Courtney advanced via her position that were or became socially recognizable for EBs that defined the expectations and conventions of interactions in her classroom (Herbel-Eisenmann et al., 2015). Given this, I do not claim the storylines presented herein were exclusive or unique to EBs, but they were evident for the EBs in Courtney's class. Moreover, it is outside the scope of this paper to describe the storylines constructed for all students across the two years.

Across the data, two prominent storylines were promoted by Courtney: EBs are mathematically competent and EBs can explain their mathematical reasoning to others (see Table 4 for selected evidence). These storylines were advanced across each respective year and EB and, at times, overlapped (i.e., multiple storylines were advanced in one turn).

**Table 4**

*Storylines of EBs and Selected Evidence*

| Storyline | Selected Evidence |
|---|---|
| EBs are mathematically competent | "that's a smart way of thinking about it [Bryce]. I like thinking about it like that, I'm a visual person."<br>"I think it's a really effective way of doing it"<br>"I like Alonzo's idea" |
| EBs can explain their mathematical reasoning to others | "I scanned in Alonzo's work because I thought that he did a *nice job* of explaining this a few different ways"<br>"Ok, so, Lea had a *really cool idea*, can you explain your idea?"<br>"Can you go on up and explain how you solved number two" |

### *Storyline 1: EBs are Mathematically Competent*

Mathematical competence is important for EBs since it defines what counts as mathematics and who gets to do it (Gresalfi et al., 2009). However, for storylines of competence to take hold, student acts must be recognized, which is most powerfully done through teachers' conferred rights and duties. The storyline that EBs are mathematically competent was repeatedly fostered through Courtney's interactive positionings of individual EBs. In this way, Courtney positioned EBs as engaging in mathematical practices that were culturally and socially valued and representative of academic success (Gresalfi et al., 2009). These positionings most often took the form of an EB possessing valued mathematical thinking, being mathematically efficient, solving problems accurately, and being able to explain problem-solving strategies. Since the latter positioning contributes to the storyline that EBs can explain their mathematical reasoning, the description of these positionings is omitted from this section and provided in the next.

To position EBs' mathematical thinking as valued, Courtney would qualify EBs' thinking with adjectives such as "cool," "smart," "awesome," or "good" (e.g., "awesome strategy") and, oftentimes, would include "really" to further emphasize the value (e.g., "really cool," "really good," "really smart"). In addition, Courtney would refer to an EB's thinking as something she "liked" or position a contribution as valuable by indicating the speaker had done well (e.g., "Nice job Samuel"; Gresalfi et al., 2009). Since Courtney was socially identified as the content expert and possessed rights and duties unavailable to students, she could define what counted as valuable mathematical thinking and who was considered "smart." Thus, her positioning acts had the power to shift interactions in the classroom (Reeves, 2009; Tait-McCutcheon & Loveridge, 2016; Turner et al., 2013; Wood, 2013).

Courtney valued mathematical efficiency in problem solving and was explicit about this with students. For instance, she stated, "We've been talking a lot about efficiency and making sure that your strategies are quick and that you use your time wisely." Consequently, being mathematically efficient was positioned as a characteristic of mathematical competence. When this occurred Courtney was always explicit, such as "If you wanted to be more *efficient*, you might think about it like Alonzo did" or "He [Bryce] was being very efficient."

The ability to accurately solve mathematical problems was also positioned by Courtney as characteristic of EBs who were mathematically competent. At times, this positioning was explicit, such as when she stated, "He [Alonzo] *solved* it many different ways and every single time he *solved* it, he got the same answer," and, in this particular act, Courtney also emphasized Alonzo's ability to use multiple strategies. At other times, the positioning was indicative of accuracy, such as "figured out" a problem. While it may be common in some classrooms to include incorrect solution strategies as valuable points for learning and an aspect of mathematical competence, Courtney did not emphasize this in her classroom or in her storyline for EBs. Instead, she focused on positioning EBs in ways that accentuated their mathematical accuracy. Courtney may have chosen to do this to bolster EBs self-confidence in mathematics or prevent situations where EBs' thinking could be perceived negatively by peers. Another reason may have been a desire to proffer a storyline that contrasted with the more prominent storyline that EBs need remediation and support in mathematics (de Araujo et al., 2016; de Araujo & Smith, 2022; Gutiérrez, 2008). Over the two years, Courtney leveraged her position to call out "smart" EBs over 185 times through the positioning acts of inviting EBs to share mathematical ideas, valuing EBs' mathematical contributions, and inviting peers to consider EBs' mathematical contributions. Consequently, Courtney's positioning acts identified valued ways of being in the classroom that were indicative of mathematical competence.

### *Storyline 2: EBs Can Explain their Mathematical Reasoning to Others*

The ability to explain one's mathematical reasoning to others provides opportunities to develop, refine, or clarify thinking, engage in mathematical discussion, and/or advance lessons. This practice was valued in Courtney's classroom as shown by her frequent requests for students to explain. Even though the benefits of explaining reasoning are well known, requests to do this are infrequently used in classrooms generally and with EBs specifically (Iddings, 2005; Planas & Gorgorió, 2004; Weiss et al., 2003). In contrast to this research, Courtney was found to often ask EBs to explain their mathematical reasoning and representations.

Courtney expected students, including her EBs, to explain their reasoning to others. One way she did this was to regularly pre-select 2-3 students to present their problem-solving strategies at the close of her lessons. Sometimes, Courtney would set the stage for the presenter by asking or directing them to explicitly "explain" their strategy. At other times, Courtney used language that referred to explanation, such as, "Alright, Bryce what did you do [to solve the problem]?" Consequently, these statements positioned EBs as students who had a strategy they could articulate to peers, shifted the duty of explaining strategies from Courtney onto EBs, and provided extended talk time for the EB in their L2. Additionally, in some cases, Courtney highlighted the value of these strategies by prefacing the EB's explanation, such as "Lea had a *really cool* idea. Can you explain your idea [to solve the problem]?" or "I scanned in Alonzo's work because I thought that he did a *nice job* of explaining this a few different ways." Statements like these reinforced the EB's explanation as valuable and a point of learning and positioned the EB as mathematically competent.

Requests to explain mathematical reasoning were not limited to the close of the lesson but happened throughout as well. For instance, when debating the appropriateness of 42 to represent two tens and four ones in a class discussion, Courtney stated, "Bryce says that would be 24. Why would that be 24 [Bryce]?" Alternatively, Courtney would ask an EB about details in their problem-solving strategy to elucidate reasoning, such as "How come you chose to add the three groups of 19 like that instead of 3+3+3+3+3 [indicating 19 groups of 3]?" while Alonzo described his strategy for summing three groups of 19. These types of positioning acts allowed EBs extended talk time, retain the conversational floor, and, in the case of Alonzo, highlight the deliberateness of an approach.

Courtney expected EBs—as well as other students—to explain mathematical representations. This expectation was shown through questions that varied in specificity. For instance, she would ask general questions, such as "[Lea] tell us about your picture," and more specific questions, such as "Why'd you [Bryce] put that line there, what's that mean?" These acts positioned EBs as individuals who had the capability to explain mathematical representation to others. To reinforce EBs ability to explain representations, Courtney would refer to the EB as someone who had explained. For example, after Bryce shared Courtney stated, "*Bryce is telling us* the numerator represents the number of pieces that the person gets and the denominator represents the number of pieces you cut that whole into." In this way, Courtney acknowledged an explanation had occurred and, at times, publicly and directly expressed gratitude for the explanation.

Across the data, Courtney positioned EBs as students who can explain their mathematical reasoning to others over 75 times through two positioning acts: inviting EBs to share mathematical ideas and inviting peers to consider EBs' mathematical contributions. In this way, Courtney advanced a storyline for EBs in this study that countered the belief that EBs cannot explain their thinking or take an active role in mathematical discussions as they acquire another language. Moreover, the acts she employed in conjunction with her explanation requests positioned EBs' explanations as valued, points of learning, and comparable to her own explanations. Therefore, the combination of these positions and other productive storylines (e.g., EBs explanations are just as valuable as Courtney's, EBs are mathematically competent) served to advance the storyline that EBs can explain their reasoning to others and further support prior research from other contexts that illustrate EBs participation in classroom discussions is contingent on the teacher (Turner et al., 2013; Yoon, 2008).

**Summary**. As evidenced in the data, Courtney strategically used acts to foster storylines that EBs are mathematically competent and can explain their mathematical reasoning to others. Notably, these storylines were frequently found to occur simultaneously in interactions, which attests to their complexity and ability to be at play in any given interaction. Such findings provide further evidence of the nuanced ways teachers interact with students and how teachers can position students—particularly those who have been historically underserved in mathematics—in storylines at multiple scales (e.g., utterance, lesson, academic year) that run counter to dominant narratives that perpetuate inequities. In this way, the storylines Courtney promoted individually for EBs across the data served to counter deficit-oriented storylines for EBs as a collective via their group association. Thus, Courtney facilitated opportunities to reshape who can be mathematically successful on a multi-year scale.

## Discussion and Conclusion

In this study, I used the lens of positioning theory (van Langenhove & Harré, 1999) to examine the discursive practices of one third-grade monolingual teacher, Courtney, and the ways she facilitated EBs participation in whole class mathematical discussions across two academic years. Findings from this study show Courtney implemented three prevalent interactive positioning acts, often in conjunction with one another rather than in isolation. The interactive positionings were inviting EB to share mathematical thinking, valuing EB mathematical contributions, and inviting peers to consider EBs' mathematical contributions. These findings extend Turner and colleagues' (2013) study of a bilingual teacher-researcher in an after-school program by shedding new light on the applicability of the positioning acts and other acts across contexts, teachers, and time as well as address calls for "more research on effective teaching and learning environments" for EBs and "richer descriptions of those environments" (Gutiérrez, 2008, p. 362) as well as examples of storylines in mathematics (Herbel-Eisenmann et al., 2015).

In contrast to Turner and colleagues' (2013) study, Courtney taught in a school with historically low populations of EBs and was constrained by class sizes and educational demands (e.g., curriculum, policies, standardized assessments). These drastically different U.S. school settings demonstrate the usefulness of the positioning acts for EBs across contexts. Said another way, the findings indicate the positioning acts can be used in classrooms with both high and low concentrations of EBs in the U.S. to foster EBs' participation in mathematical discussions. Additionally, the findings illustrate the positioning acts can be implemented by teachers who are in the early stages of thinking and learning about positioning theory. This is notable since the teacher-researcher in Turner and colleagues' (2013) study was familiar with positioning theory, understood the power of teacher positioning on EBs' learning, and was strategic in their use of discursive practices to position students in particular ways right from the start of the after-school program. Consequently, Courtney offers a picture of what positioning acts a teacher may initially begin to use as they learn about positioning and continue to refine across multiple years with different EBs with various mathematical and linguistic competencies. Furthermore, the positioning acts appeared to affect EBs' mathematical identities (e.g., Bryce's desire to share his problem-solving strategy with the class) and peers' interactive positionings of EBs (e.g., a peer's compliment on Bryce's efficient representation). Although prior research has identified teachers' positioning of EBs can affect the development of mathematical identities and the ways peers' interactively position EBs (Esmonde, 2009; Ju & Kwon, 2007; Turner et al., 2013; Wood, 2013; Yamakawa et al., 2009; Yoon, 2008), examining this effect was not a focus of this study.

It is important to note that Courtney's participation in ongoing professional development likely centered her attention on EBs and the ways she interacted with them. As a result, other teachers may also need professional development to focus and maintain their attention on EBs as they learn about positioning theory. Such professional development may begin with supporting teachers to first recognize how acts, positions, and storylines affect their own lived experiences in and out of school settings. Next, teachers could begin to think critically about ways to leverage their acts to (1) ensure EBs participate in productive ways as advocated by the NCTM (2013, 2014) and (2) challenge dominant narratives of who can be, who is, and what counts as mathematically successful as they strive for equitable mathematics instruction.

Through the interactive positioning acts, Courtney circulated multiple storylines for EBs collectively across the two years, such as EBs are mathematically competent and EBs can explain theirs or others' mathematical reasoning. Importantly, these storylines took hold because student acts were recognized specifically by Courtney. If, on other hand, Courtney would have undermined EBs' explanations (e.g., responding in ways that discredited their explanation), the storyline that EBs can explain theirs and others' mathematical reasoning would not have circulated. Even though the storylines Courtney circulated may not have transferred across classrooms in subsequent years for the EBs in this study, they were present across multiple years for EBs in Courtney's classroom. In this way, the storylines Courtney advanced for EBs defined the expectations and conventions of interactions in her classroom, served to create socially recognizable storylines for EBs, and had the ability to reshape who can be mathematically successful on a multi-year scale (Herbel-Eisenmann et al., 2015).

As a white, monolingual, elementary teacher, Courtney characteristically represents many elementary teachers in the U.S. (Grissom et al., 2015; Sleeter, 2001) and, given her success in teaching mathematics to EBs (Chval et al., 2014; Estapa et al., 2016; Pinnow & Chval, 2015), is in a unique position to offer insight into the ways other monolingual teachers can use discursive practices to create opportunities for EBs to participate using varied forms of language in mathematical discussions regardless of their competencies in EBs' first language. Although Courtney was able to implement the positioning acts deftly, it may be unrealistic to expect teachers to integrate all the positionings at once. As a result, teachers may find it beneficial to employ the positioning acts one by one as they begin to make changes in their practice. For instance, mathematics teacher educators may encourage future and current teachers to begin implementing Courtney's most common positioning act first (i.e., inviting EBs to share mathematical thinking) as opposed to those used less frequently. In this process, teachers should simultaneously reflect on their existing positioning acts, such as asking themselves, "What am I asking EBs to share about their mathematical thinking in whole class discussions?" or "What is one thing I will ask ____ to share in class tomorrow about their mathematical thinking?" Alternatively, a teacher may focus on a positioning act they perceive as easier to initially implement, such as valuing EBs' mathematical contributions. A teacher could then focus on drawing explicit attention to a desired practice an EB demonstrates (e.g., "Zainab was being *very efficient*") or recommend peers embody aspects of an EB (e.g., "If you wanted to be *more efficient*, you might think about it like Mariam did"). When employed, such acts interactively position the EB as possessing desirable mathematical thinking, advance their storyline of mathematical competence, challenge historic stereotypes of who can do mathematics (Battey & Leyva, 2016; de Araujo et al., 2016), and fulfill teachers' rights and duties to mediate interactions between EBs and peers to ensure EBs' mathematical contributions are positioned as valuable (Gorgorió & Planas, 2001; Secada & De La Cruz, 1996).

Although the use of positioning theory in mathematics education research is burgeoning, researchers (Herbel-Eisenmann et al., 2015) have called for greater attention to the acts and storylines that influence positions in classroom settings. Thus, the detailed analysis of acts, positions, and storylines help to fill this gap in the literature. Moreover, the analysis reveals the presence of multiple positioning acts and storylines in *each* interaction, which provides further evidence of the nuanced ways teachers interact with students, highlights the complexity of classroom interactions, and confirms the importance of the teacher in student positioning. In addition, there appears to be a potentiality for the positioning acts to advance storylines for EBs at multiple scales (i.e., utterance, lesson, academic year) that draw attention to their competencies and challenge existing deficit-oriented storylines (de Araujo et al., 2016; de Araujo & Smith, 2022; Gandara et al., 2005; Pettit, 2011). When promoted over time, such storylines can shape what becomes socially recognizable for EBs in mathematics and can support efforts to ensure equitable mathematics instruction for *every* student. Despite this, unanswered questions remain, such as: How does learning about positioning theory support teachers' understanding and integration of the previously described positioning acts? In what ways do teachers' draw on positioning theory to describe the intention of their acts and interactive positions in the classroom? What specific challenges do teachers face when implementing the positioning acts within and across different classes and contexts? An exploration of these research questions would expand our understanding of the interplay between understanding positioning theory and teacher acts in the classroom.

*This work was supported by the National Science Foundation under Grant Number DRL-0844556.*

**Erin Smith** (erin.smith@unlv.edu) is an assistant professor of mathematics education at the University of Nevada, Las Vegas. Dr. Smith's research focuses on increasing access to rigorous mathematics instruction for multilingual learners, building caregivers' capital in mathematics education, and leveraging community spaces to prepare culturally sustaining, community-informed mathematics teachers.

## References

Anderson, K. T. (2009). Applying positioning theory to the analysis of classroom interactions: Mediating micro-identities, macro-kinds, and ideologies of knowing. *Linguistics and Education*, *20*(4), 291–310.

Ballantyne, K. G., Sanderman, A. R., & Levy, J. (2008). *Educating English language learners: Building* *teacher capacity. National Clearinghouse for English Language Acquisition & Language Instruction Educational Programs*. Washington, D.C.: National Clearinghouse for English Language Acquisition.

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). *Report of the 2018 NSSME+*. Chapel Hill, NC.

Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). *Report of the 2012 National Survey of Science and Mathematics Education.* Chapel Hill, NC.

Battey, D., & Leyva, L. A. (2016). A framework for understanding whiteness in mathematics education. *Journal of Urban Mathematics Education*, *9*(2), 49–80.

Berman, L. (1999). Positioning in the formation of a "national" identity. In R. Harre & L. van Langenhove (Eds.), *Positioning theory: Moral contexts of intentional action* (pp. 138–159). Malden, MA: Blackwell Publishers Inc.

Brenner, M. E. (1998). Development of mathematical communication in problem solving groups by language minority students. *Bilingual Research Journal*, *22*(2), 149–174.

Cazden, C. B. (2001). *Classroom discourse: The language of teaching and learning* (2nd ed.). Portsmouth, NH: Heinemann.

Chval, K. B., Chavez, O., Pomerenke, S., & Reams, K. (2009). Enhancing mathematics lessons to support all students. In D. Y. White & J. S. Silva (Eds.), *Mathematics for every student: Responding to diversity PK-5* (pp. 43–52). Reston, VA: National Council of Teachers of Mathematics.

Chval, K. B., Pinnow, R. J., & Thomas, A. (2014). Learning how to focus on language while teaching mathematics to English language learners: A case study of Courtney. *Mathematics Education Research Journal*, *27*(1), 103–127.

Chval, K., Smith, E., Trigos-Carillo, L., & Pinnow, R. (2021). *Teaching math to multilingual students: Positioning English learners for success grades K-8.* Corwin and the National Council of Teachers of Mathematics.

Darling-Hammond, L., & Berry, B. (2006). Highly qualified teachers for all. *Educational Leadership*, *64*(3), 14–20.

de Araujo, Z., Roberts, S. A., Willey, C., & Zahner, W. (2018). English Learners in K–12 mathematics education: A review of the literature. *Review of Educational Research*, *88*, 879–919.

de Araujo, Z. & Smith, E. (2022). Examining ELLs' learning needs through the lens of algebra curriculum materials. *Educational Studies in Mathematics, 109,* 65–87. https://doi.org/10.1007/s10649-021-10081-w

de Araujo, Z., Smith, E., & Sakow, M. (2016). Reflecting on the dialogue regarding the mathematics education of English learners. *Journal of Urban Mathematics Education, 9*(2), 33–48.

Duff, P. A. (2002). The discursive co-construction of knowledge, identity, and difference: An ethnography of communication in the high school mainstream. *Applied Linguistics*, *23*(3), 289–322.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, *20*(4), 399–483.

Enyedy, N., Rubel, L., Castellón, V., Mukhopadhyay, S., Esmonde, I., & Secada, W. (2008). Revoicing in a multilingual classroom. *Mathematical Thinking and Learning*, *10*(2), 134–162.

Esmonde, I. (2009). Ideas and identities: Supporting equity in cooperative mathematics learning. *Review of Educational Research*, *79*(2), 1008–1043.

Esmonde, I., & Langer-Osuna, J. M. (2013). Power in numbers: Student participation in mathematical discussions in heterogeneous spaces. *Journal for Research in Mathematics Education*, *44*(1), 288–315.

Estapa, A., Pinnow, R. J., & Chval, K. B. (2016). Video as a professional development tool to support novice teachers as they learn to teach English language learners. *The New Educator*, *12*(1), 85–104.

Fairclough, N. (2010). *Critical discourse analysis: The critical study of language* (2nd ed.). Harlow, UK: Pearson Education.

Fosnot, C. T. (2007). *The t-shirt factory: Place value, addition, and subtraction*. Portsmouth, NH: Firsthand Heinemann.

Gandara, P., Maxwell-Jolly, J., & Driscoll, A. (2005). *Listening to teachers of English language learners: A survey of California teachers' challenges, experiences, and professional development needs. Policy Analysis for California Education, PACE (NJ1)*. Santa Cruz, CA: The Center for the Future of Teaching and Learning.

García, O. (2009). Education, multilingualism and translanguaging in the 21st century. In T. Skutnabb-Kangas, R. Phillipson, A. K. Mohanty, & M. Panda (Eds.), *Social justice through multilingual education* (pp. 140–158). Tonawanda, NY: Multilingual Matters.

Gee, J. P. (2008). *Social linguistics and literacies: Idealogy in discourses* (3rd ed.). London, UK: Routledge.

Gibbons, P. (1992). Supporting bilingual students for success. *Australian Journal of Language and Literacy*, *15*(3), 225–236.

Gibbons, P. (2008). "It was taught good and I learned a lot": Intellectual practices and ESL learners in the middle years. *Australian Journal of Language & Literacy*, *31*(2), 155–173.

Goffman, E. (1981). *Forms of talk*. Philadelphia, PA: University of Pennsylvania Press.

Gorgorió, N., & Planas, N. (2001). Teaching mathematics in multilingual classrooms. *Educational Studies in Mathematics*, *47*(1), 7–33.

Green, J. L., Brock, C., Baker, W., & Harris, P. (2020). Positioning theory: Its origins, definition, and directions in education an explanatory theory and analytic lens. In N. S. Nasir, C. D. Lee, R. Pea, & M. M. de Royston (Eds.), *Handbook of the Cultural Foundations of Learning* (pp. 119–140). Routledge.

Gresalfi, M., Martin, T., Hand, V., & Greeno, J. (2009). Constructing competence: An analysis of student participation in the activity systems of mathematics classrooms. *Educational Studies in Mathematics*, *70*(1), 49–70.

Grissom, J. A., Kern, E. C., & Rodriguez, L. A. (2015). The "representative bureaucracy" in education. *Educational Researcher*, *44*, 185–192.

Gutiérrez, R. (2002). Beyond essentialism: The complexity of language in teaching mathematics to Latina/o students. *American Educational Research Journal*, *39*(4), 1047–1088.

Gutiérrez, R. (2008). A "gap-gazing" fetish in mathematics education? Problematizing research on the achievement gap. *Journal for Research in Mathematics Education*, *39*(4), 357–364.

Harper, C., & De Jong, E. (2004). Misconceptions about teaching English-language learners. *Journal of Adolescent & Adult Literacy*, *48*(2), 152–162.

Harré, R. (2012). Positioning theory: Moral dimensions of socio-cultural psychology. In J. Valsiner (Ed.), *The Oxford Handbook of Culture and Psychology* (pp. 191–206). New York, NY: Oxford University Press.

Harré, R., Moghaddam, F. M., Cairnie, T. P., Rothbart, D., & Sabat, S. R. (2009). Recent advances in positioning theory. *Theory & Psychology*, *19*(1), 5–31.

Harré, R., & Slocum, N. (2003). Disputes as complex social events: On the uses of positioning theory. *Common Knowledge, 9*(1), 100-118.

Harré, R., & van Langenhove, L. (1991). Varieties of positioning. *Journal for the Theory of Social Behaviour*, *21*(4), 393–407.

Harré, R., & van Langenhove, L. (1999). The dynamics of social episodes. In R. Harré & L. van Langenhove (Eds.), *Positioning theory: Moral contexts of intentional action* (pp. 1–13). Malden, MA: Blackwell Publishers Inc.

Herbel-Eisenmann, B., Wagner, D., Johnson, K., Suh, H., & Figueras, H. (2015). Positioning in mathematics education: Revelations on an imported theory. *Educational Studies in Mathematics*, *89*(2), 185–204.

Hufferd-Ackles, K., Fuson, K. C., & Sherin, M. G. (2004). Describing levels and components of a math-talk learning community. *Journal for Research in Mathematics Education*, *35*(2), 81–116.

Iddings, A. C. D. (2005). Linguistic access and participation: English Language Learners in an English-dominant community of practice. *Bilingual Research Journal*, *29*(1), 165–183. https://doi.org/10.1080/15235882.2005.10162829

Inagaki, K., Hatano, G., & Morita, E. (1998). Construction of mathematical knowledge through whole-class discussion. *Learning and Instruction*, *8*(6), 503–526.

Ju, M.-K., & Kwon, O. N. (2007). Ways of talking and ways of positioning: Students' beliefs in an inquiry-oriented differential equations class. *The Journal of Mathematical Behavior*, *26*(3), 267–280.

Kawanaka, T., Stigler, J. W., & Hiebert, J. (1999). Studying mathematics classrooms in Germany, Japan and the United States: Lessons from the TIMSS videotape study. In I. Huntly, G. Kaiser, & E. Luna (Eds.), *International comparisons in mathematics education* (pp. 96–113). Philadelphia, PA: Taylor & Francis

Kayi-Aydar, H. (2019). *Positioning Theory in Applied Linguistics*. Cham, Switzerland: Palgrave Macmillan.

Khisty, L. L., & Chval, K. B. (2002). Pedagogic discourse and equity in mathematics: When teachers' talk matters. *Mathematics Education Research Journal*, *14*(3), 4–18.

Lemke, J. L. (1990). *Talking science: Language, learning, and values.* Norwood, NJ: Ablex Publishing Corp.

Lerman, S. (2001). Cultural, discursive psychology: A sociocultural approach to studying the teaching and learning of mathematics. *Educational Studies in Mathematics*, *46*(1), 87–113.

Lightbrown, P. M., & Spada, N. (2013). *How languages are learned* (4th ed.). Oxford, U.K.: Oxford University Press.

Lucas, T., Villegas, A. M., & Freedson-Gonzalez, M. (2008). Linguistically responsive teacher educxation: Preparing classroom teachers to teach English language learners. *Journal of Teacher Education*, *59*(4), 361–373.

Martin-Beltrán, M. (2010). Positioning proficiency: How students and teachers (de) construct language proficiency at school. *Linguistics and Education*, *21*(4), 257–281.

McHoul, A. (1978). The organization of turns at formal talk in the classroom. *Language in Society*, *7*, 183–213.

McVee, M. (2011). Positioning theory and sociocultural perspectives: Affordances for educational researchers. In M. McVee, C. H. Brock, & J. A. Glazier (Eds.), *Sociocultural research in literacy: Exploring culture, discourse, narrative, and power in diverse educational contexts* (pp. 1–22). Hampton Presss, Inc.

Mehan, H. (1979). *Learning lessons: Social organization in the classroom*. Cambridge, MA: Harvard University Press.

Mesa, V., & Chang, P. (2010). The language of engagement in two highly interactive undergraduate mathematics classrooms. *Linguistics and Education*, *21*(2), 83–100.

Moghaddam, F. M., & Harré, R. (2010). Words, conflicts, and political processes. In F. M. Moghaddam & R. Harré (Eds.), *Words of conflict, words of war: How the language we use in political processes sparks fighting* (pp. 1–28). Santa Barbara, CA: Praeger.

Moghaddam, F. M., Harré, R., & Lee, N. (Eds.). (2007). *Global conflict resolution through positioning analysis*. New York, NY: Springer.

Moschkovich, J. (2002). A situated and sociocultural perspective on bilingual mathematics learners. *Mathematical Thinking and Learning*, *4*(2), 189–212.

Nasir, N. S. (2016). Why should mathematics educators care about race and culture. *Journal of Urban Mathematics Education*, *9*(1), 7–18.

National Academies of Sciences, Engineering, and Mathematics. (2018). *English learners in STEM subjects: Transforming classrooms, schools, and lives*. Washington, D.C.: The National Academies

Press.

National Assessment of Educational Progress [NAEP]. (2022). *NAEP Report Card: 2022 NAEP Mathematics Assessment.* Washington, DC: Author.

National Center for Educational Statistics. (2016). *English language learners in public schools*. Washington, DC: Author.

National Council of Teachers of Mathematics. (2013). *Teaching mathematics to English language learners: A position of the National Council of Teachers of Mathematics*. Reston, VA: Author

National Council of Teachers of Mathematics. (2014). *Principles to Action*. Reston, VA: Author.

Pappamihiel, N. E. (2002). English as a second language students and English language anxiety: Issues in the mainstream classroom. *Research in the Teaching of English*, *36*(3), 327–355.

Patton, M. Q. (2015). *Qualitative research & evaluation methods: Integrating theory and practice* (4th ed.). Thousand Oaks, CA: SAGE Publications.

Pettit, S. K. (2011). Teachers' beliefs about English language learners in the mainstream classroom: A review of the literature. *International Multilingual Research Journal*, *5*(2), 123–147.

Pinnow, R. J., & Chval, K. B. (2015). "How much you wanna bet?": Examining the role of positioning in the development of L2 learner interactional competencies in the content classroom. *Linguistics and Education*, *30*, 1–11.

Planas, N., & Gorgorió, N. (2004). Are different students expected to learn norms differently in the mathematics classroom? *Mathematics Education Research Journal*, *16*(1), 19–40.

Raborn, D. T. (1995). Mathematics for students with learning disabilities from language-minority backgrounds: Recommendations for teaching. *New York State Association for Bilingual Education Journal, 10,* 25–33.

Reeves, J. (2009). Teacher investment in learner identity. *Teaching and Teacher Education*, *25*(1), 34–41.

Santos, M., Darling-Hammond, L., & Cheuk, T. (2012). *Teacher development to support English language learners in the context of Common Core State Standards*. Stanford, CA: Understanding Language.

Secada, W. G., & De La Cruz, Y. (1996). Teaching mathematics for understanding to bilingual students. In J. LeBlanc Flores (Ed.), *Children of la frontera: Binational efforts to serve Mexican migrant and immigrant children* (pp. 285–308). Charleston, WV: ERIC Clearinghouse on Rural Education & Small Schools.

Setati, M. (2005). Teaching mathematics in a primary multilingual classroom. *Journal for Research in Mathematics Education, 36*(5), 447–466.

Sinclair, J., & Coulthard, M. (1975). *Towards an analysis of discourse: The language of teachers and pupils*. London, UK: Oxford University Press.

Sleeter, C. E. (2001). Preparing teachers for culturally diverse schools. *Journal of Teacher Education*, *52*(2), 94–106.

Smith, E. (2022). A teacher's positioning of a multilingual learner in the first month of the school year. *Research in Mathematics Education*. DOI: 10.1080/14794802.2022.2133004

Søreide, G. E. (2006). Narrative construction of teacher identity: Positionig and negotiation. *Teachers and Teaching*, *12*(5), 527–547.

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

Tait-McCutcheon, S. L., & Loveridge, J. (2016). Examining equity of opportunities for learning mathematics through positioning theory. *Mathematics Education Research Journal*, *28*(2), 1–22.

Tan, S., & Moghaddam, F. M. (1995). Reflexive positioning and culture. *Journal for the Theory of Social Behaviour*, *25*(4), 387–400.

Turner, E., Dominguez, H., Maldonado, L., & Empson, S. (2013). English learners' participation in mathematical discussion: Shifting positionings and dynamic identities. *Journal for Research in Mathematics Education*, *44*(1), 199–234.

van Langenhove, L. (2011). Conversation as the primary social reality. In L. van Langenhove (Ed.), *People and Societies: Rom Harré and Designing the Social Sciences* (pp. 65–68). Routledge.

van Langenhove, L., & Harré, R. (1999). Introducing positioning theory. In R. Harre & L. van Langenhove (Eds.), *Positioning theory: Moral contexts of intentional action* (pp. 14–31). Blackwell Publishers Inc.

Weiss, I. R., Pasley, J. D., Smith, P. S., Banilower, E. R., & Heck, D. J. (2003). *Looking inside the classroom: A study of K-12 mathematics and science education in the United States*. Chapel Hill, NC.

Wood, M. B. (2013). Mathematical micro-identities: Moment-to-moment positioning and learning in a fourth-grade classroom. *Journal for Research in Mathematics Education*, *44*(5), 775–808.

Yamakawa, Y., Forman, E., & Ansell, E. (2009). Role of positioning: The role of positioning in constructing an identity in a third grade mathematics classroom. In K. Kumpulainen, C. E. Hmelo-Silver, & M. Cesar (Eds.), *Investigating Classroom Interaction: Methodologies in Action.* (pp. 179–201). Sense Publishers.

Yoon, B. (2008). Uninvited guests: The influence of teachers' roles and pedagogies on the positioning of English language learners in the regular classroom. *American Educational Research Journal*, *45*(2), 495–522.

# Appendix A

## Transcription key

| Symbol | Key |
|---|---|
| = | Adjacent speech |
| ? | Rising intonation as with a question |
| , | Natural break/pause in speech |
| — | Abrupt change in speech |
| … | Longer pause in speech (~2 natural pauses) |
| : | Elongated sound |
| (#) | Pause length in seconds |
| TWO | Louder speech |
| // // | Overlapping speech |
| ! | Said with excitement |

## Appendix B

### Teacher Positioning Act Coding Scheme

| Category | | Code | Description |
|---|---|---|---|
| Mathematics | Invite | TSHARE | Teacher invites EB math thinking, noticing, observation, or solution strategy |
| | | TJUS | Teacher asks EB to clarify, justify, or explain math claim or solution |
| | Peer Invite | TDIR | Teacher invites peers to consider EB's contribution |
| | Ownership | TOWN | Teacher assigns or restates ownership to EB |
| | Documenting | TDOC | Teacher documents EB math idea or claim |
| | Representative | TREP | Teacher positions EB as representation of a group |
| | Revoicing | TAMPCLAR | Teacher revoices to amplify or clarify EB contribution |
| | | TBLD | Teacher reconceptualizes/extends/builds on EB math contribution |
| | | TREVACT | Teacher revoices EB math actions |
| | Value | TVAL | Teacher makes value judgment on EB justification, explanation, thinking, claim, idea, noticing, observation, or strategy |
| | Knowledge | TKNOW | Teacher states or confirms EB math knowledge or ideas |
| Linguistic | Documenting | TDOCL | Teacher documents EB linguistic contribution |
| | Value | TVALLING | Teacher makes value judgment of EB linguistic contribution |
| | Revoicing | TREVLING | Teacher revoices EB linguistic contribution |
| | | TBLDLING | Teacher builds/extends on EB linguistic contribution |
| | Invitations | TLING | Teacher invites EB linguistic contribution |

ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 27, NO. 4, 107-117

International Consortium for Research in
Science & Mathematics Education

# Together in a Productive Struggle: Unpacking Student and Teacher Productive Struggle in Mathematics

Katherine Baker
*Elon University*

Madison Clark
*Elon University*

Danielle Moloney Gallagher
*North Carolina State University*

**ABSTRACT**

This article features a fifth grade mathematics exploration planned to facilitate students' productive struggle. The exploration was a catalyst for a team of educators to unpack the teacher's experience when facilitating students' productive struggle. The team called this *teacher productive struggle* and shares about the construct contextualized in the exploration.

*Keywords:* elementary, mathematics exploration, productive struggle

## Introduction

In 2020, we collaborated as teacher educator, prospective teacher, and practicing teacher (respectively) in Moloney's fifth grade mathematics classroom. During one lesson, geoboards were used to facilitate unpacking the relationship between area and perimeter. This was Clark's first time observing students working with geoboards, and she noted how the tool was used to support students' productive struggle. It was also the first time our team of three educators considered what it might mean for a teacher to productively struggle during mathematics instruction that facilitates students' productive struggle. While the concept of students' productive struggle in mathematics had been read about, discussed, and supported in instruction, what unfolded in our team's post-lesson reflection was how Moloney felt as her students did, those who productively struggled with the mathematics. We called this personal experience her *teacher productive struggle*.

This article provides an overview of Moloney's lesson, which included geoboards, and her teaching that allowed for students' productive struggle. We share about this lesson exploration to provide insight into a teacher's feelings and thoughts during the facilitation of students' productive struggle. We unpack this teacher's insights throughout one exploration and within one context, so that other educators can begin to compare and identify their own *teacher productive struggle* and consider what that might encompass. Then, like our team, educators can collaborate with open and honest conversations about the apprehensions and benefits of facilitating students' productive struggle and the experience of their own teacher productive struggle.

---

## What is Productive Struggle?

Student productive struggle occurs when students have opportunities to engage with appropriately challenging mathematics ideas and problems which require struggle and perseverance (Hiebert & Grouws, 2007). Student productive struggle is evoked through effective teaching strategies that encourage students to work through challenging mathematical ideas and relationships, with the goal of developing a greater sense of mathematical literacy and understanding, rather than just focusing on finding correct solutions (National Council of Teachers of Mathematics [NCTM], 2014). These teaching strategies may include observing and utilizing student strategies, activating students' prior knowledge, providing ample opportunities for students to pause and reflect on their own thinking through the use of strategic questioning, and highlighting that student struggle and perseverance in mathematics is recognized, valued, and ultimately productive (Baker et al., 2020). Teachers should be transparent about and reinforce with students that struggle is a natural and essential part of mathematical problem-solving (Wilson et al., 2019). To encourage more equitable spaces, teachers must work to ensure all students have access to cognitively demanding tasks that spur productive struggle and deep thinking, especially students from historically marginalized groups whose access has been limited (Lynch et al., 2018).

Since the construct of student productive struggle has been defined and discussed by mathematics researchers and educators, including its value and what it may look like in the context of a classroom for the student learner, our team began to reflect on a teacher's experience while facilitating students' productive struggle. Engaging students in appropriately challenging mathematical opportunities that encouraged their risk-taking opened the door for teacher risk-taking as well. We began to conceptualize the educator's thoughts and feelings during the facilitation of student productive struggle as *teacher productive struggle*, a term which serves to encompass both the apprehensions and benefits a teacher experiences alongside student productive struggle. We did not and do not use the term *teacher productive struggle* to mean we are struggling with the choice to offer tasks that induce student productive struggle; we believe students deserve to tinker with the mathematics and we work to "trust students with open-ended, multidimensional, challenging tasks" (Skinner et al., 2019). We do use the term to capture the momentary discomfort teachers may feel to as students experience momentary discomfort during challenges and problem solving.

What we share in the article highlights moments of student productive struggle in a fifth-grade mathematics Geoboard exploration in order to reveal Moloney's own teacher productive struggle. In the student exploration, we bring to attention two characteristics of student productive struggle as defined by Hiebert and Grouws (2007): (a) utilizing existing knowledge to engage in solving challenging problems which do not have immediate solutions, and (b) perseverance through problem solving in an effort to enhance mathematical understanding. We unpack Moloney's experience in response to facilitating these two characteristics in this specific mathematics exploration. Finally, we expand on teacher productive struggle beyond the specific exploration and classroom interactions.

## Guiding Philosophies and Context of Our Mathematics Teaching

Our understanding of *teacher productive struggle* is grounded in our philosophy of mathematics education. Collectively we believe in conceptually based teaching that offers all students the opportunity to engage with and make sense of mathematical concepts (NCTM, 2014). These experiences are grounded in cognitively demanding tasks that allow for problem-solving with multiple strategies and connections across representations (Smith & Stein, 2018; Stein & Smith, 1998). We believe these learning experiences should be structured in a way that provides access to all students, disrupting patterns of marginalization that can exist in mathematics classrooms (Chao et al., 2014; Wilson et al., 2019). In addition, we believe discussion and student-to-student discourse supports students' understanding of mathematics (Chapin et al., 2013). In order to effectively facilitate these task-based, discussion-based, conceptually driven mathematics experiences for students, teachers need mathematical knowledge for teaching (MKT), a specialized knowledge of both the mathematical content and the pedagogical practices that support student learning (Ball et al., 2008). Our construct of teacher productive struggle is grounded in our acknowledgement that MKT is necessary; we cannot facilitate student productive struggle and give students the mathematical opportunities they deserve without investing in thoughtful problem selection, unpacking the mathematics content ourselves before exploring it with students, and considering the potential strategies students might use in their problem solving (Carpenter et al., 2014).

The particular exploration shared next is situated in Moloney's fifth grade classroom mid school year. At the time of this exploration, Moloney was in her fifth year of teaching, and was specializing in fifth grade mathematics teaching. The school was in the process of adopting the *Bridges* (2016) curriculum, and this was the first year with the curriculum for both the teacher and the students. The students in this class were familiar with experiences of productive struggle in mathematics. Throughout their fifth-grade year, students were exposed to cognitively demanding mathematical tasks and were given consistent opportunities to discuss mathematical concepts. Baker and Clark collaborated in university coursework and an undergraduate research project that explored humanizing mathematics (Gutiérrez, 2009, 2010; Yeh & Otis, 2019), and they collaborated with Moloney and her students to engage in mathematics both inside the classroom and in outside spaces. While this article features Moloney's classroom context and personal experience with teacher productive struggle in that context, our team acknowledged that we have each experienced teacher productive struggle within our varied mathematics teaching and learning contexts. As you read, keep in mind that teacher productive struggle is not unique to fifth grade mathematics teaching and learning, but rather can occur across grade levels and content areas, and consider how it might connect to other contexts.

## The Geoboard Exploration

An overview of the Geoboard exploration and its intended goals is featured in Figure 1. Before Moloney introduced the geoboards to students, she first accessed students' prior knowledge by asking them to consider how perimeter, area, and multiplication are related. The students discussed these relationships in a turn-and-talk format and then shared some of their discussion points with the entire class. One student expressed that perimeter is "adding all sides of a shape," and another shared that "sometimes you can multiply to find perimeter if all sides of the shape are the same." Another shared that "area is the number of square units a shape is made up of." Moloney wrote these student definitions on the classroom white board for students to refer to during the exploration. She then launched the geoboard exploration, distributing the geoboards, and allowing students three minutes to explore, make observations, and consider "what it can and can't do to help think about math."

**Figure 1**

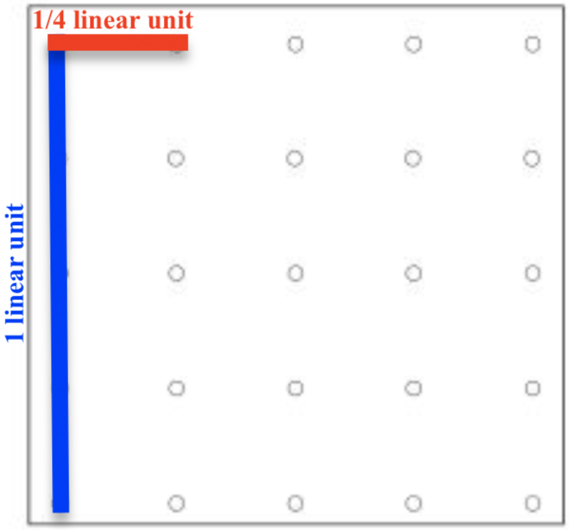
*Fifth Grade Geoboard Exploration Overview*

| | |
|---|---|
| The Geoboard Exploration | **Content Goal:** Explore the relationship between area and perimeter using a geoboard as a visual representation and model.<br>**Productive Struggle Goal:** Understand that not all problems are solved instantly or in one math session; be comfortable letting problems linger into future days; attempt different strategies if the current one is not working.<br>**Student Experience**: Students begin to explore how to represent perimeter and area of fractional measurement lengths on a geoboard and model what that perimeter and area represents.<br>**Model of Student 5 x 5 Geoboard:**<br><br>Lesson adapted from *Bridges* (2016) 5th Grade Curriculum |

Next, Moloney displayed an enlarged geoboard and explained that the outline of the peg area of the board represented one square unit. She posed the question, “If the area is one square unit, what is the perimeter and how do you know?” Moloney’s purpose for initiating the exploration with this question was to support students in seeing that each length of the side of the geoboard was one unit, and that each linear space from peg to peg was one fourth of a unit, as seen in Figure 2.

**Figure 2**

*Geoboard Labeled with One Linear Unit and One-fourth of a Linear Unit.*



Students were first invited to explore this question using rubber bands on their physical geoboard and with a printed copy of the geoboard image. After some independent work time with the materials, Moloney paused the class for a group discussion around initial thoughts about the value of the perimeter. A student offered, “the perimeter of the geoboard is four square units.” Moloney caught that the perimeter would be four *linear* units, not four *square* units. However, rather than correct this, she wanted to see if the class could help refine the thinking and language. This would help the class review the connection between the concepts of perimeter and area. She prompted the entire class by saying, “If the area of the board is one square unit, [Student A] says the perimeter would be four square units. Do you agree or disagree?” She encouraged students to share their ideas with their table groups. As students discussed this prompt, they re-examined their own work and materials, and Moloney circulated the room, conversing with the small groups. A whole group discussion and class vote followed, revealing that students were indecisive about the validity of Student A's statement. Five students agreed with Student A’s statement, nine disagreed, and multiple students refrained from voting on the validity of the statement just yet.

Faced with the group indecision, Moloney prompted students to share their reasoning as to why the perimeter of the geoboard would, or would not, be four square units. Moloney wanted to elicit various ideas so that students could use others' thoughts as evidence to support their own thinking. The following are examples of the students’ contributions.

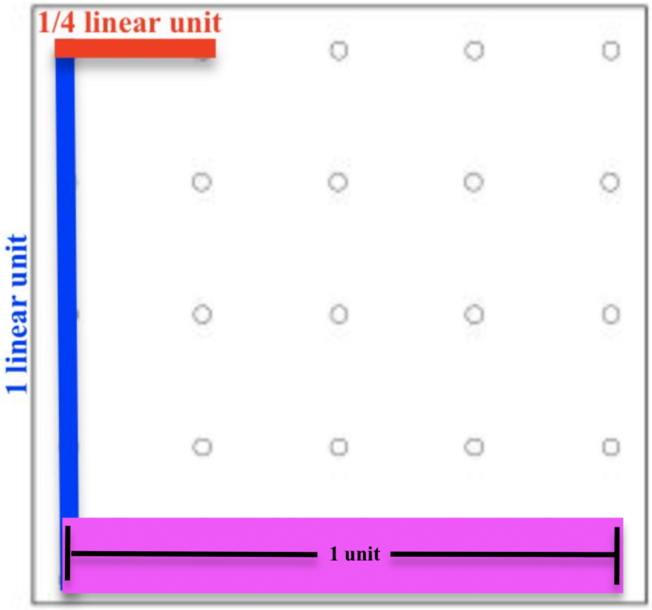
> **Student 1**: I reasoned that one unit divided by four (one side divided into four pieces) equals 1/4 unit. [Student goes up to the board to demonstrate that one side is 4/4 units which is equal to one whole.]
> **Student 2**: I know the perimeter represents the outside of the rectangle and I counted 16 [1/4th] segments. So, the perimeter equals 16 units.
> **Student 3**: I am confused by these answers because the total area is supposed to be one square unit, so I’m still not sure what the perimeter would be and how we would think about that.
> **Student 4**: I think that if the area is one square unit, the perimeter is four units, not square units. And that works with what Moloney said at the beginning about the area being one square unit total and us having to find perimeter, which is in units.

After allowing time for students to listen and ask questions of one another, Moloney conducted a re-vote, which highlighted continued indecision and confusion among students. Three students shared that they believed “area = 1 sq. unit” [notation as verbally shared and as written out on board to present to the whole class] and “perimeter = 4 units”, noting that no one thought the “square” should stay with the way the perimeter’s value was being expressed. Five students now voted that they thought “area = 16 sq. units” and “perimeter = 16 units” after hearing that answer offered. Again, multiple students refrained from voting. At this point both the students and Moloney were visibly struggling to determine what the next move should be. This was expressed through confused and scrunched facial gestures, slumped body language, and shoulder shrugs. Moloney used a “Teacher Time Out” (Gibbons et al., 2017) with Baker to quickly run through options, considering the costs and benefits of stopping the lesson there for the day or attempting an alternative strategy for facilitating the lesson that would allow students to keep working. After considering the mathematical goals for the lesson, the team decided to introduce a tool that would help students focus on the distinction between linear and square units. Before jumping back into the mathematics, however, Moloney used a powerful and important teaching move for her classroom community by asking the class, “Who’s confused? Be honest.” As the majority of students in the class raised their hands, Moloney responded, “Great!” and thanked them for their honesty. She took this moment to share that she was also confused about how to proceed, and that both her confusion and their confusion was okay. She reassured students that they would work with one another to figure out a path and an answer. This reassuring moment served several purposes - to let students know it was okay to feel confused, to let students know that the confusion would not persist, and to let them know that she would support them to the other side of the initial confusion.

Moloney's next step was to guide students back to some of the critical mathematical moments shared in the discussion that could help move the class forward in their understanding (see Baker et al., 2020 for more on this reorientation strategy). She reemphasized to students that they were working in linear units, and she asked a student to explain what that meant in context. Once students had clarification of the units and expressed understanding of the difference between units and square units, Moloney introduced a new tool to further help students determine the perimeter of the geoboard. This new tool was a pink strip of paper, where "one strip of paper equals one unit". See Figure 3 for this tool.

**Figure 3**

*Labeled Geoboard with Pink Ruler*



While it was not necessarily pre-planned to introduce this specific tool during the lesson, the teacher had applicable tools on hand as a result of intentional pre-planning with MKT and mathematical learning goals in mind. Moloney shared, "the pink strip is like a ruler that measures one unit. What do we think the perimeter is now that we have our ruler?"

As students discussed and used this new tool with their geoboards, the class quickly concluded that the perimeter of the geoboard is four units and that this answer fit with the area being one square unit because, as one table group enthusiastically shared, "each side of the geoboard is one linear unit and the geoboard is actually one square!" Moloney ended the lesson by expressing to students that they would continue to use and learn with the geoboard in future lessons, exploring mathematics content with both fractional and whole number units of length. The long-term goal for this initial lesson with the geoboard was to lead into future learning experiences representing other more advanced questions of fraction multiplication on the geoboard. Moloney left her students with this final thought: "That was hard math with small numbers." She encouraged them to consider that "hard" does not always involve big numbers or intense problems, that challenging mathematics can happen anywhere, with any problem, and that collaboration is an effective way to productively struggle.

## Teacher Productive Struggle During the Exploration

After the exploration, the educator team debriefed Moloney's intended teaching moves to facilitate students' productive struggle, and to also unpack what she was experiencing during the facilitation. Regarding the teaching practice of *facilitating students' use of existing knowledge to engage in solving challenging problems which do not have immediate solutions*, Moloney expressed her attempts to strike the balance between giving enough information, and guidance for students to draw conclusions about area and perimeter without giving the mathematics away or interfering with the students' thinking. In posing the initial question to students about finding the perimeter when knowing the area, she aimed to build upon existing knowledge about perimeter and area and also let students productively struggle to generate hypotheses about area, perimeter, and their relationships.

Moloney also expressed that she introduced a new mathematics tool, the geoboard, to facilitate student understanding of area and perimeter through a visual and physical exploration, because this tool would be beneficial to future lessons. She experienced a teacher productive struggle when considering how to facilitate effective use of the geoboard without letting it impede the mathematical sensemaking. Moloney shared that she felt confident in her choice to let students explore the tool initially, and make general observations, but was uncertain about how to guide students toward the mathematical goal without giving too much away. Balancing these turns in emotions around the same tool, in the same timeframe, was part of Moloney's teacher productive struggle.

In regard to *facilitating students' perseverance through problem solving in an effort to enhance mathematical understanding*, Moloney sought to adequately set up students for the geoboard exploration by exposing them to a productive struggle during the area and perimeter discussion, where they would hopefully gain skills and mindsets about persisting in mathematics. She was optimistic about her students' abilities to uncover important mathematical ideas, but began to question the timing of this exploration, and the pacing of its problem solving once students expressed confusion and frustration. She wondered if the task was not presented at the right point, or if it was too open-ended to support a mathematical goal (i.e., leading to many disconnected paths and ideas). She reflected on how her instructional decisions might influence a productive or unproductive student struggle. During the lesson, Moloney also experienced her own productive struggle as she balanced allowing students to grapple with the mathematics versus knowing when to step in with the whole class or individual learners. Constantly noticing students' affects and trying to determine the line between productive versus unproductive struggle added to Moloney's own productive struggle. Additionally, Moloney acknowledged that openly taking the Teacher Time Out during the geoboard exploration and debating the best teaching decision in the moment was an opportunity to highlight her own productive struggle alongside the students. She hoped this was a teaching moment that reassured students that it is acceptable to struggle, that Moloney supported them, and that they would have opportunities to reset and look at the problem from a fresh perspective. Ultimately, Moloney experienced encouragement and excitement by what students were sharing, knowing that they were growing in knowledge of the mathematics content and engaging in the productive struggle to persist through the geoboard exploration.

## Recapping and Expanding on Teacher Productive Struggle

In review, Moloney experienced teacher productive struggle while she was trying to facilitate productive struggle for her students during a lesson. Table 1 overviews student productive struggle characteristics as well as the productive struggle that a teacher may experience in response during a lesson. Of note, in-the-moment teacher productive struggle that occurs while attempting to facilitate student productive struggle is only one layer of teacher productive struggle. In future debrief sessions, the team also discussed that productively struggling as a teacher encompasses decisions about the curriculum and interactions with colleagues.

## Productively Struggling with Curriculum

As Moloney grew more comfortable in her understanding of what it meant to facilitate and support student productive struggle during individual lessons, she also challenged herself to consider and expand upon the opportunities that produce it. This meant considering how she utilized her school's mandatory curriculum in a way that served to facilitate her students' productive struggle (Drake et al., 2015). Moloney expressed that she experienced a teacher productive struggle in this effort, as she was fearful that attempting to manipulate the curriculum to allow for greater student productive struggle may harm student learning in the future, depending on how students' future teachers chose to access the curriculum. This was part of the teacher productive struggle that Moloney faced regarding her teaching choices and decision making, and how these choices impacted students. Even with this fear, Moloney recognized that if students followed a curriculum lockstep in future years, her emphasis on productive struggle now would still equip them with skills to evaluate mathematical solutions, and the chance to know what it feels like to persevere through a mathematical problem-solving scenario.

## Productively Struggling with Colleagues

Moloney's situation also highlights a third layer of teacher productive struggle, as it is more difficult for a teacher to feel confident in their abilities to facilitate student productive struggle if they do not have critical colleagues that can support, challenge, and problem solve with them when innovative lessons do not unfold as planned. Moloney recognized that she is more hesitant to try new approaches and pedagogies if she does not feel that she will have colleagues who will problem solve, or encourage her to continue to explore how productive struggle might be part of an equitable mathematics classroom space. She sought to adapt her school's adopted curriculum to her students' mathematical contributions and needs. However, she sometimes struggled to engage and persist in alternative pedagogical practices if she felt that she would not have others' support to do this.

**Table 1**

*Characteristics of Student and Teacher Productive Struggle and How They Relate*

| Student Productive Struggle Characteristic | Teacher Productive Struggle Experiences | Possible Teacher Responses |
|---|---|---|
| When a student is engaging in solving challenging problems which do not have immediate solutions through the activation of prior knowledge... | ● A teacher might feel tension trying to balance providing students with adequate mental and physical tools to solve the problems and giving too much away.<br>● A teacher might feel encouraged to engage in strategic questioning of students as a means to allow students access to deeper mathematical knowledge and understanding, and to get to know their learners' affects and problem-solving personalities. | ● A teacher may use a physical tool (e.g., a paper strip) and/or a visual to scaffold the given problems and allow students to access the key mathematical ideas.<br>● A teacher may refer to pre-planned additional questions to probe student thinking and access key ideas.<br>● A teacher may utilize talk moves (Chapin et al., 2013), such as student turn and talks, revoicing, or offering extended think time.<br>● A teacher may consider the lived experiences, identities, and funds of knowledge (Moll et al., 1992) of students to contextualize the mathematical problem.<br>● A teacher may draw upon past mathematical content experiences or mathematical backgrounds in framing or reframing the problem. |
| When a student is persevering through problem solving in the mathematics experience... | ● A teacher might feel a pressure to move the mathematics along more quickly and guide students to the correct answer.<br>● A teacher might feel excited to continue to push students to think deeper about the mathematics, as the students are effectively engaged and having critical mathematical insights. | ● A teacher may take a "Teacher Time Out" (Gibbons et al., 2017) to determine how to respond to student thinking in the lesson.<br>● A teacher may humanize the experience by making the shared productive struggle of both student and teacher known.<br>● A teacher may discover a new line of questioning to drive student thinking in the midst of their own teacher productive struggle. |

## Why Persist with Productive Struggle?

Moloney recognized that despite the apprehensions that arise when facilitating students' productive struggle, her belief in the benefits of facilitating student productive struggle, as well as her motivation to challenge the dominant narratives in schools about which students have access to rich mathematics that facilitates productive struggle, outweighed these fears. She continued offering her students mathematics that facilitated productive struggle because she saw that they were able to engage in content in new and unique ways, and both Moloney and her students felt accomplished when they were able to persevere through a struggle. Student productive struggle in Moloney's classroom also served to foster a stronger community bond among students as they worked together to engage in challenging mathematics. Moloney was also aware that while she was fearful of using students during *the experimental phase*, when attempting new teaching practices, her students deserved her trust that they could accomplish big things in the mathematics space. Moloney has seen that her students think more critically and engage with the mathematics more deeply when they are given opportunities to productively struggle, and while this may not be the way that the curriculum was designed, she continues to engage in this work.

## What's Next?

One suggestion for unpacking productive struggling in your own context is to read this article with a colleague or colleagues and compare which feelings you may have experienced while facilitating productive struggle for your students. In starting to name possible apprehensions, it might help to take a step together to facilitate an experience for students that promotes productive struggle. Another suggestion is to anticipate feelings while planning a lesson that includes productive struggle. Prior to introducing a lesson, generate lists about what your students might do, feel, or say when they are experiencing productive struggle during the lesson, and consider what you might do, feel, or say while facilitating it. Thinking about what productive struggle might look and feel like in your context may better support your ability to persist in the facilitation of it. As educators, we must strive to embrace the power of appropriate struggle as an opportunity for learning and growth for both students and educators. Our students can persist in their productive struggle of the mathematics content understanding if we trust them in the productive struggle and trust ourselves to persist in our facilitation of it.

*This work was partially supported by a Seed Grant Award from Rowan University.*

**Katherine Baker** (kbaker17@elon.edu) is an Associate Professor of Education at Elon University where she supports prospective teachers in their mathematics education and instruction. She collaborates with prospective teachers, practicing teachers, and teacher educators to explore students' mathematical thinking and how to use that thinking in instructional decision making.

**Madison Clark** (mclark36@elon.edu), Elon University Class of 2021, was an Honors Fellow and studied Elementary Education. She conducted undergraduate research in Teaching Math Outside and Teacher Productive Struggle with Dr. Baker. After graduating she moved to Nashville, TN where she taught Sixth Grade mathematics. Madison is currently living and teaching in Spain.

**Danielle Moloney Gallagher** (dmolone@ncsu.edu) is a former fifth grade mathematics and science teacher. She is currently pursuing her doctorate in Teacher Education and Learning Sciences at North Carolina State University.

## References

Baker, K., Jessup, N. A., Jacobs, V. R., Empson, S. B., & Case, J. (2020). Productive struggle in action. *Mathematics Teacher: Learning and Teaching PK-12*, *113*(5), 361-367.

Ball, D.L, Thames, M.H. & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*(5), 389-407.

Carpenter, T. P., Fennema, E., Franke, M. L., Levi, L., & Empson, S. B. (2014). *Children's mathematics: Cognitively guided instruction* (2nd ed.). Heinemann.

Chao, T., Murray, E., & Gutiérrez, R. (2014). What are classroom practices that support equity-based mathematics teaching? A research brief. National Council of Teachers of Mathematics.

Chapin, S. H., O'Connor, C., & Anderson, N. C. (2013). *Classroom discussions: Using math talk to help students learn, Grades K-6*. (3rd ed.) Math Solutions.

Drake, C., Land, T. J., Bartell, T. G., Aguirre, J. M., Foote, M. Q., McDuffie, A. R., & Turner, E. E. (2015). Three strategies for opening curriculum spaces. *Teaching Children Mathematics*, *21*(6), 346-353.

Gibbons, L. K., Kazemi, E., Hintz, A., & Hartmann, E. (2017). Teacher time out: Educators learning together in and through practice. *NCSM Journal of Mathematics Education Leadership*, *18*(2), 28-46.

Gutiérrez, R. (2009). Framing equity: Helping students "play the game" and "change the game." *Teaching for Excellence and Equity in Mathematics ,1(1),* 4-8.

Gutiérrez, R. (2010). The sociopolitical turn in mathematics education. *Journal for Research in Mathematics Education, 44*(1), 37-68.

Hiebert, J., & Grouws, D. A. (2007). The effects of classroom mathematics teaching on students' learning. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 371-404). Information Age Publishing.

Lynch, S. D., Hunt, J. H., & Lewis, K. E. (2018). Productive struggle for all: Differentiated instruction. *Mathematics Teaching in the Middle School*, *23*(4), 194-201.

Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into Practice, 31*(2), 132-141.

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematical success for all.* NCTM.

Skinner, A., Louie, N., & Baldinger, E. M. (2019). Learning to see students' mathematical strengths. *Teaching Children Mathematics*, *25*(6), 338-345.

Smith, M. S. & Stein, M. K. (2018). *5 Practices for orchestrating productive mathematics discussion*. NCTM.

Stein, M. K., & Smith, M. S. (1998). Mathematical tasks as a framework for reflection: From research to practice. *Mathematics Teaching in the Middle School*, *3*(4), 268-275.

The Math Learning Center. (2016). *Bridges in Mathematics Grade 5.* The Math Learning Center.

Wilson, J., Nazemi, M., Jackson, K., & Wilhelm, A. G. (2019). Investigating teaching in conceptually oriented mathematics classrooms characterized by African American student success. *Journal for Research in Mathematics Education*, *50*(4), 362-400.

Yeh, C., & Otis, B. M. (2019). Mathematics for whom: Reframing and humanizing mathematics. *Occasional Paper Series*, *2019*(41), 8.

ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 27, NO. 4, 118-140

ICRSME
International Consortium for Research in
Science & Mathematics Education

# Interdisciplinary Teaching: Solving Real-Life Physics Problems through Mathematical Modelling

Demet Baran-Bulut
*Recep Tayyip Erdogan University*

Tuğba Yüksel
*Recep Tayyip Erdogan University*

## ABSTRACT

Physics and mathematics represent closely intertwined fields, wherein physicists employ mathematical modeling to address intricate problems. A challenge encountered by physicists involves bridging conceptual understanding with mathematical equations, a task that educators can facilitate by supporting students in navigating these two realms of comprehension. Mathematical modeling has exhibited potential in assisting students in recognizing that the domains of physics and mathematics are not insurmountably complex. The present study investigated the capability of science preservice teachers (PSTs) enrolled in an introductory physics course to resolve real-life physics problems by adhering to the stages of mathematical modeling. Data were gathered through the Interdisciplinary Modeling Eliciting Activity, allowing students to collaboratively discuss problems and devise solutions. Analysis was executed utilizing the interdisciplinary mathematical modeling (IMM) framework. The activity provided an inclusive platform for all students, including those who typically remained reticent during classes, to actively participate in group discussions and articulate their ideas. Despite the successful navigation of the problem with the guidance of the IMM framework, groups encountered challenges in certain tasks such as parsing/grouping and generating a context. Overall, the study demonstrated promise in augmenting PSTs' enthusiasm for physics and enhancing their comprehension of mathematical models within the discipline.

*Keywords:* interdisciplinary mathematical modelling (IMM); science preservice teachers; linear motion

## Introduction

Every teacher should possess subject-specific and general competencies for the teaching profession, encompassing knowledge, skills, and attitudes to support their development in their respective fields. Among the subject-specific competencies applicable to science teachers, scientific, technological, and social development competences are essential. The ability to develop students' problem-solving skills is considered a crucial competence expected from teachers, particularly science educators. Therefore, science teachers are expected to impart awareness about potential solutions to their students' daily life problems, which, in turn, necessitates the teachers to possess such skills themselves. Mathematical modeling can provide valuable experience in the development of this competence.

From a mathematical perspective, mathematical modeling plays a significant role in generating solutions to problems faced in daily life. Generally, mathematical modeling includes two subprocesses: developing mathematical solutions and interpreting these mathematical solutions in a real-life context (Borromeo-Ferri, 2006; Lesh & Doerr, 2003). Mathematical models are tools that contain abstractly taught mathematical concepts used to explain real-life situations. For example, the trigonometric functions used in selecting seats to obtain the best screen view in a cinema are mathematical models. Similarly, a watch repairman who notices that the pendulum of a pendulum clock swings slower than it should understands concepts such as gravitational acceleration, period, and function, and uses this information during repair, which is an example of mathematical models.

Mathematical modeling is the process of mathematically expressing a real-life situation that poses a problem and explaining it using mathematical models (Berry & Houston, 1995). However, teaching and learning mathematical modeling can be explained by the formation of different understandings beyond this perspective. Modeling can be classified based on its intended use and the approaches used to handle mathematical modeling in the classroom. Mathematical modeling can be adopted as a tool when used to teach a concept and as an objective when used to foster mathematical proficiency (Julie & Mudaly, 2007; Niss et al., 2007). In this study, mathematical modeling is viewed as a tool for teaching the concept of linear motion while also serving as an objective to assess student competencies in the mathematical component of physics problems. The emphasis is on giving students the ability to create mathematical models and develop mathematical modeling competencies. Through the modeling activity used in this study, students were expected to accomplish the interdisciplinary mathematical modeling cycle. Moreover, as part of this iterative process, they were required to develop mathematical models that can be applied to problems involving physics concepts.

## Interdisciplinary Mathematical Modelling (IMM)

Mathematical modelling activities require interdisciplinary connections since the problems represent real-life situations, which often involve a wealth of complications that require the application of various sciences to understand. IMM is a perspective that involves the simultaneous employment of multiple disciplines (Dogan et al., 2018). IMM encompasses the development of solutions to real-life problems through models with the help of both mathematics and science. Within the scope of IMM, a wide range of disciplines can be combined, or merely be a combination of two disciplines. Figure 1 illustrates the IMM process that involves mathematics and science.

**Figure 1**

*Interdisciplinary Mathematical Modelling (IMM) process (Dogan et al., 2018)*

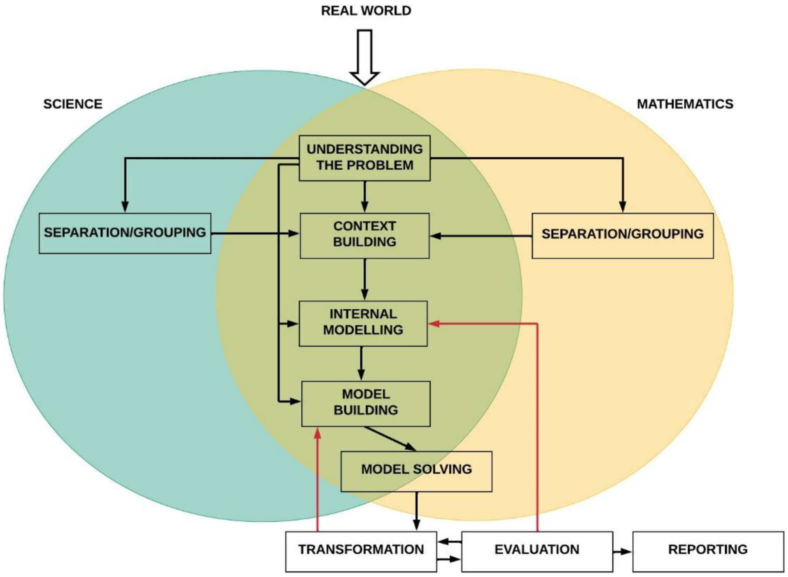


Figure 1 illustrates that the IMM process commences in the context of real-life situations. The following sections and Table 1 provide a description of each stage.

**Table 1**

*IMM Stages and Example of Expected Outcomes*

| **IMM Stages** | **Example of expected outcomes** |
|---|---|
| In this step, problem solvers are expected to articulate their understanding of the problem, transitioning from the real world to the common ground shared by mathematics and science. | They should be able to express key problem details, such as the velocity of the second car approaching at 80 km/h and the placement of the reflector at a distance of 30 meters behind the broken vehicle. |
| Separation/grouping: In this step, participants should associate the concepts involved in the problem with the relevant disciplines, mathematics and physics, and grasp them through mental processing. | They should be able to apply equations such as x=vt and represent them through graphs. |
| Context building: Problem-solvers should observe the interconnections between concepts, form linkages, and make necessary associations. This stage may not occur simultaneously throughout the entire problem-solving process. | At this stage, problem solvers should be able to plan to draw a velocity-time graph by re-associating categorized concepts with individual disciplines such as mathematics and physics. |
| Internal modelling: Problem solvers should organize available data, produce ideas and assumptions, and engage in required planning to lead them towards a solution. | They should be able to make assumptions, such as that the area under the velocity-time graph can help calculate the distance traveled by the vehicle. |
| Model building: At this stage, the internal model is translated into a mathematical model by formulating the problem in mathematical terms and constructing a model that leads to the solution. | Problem solvers are expected to produce the solution using the velocity-time graph as a mathematical model. |
| Model solving: Once the model is established, the problem solver proceeds with the mathematical solution of the model with the help of his previous mathematical knowledge. Even though this stage mostly occurs in the domain of mathematics, given the extensive use of mathematical structures and operations involved, the problem solver takes advantage of scientific knowledge as well. | At this stage, problem solvers are expected to apply their mathematical knowledge to calculate the area of the triangle and rectangle to solve the problem. |
| Transformation: At this stage, the problem solvers think about the real-life consequences of the solution developed through the application of the model. | At this stage, problem solvers are expected to be able to think about the solution by using the velocity-time graph, which is acceptable for similar situations in real life, etc. |
| Evaluation: This stage entails testing the real-life applicability and accuracy of the solution. | At this stage, problem solvers are expected to assess the solution using the velocity-time graph to determine its validity for similar situations. |
| Reporting: When the model is deemed usable in real-life, a report is prepared detailing the mathematical model and its components. | At this stage, problem solvers are expected to be able to decide the solution by discussing the velocity-time graph that is usable in a real-life situation, reporting the details of the mathematical model, etc. |

According to Dogan et al. (2018), the theoretical framework of the IMM process allows for a flexible transition between its stages. For example, an individual who cannot find a real-life equivalent to the developed model, or realizes that it cannot be applied to real-life, can still move from the transformation or evaluation stage to the model building stage or to higher-level stages such as understanding the problem. The degree of flexibility provided also means that some stages can be skipped for progress to be achieved. For instance, one can proceed directly to the mental model building stage without separating or grouping the concepts with reference to individual disciplines in the grasping the problem stage.

IMM can be viewed as an effective means of establishing interdisciplinary connections. In fact, a study conducted with mathematics and science teachers found that activities structured around IMM enabled the coverage of different disciplines simultaneously (Gurbuz et al., 2018). Additionally, the same study observed that mathematical modeling was appropriate for associating various disciplines (English, 2015), and the IMM approach that emerged from this feature suggests that the standards belonging to different disciplines can be taught together (Dogan et al., 2018).

## Interdisciplinary Component of the IMM: In the Context of Physics and Mathematics

Mathematics is a discipline that has extensive associations with a wide range of fields, making it a useful tool for various sciences. Among these, physics is a field where mathematics is used most extensively (Redish & Gupta, 2010). While some topics in physics are taught with less emphasis on mathematics, acceleration is an example of a topic that is embedded within mathematical formulations (Basson, 2002).

Teaching various disciplines in connection with each other has been shown to help learners develop solutions more easily for the problems they face in daily life (Carrejo & Marshall, 2007; Prins et al., 2009). Additionally, courses emphasizing the connections between various disciplines are thought to pique students' interest and motivation (Dervisoglu & Soran, 2003; Lyublinskaya, 2006; Ogunsola-Bandele, 1996). Several studies have highlighted the importance of teaching mathematics and physics in conjunction, providing a more solid foundation for concepts and promoting effective learning (Erickson, 2006; Munier & Merle, 2009; Redish & Gupta, 2010). To this end, the literature is rich in studies attesting to the effective use of physics models in teaching mathematics and geometry, which can support meaningful learning by rendering abstract concepts more understandable (Bing & Redish, 2009; Munier & Merle, 2009). Conversely, using mathematical models to teach physics concepts has been found to produce positive results, such as developing positive attitudes towards physics classes and facilitating the learning of challenging concepts (Marshall & Carrejo, 2008; Takaoglu, 2015).

However, some topics in physics are related to real-life cases, and students may already have an accurate or inaccurate understanding of these concepts. These concepts may be easier or harder to teach, depending on students' existing knowledge and misconceptions. Motion is an example of a topic that poses such challenges (Aksit & Wiebe, 2020; Bani-Salameh, 2016). Students may experience difficulties understanding concepts such as velocity, position, and acceleration, which can be misleadingly similar but essentially different (Bani-Salameh, 2016). Additionally, interpreting negative and positive acceleration, along with drawing and interpreting velocity-time and position-time graphs, are among the challenges that students may encounter (Goldberg & Anderson, 1989; McDermott et al., 1987; Nemirovsky & Rubin, 1992; Pendrill & Ouattara, 2017). The literature has addressed these issues, providing insights into how to teach such concepts more effectively.

Certain fundamental concepts of classical mechanics serve as the cornerstone of science and physics courses taught in primary and secondary schools (Basson, 2002), with their implications being noticeable in everyday life (Singh & Schunn, 2009). Linear motion and acceleration are among these concepts. As these concepts have implications in everyday life, students often hold normative and/or non-normative ideas about them (Clement, 1982; DiSessa, 1982; Halloun & Hestenes, 1985). Non-normative ideas, based on common sense rather than scientific principles, cause confusion and impede the learning experience for students, particularly when it comes to the concepts of acceleration and velocity. Therefore, during the teaching process, concepts like acceleration should be presented in real-life contexts through clear problem situations and with clear mathematical foundations. Based on this view, the current study proposes a novel approach to teaching physics concepts (particularly linear motion and acceleration) related to real-life cases using mathematical modeling, as opposed to conventional approaches to teaching physics.

Most discussions on the positive effects of interdisciplinary associations reference the significant obstacles teachers face in interdisciplinary teaching processes (Morrison & McDuffie, 2009; Weinberg & Sample McMeeking, 2017). The lack of adequate resources or materials, or the teachers' lack of experience in establishing associations between their own discipline and other disciplines, forces them to focus primarily on their trained discipline (Bybee, 2010). Additionally, students often find the integration of multiple disciplines to be complicated and overwhelming (Dervisoglu & Soran, 2003; Ogunsola-Bandele, 1996). Therefore, teachers require a new, simpler method that can be applied in the context of interdisciplinary integrations. Whereas students would appreciate a new approach to aid in understanding concepts and making the learning process enjoyable through the use of various disciplines in an integrated and interconnected manner. In this regard, the use of mathematical modeling to teach challenging physics concepts stands out as a potentially helpful method.

## Research Purpose and Questions

In light of current research, it can be concluded that the use of IMM clearly aids in increasing competence and knowledge levels across all disciplines by fostering comprehensive interdisciplinary connections. Previous studies conducted with science preservice teachers (PSTs) have indicated that physics courses are often taught in a discipline-based manner with relatively low levels of success (Michaluk et al., 2018; Pollock, 2006). Thus, the present study aims to investigate problem-solving processes through an IMM activity requiring the combined use of mathematics and physics by PSTs enrolled in the Science Teaching Program.

The evaluation of PSTs' modelling skills applicable to problem-solving processes is critical in terms of establishing their subject-specific competencies and problem-solving skills necessary for teaching in real classrooms. Developing mathematical modelling abilities in PSTs is essential since they will eventually teach science from an interdisciplinary perspective to middle school students. Moreover, instilling in-service and PSTs with sufficient mathematical modelling abilities, as well as executing modelling assignments in the classroom, is essential for the efficient integration of mathematical modelling into science education programs at all levels.

Therefore, this study focuses on PSTs' completion of an IMM task. The research questions guiding this study are:

1. To what extent do science PSTs solve a real-life physics problem by following the stages of mathematical modelling?
2. Which stages of IMM pose the most significant challenges for PSTs to complete during the mathematical modelling process?

## Methodology

### Research Method

The present study utilized a collective case study research approach, which is a qualitative research methodology that allows for an in-depth review of a pre-defined system. According to

Creswell (2007), case studies are typically conducted on a single person or a group of people, an event, or other entity that is less well-defined than a single person. In this study, we examined the real-life physics problem-solving processes of two groups of science PSTs and identified how they progressed through the stages of interdisciplinary mathematical modelling. To achieve this goal, we conducted an articulated analysis of each case's discussions and decisions. Therefore, we designed our data collection procedure based on multiple case studies.

### Participants

The study group for this research comprises six PSTs, consisting of four females and two males. These PSTs were enrolled in an introductory physics course, which forms part of a science teaching program offered at a university in Türkiye. As the study was extracurricular, participants were entirely voluntary. This study particularly focused on science PSTs, as they constitute a fundamental element of the learning environment. The research aimed to examine the problem-solving process of PSTs, whereby their interpretation of the problem setting was influenced by real-world information. PSTs are required to acquire mathematical modelling skills, since they will eventually teach science from an interdisciplinary perspective to middle school students.

### Context of The Study

The PSTs in the study were divided into two groups based on their performance levels on the midterm exam scores. This was done to ensure that the students were evenly distributed among the groups with respect to their high, medium, and low scores. Since most of the questions on the midterm exam were related to linear motion and acceleration, the scores served as a reliable indicator of their preparedness. Previous research studies have emphasized the importance of group work in the effective implementation of mathematical modelling activities (Antonius et al., 2007; Erbas et al., 2016). Therefore, the present study was designed to incorporate a group activity centered around modelling, which required the participants to work collaboratively.

### The Practice Exercise

Before commencing the modeling activity, the participants received an introduction to mathematical modeling. To enhance their understanding of the process, the *Water Tank* activity designed by Erbas et al. (2016) was implemented, encompassing various physics concepts. In this activity, the pre-service teachers (PSTs) collaborated in groups to formulate a mathematical model addressing a problem related to creating an altitude-volume graph. This graph aimed to assist in developing an animation for three differently shaped water tanks. The participants were tasked with utilizing mathematical knowledge, including functions, derivatives, and graphical representation.

Engaging in this mathematical modeling practice facilitated communication within the groups and provided the participants with an experiential understanding of how to navigate through the stages of the Instructional Model for Mathematics (IMM). Following the allocation of adequate time to the PSTs, we conducted discussions with all groups, outlining the tasks required for each step of the Water Tank exercise and demonstrating approaches to the various phases.

### The IMM Activity

After ensuring the participants' comprehension of mathematical modeling strategies, we introduced the *Braking Distance of a Car* activity developed by Erbas et al. (2016) to assess their group discussions and problem-solving strategies for addressing a real-life problem. This activity encapsulates a real-world context of linear motion as a physics concept and linear functions as a mathematical context. To derive a solution for the activity, pre-service teachers (PSTs) were required to possess a comprehensive understanding of various skills, including the analysis of linear motion, the interpretation of the velocity-time graph, the determination of the quantity of motion and acceleration, and the application of mathematically correct operations throughout the process.

## Data Collection Instruments and Process

To gather data, we encouraged the participants to explain their ideas and express their opinions aloud while working on a small whiteboard and worksheet. The worksheets were designed based on the steps of IMM related to the activity, and the PSTs were required to explicitly describe and justify the answers they generated at each step of their worksheets. The group conversations were recorded using both sound recorders and video cameras. Our data consisted of their work on the worksheet and whiteboard solutions, as well as their open discussions.

The activity lasted approximately 45 minutes, and the researchers visited each group every five minutes to observe their group work and discussions. If groups had questions about the stages or the problem, the researchers guided them to find the answer on their own. After completing all the stages, the groups were given five minutes to present their solutions and answer questions from other groups. Finally, the discussions between the groups were followed by the presentation of the formal solution to the problem given by the researchers. The process flow for the modeling activity is presented in Figure 2.

**Figure 2**

*Process Flow Chart for IMM Activity*

## Data Analysis

We conducted a content analysis of the data collected from worksheets, audio recordings, and video recordings in this study. Content analysis is a scientific method for examining communication content by analyzing the meaning, circumstances, and intentions expressed in messages. To effectively conduct content analysis, it is necessary to narrow down the data to concepts that define the problem under study (Elo & Kyngäs, 2008). The first step in our study was to transcribe the data obtained from video and audio recordings (Berelson, 1952).

Subsequently, two researchers independently read all the data and attempted to comprehend the process as a whole. Following this, the researchers analyzed the students' worksheets using the IMM stages presented in Figure 1. The data were analyzed and categorized according to the individual stages of the IMM framework. Our analysis focused on revealing how each group's discussion and the mathematical model development process evolved in each stage.

After the initial individual analysis, the two researchers discussed the coding of the content until 80% of their codes were in agreement. Quotations from the solutions developed by the groups and the remarks they made are presented below to support the results of the analysis. Additionally, images are included to reinforce the presentation of the findings.

# Findings

This section furnishes an analysis of the process undergone by participants during the *Braking Distance* activity. It delineates the process of each group individually, taking into account the stages inherent in the IMM (Interactive Multimedia Module) process. To streamline this section, each participating Preservice Teacher (PST) has been identified with a code number signifying both the group number and the order of the students within the group. For example, the second member of group 1 is denoted by the code number G1S2.

## The IMM Process of Group 1 Through the "Braking Distance of a Car" Activity

This section presents a detailed analysis of the problem-solving process of Group 1, which is broken down into stages based on the IMM process. The participating PSTs were identified by a code number that denotes the group number and the order of the students in the group. For instance, the 2nd member of Group 1 is referred to as G1S2.

The first stage of the IMM process is Understanding the Problem, and Group 1 commenced this stage by reading and interpreting the problem. During this process,

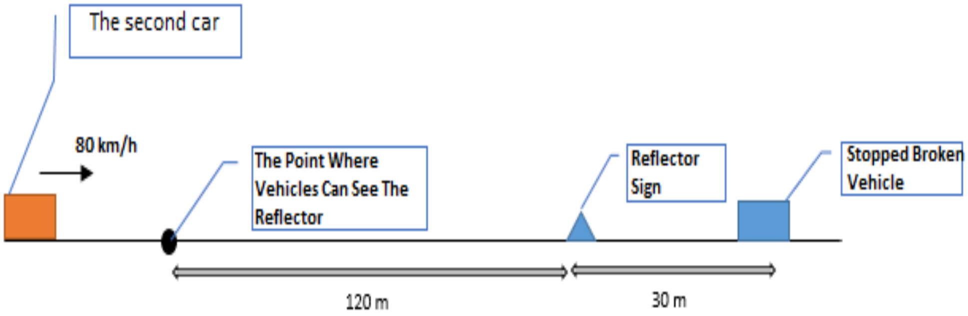
> G1S1: … *I call it nonsense* [refers to the second drivers' claim]*! There are no visible tire marks on the road. And the surveillance does not allow us to see the point where the second car hit the brakes. But we are still expected to shed some light on how the accident happened.*

The statement "I call it nonsense!" suggests that the student does not agree with the second driver's statement. Later on, in the Transformation stage for Group 1, the same student made another statement that indicated a generalization based on an incorrect piece of knowledge from their daily life. However, the other members of the group did not raise any objections regarding this point.

Following the initial statement, the group proceeded to draw a visual representation of the problem's provided input, as depicted in Figure 3. This visual representation helped the group members to understand the problem more clearly and aided them in formulating a solution.

**Figure 3**

*Group 1 Created a Model of the Drawing to Assist Grasping the Challenge.*



During the conversation that ensued while creating the drawing, the group members asserted that the second car was approaching at a velocity of 80 km/h and that the reflector was positioned 30 meters behind the broken-down car. They further claimed that the second car noticed the reflector at a distance of 120 meters from it, but there were no tire marks on the road. It is apparent that the group misinterpreted the visibility distance, mistaking it for the distance from the broken car instead of the reflector, which resulted in an incorrect estimation of the braking distance (120 m). Despite the idea originating from G1S1, none of the other group members voiced any objections and accepted the notion. Apart from this misinterpretation, Group 1 did not have any further issues in the "Understanding the Problem" stage. The remainder of the conversation held by Group 1 is presented below.

> G1S1: *The second driver claims to have hit the brakes as soon as he saw the scene. But that is only his statement. That statement can be wrong as well.*
> G1S2: *If he hit the brakes, the car would have stopped anyway.*
> G1S1: *But he couldn't stop. And also, there are no tire (brake) marks on the pavement.*
> G1S3: *We can calculate the change in velocity at 2-second intervals.*
> G1S2: *The change in velocity is already apparent on the table.*

The presented case highlights the importance of accurately understanding the problem to come up with an accurate solution. However, the group's prejudices towards the second driver's statements as inaccurate still persisted.

### *Separation/Grouping*

This stage required the group members to associate the concepts involved in the problem with the disciplines of mathematics and physics. An excerpt of the conversation that took place during this stage is presented below.

> G1S1: *We can use the formula x=vt. We can calculate it at 2-second intervals. In other words, we will increase the time in 2-second increments.*
> G1S3: *Wouldn't we have different results then? Shouldn't we be drawing a graph?*
> G1S3: *I guess so. What would the slope of the graph represent? Area under the line?*
> G1S1: *This velocity-time graph... But the velocity is not increasing in a uniform linear manner.*
> G1S3: *It did not increase because the driver hit the brakes.*
> G1S1: *Multiplying v by t would yield x, which is the distance. Multiplying the base by the height gives us the area of the triangle... So, what does it mean by stating 2-second intervals?*

At this stage, Group 1 was able to spot the method of multiplying velocity and time to calculate the distance the vehicle covered before it stopped and to calculate the distance with reference to the area under the velocity-time graph. However, they were still unable to accurately interpret the data provided on the velocity-time table with 2-second intervals and realize that it actually represented linear motion. As they found out, by multiplying the velocity by time during the IMM activity, they were able to spot the complementary aspects of the formula associated with both mathematics and physics.

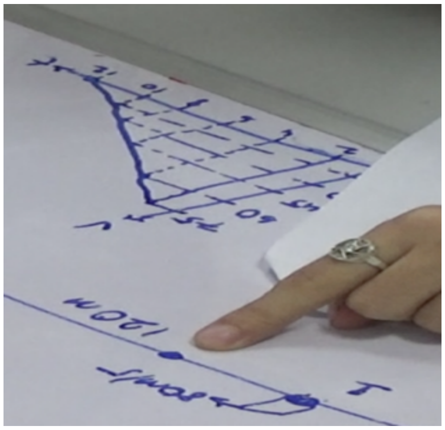
Moreover, while interpreting the graph, they were able to step into the domain of mathematics with reference to concepts such as the area of a triangle. However, in the separation/grouping stage, Group 1 failed to assign meaning to the uniform-linear motion concept in the field of physics. This observation may attest to their inability to establish adequate associations between the concepts involved in the problem and the relevant disciplines, as well as their failure to complete the separation/grouping stage.

### *Context Building*

Group 1 was observed to associate the relevant concepts with the applicable discipline but failed to group the linear motion in the previous stage. In the subsequent stages of the process, Group 1 embraced the idea of drawing a velocity-time graph through the re-association of the concepts they categorized with respect to individual disciplines (mathematics vs. physics). See Figure 4 for this information.

**Figure 4**

*Velocity-time graph by Group 1*



This is a testament to moving to the internal model-building stage. For example, there were no explicit references to the phase of identifying the context in Group 1's interactions. Although Group 1 evaluated the data on the problem in the context of two separate disciplines in the separation/grouping stage, they moved on to the next stage without interpreting the data they obtained at this stage in the context of the common field of both disciplines.

### *Internal Model Building*

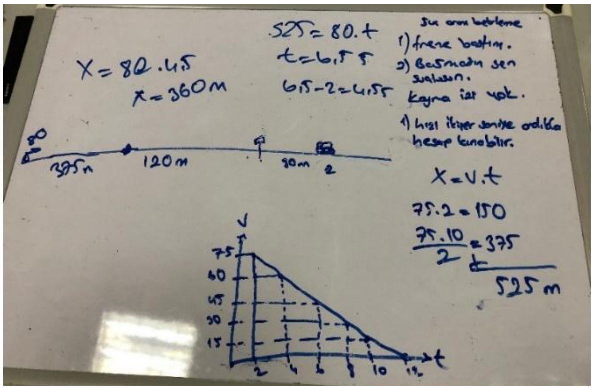
Regarding this stage, Group 1 made mistaken assumptions early in the process. As they interpreted the data available, they were observed to embrace a mistaken perspective built around the maxim "*you are to blame as you did not hit the brakes*", after reading the statement by the second driver, who said he was unable to stop even though he hit the brakes as soon as he saw the reflector. However, later on, through a better analysis of the data presented in the problem, the group arrived at the idea to draw a velocity-time graph to calculate the braking distance of the vehicle. In doing so, they were able to come up with an accurate representation of the straight linear movement as well as calculate the distance covered by the vehicle by calculating the area under the velocity-time graph.

### *Model Building*

The graph is the mathematical form corresponding to the model that Group 1 constructed in their minds with respect to the movement of the vehicle. In other words, at this stage, the solution will be produced by using the velocity-time graph as a mathematical model. As shown in Figure 5, the group has apparently developed the x=vt formula to present the area below the graph with a view to calculating the distance as another mathematical model application.

**Figure 5**

*Solution by Group 1*



Both models are accurate and could be used in the solution of the present problem. At this stage, Group 1 has achieved success by using suitable models for the problem. However, even though Group 1 came up with the correct models, they included data items with different units in the same calculation. For instance, the y-axis on the graph shown in the image shows the velocity, while the x-axis represents time. Yet, the data shown on the x-axis is in seconds, while the data shown on the y-axis is presented in km/h. And doing so led to an inaccurate solution. As the deceleration of the second vehicle is presented on a time scale of seconds, they should have used m/s as the unit of velocity, rather than km/h as presented in the problem and applied the necessary conversion.

### *Model Solving*

A glance at the solution presented in Figure 5 and the dialogue recited above reveals that Group 1 came up with the correct model (a velocity-time graph) and used their mathematical knowledge about the calculation of the area of the triangle and the rectangle to solve the problem. The transcript of the dialogue that Group 1 had on the way towards a solution is presented below.

> G1S3: [Once the graph was drawn, let's calculate the area below the graph.] *And then we calculate the distance covered.*
> G1S1: *Then we should multiply 75 by 12 and divide the result by 2* [trying to come up with a solution based on the area of the triangle].
> G1S3: *No, see, this is a rectangle.*
> G1S1: *Actually, it's a trapezoid. Take a look here! Bottom and top... Bottom plus the top...*
> G1S3: *I don't see why you are trying so hard. Divide the graph into two. Make this section a rectangle. And calculate the area of the triangle here.*
> G1S1: *That is one way to go. The trapezoid provides an even more direct route. 75 times 2 equals 150 here. And this part is 75 times 10, divided by 2.*
> G1S2: *So it's 375?*

During the discussions within the group, G1S1 stated that the graph looked like a trapezoid. Yet, it is noteworthy that G1S3 insisted on going with the calculation of the area of the rectangle and the triangle since she said that calculating the area of the trapezoid was difficult. Based on this statement, we can reach the conclusion that the students had adequate knowledge of rather conventional forms, such as triangles and rectangles, but did not know how to calculate the area of a trapezoid and they were able to associate the graphical model with a mathematical model to interpret linear motion. Additionally, when we look at the graph produced by Group 1, it reveals that the velocity was expressed in km/h and the required conversion was not applied. Therefore, the solution they came up with was incorrect, even though the models they developed were correct.

### *Transformation*

At this stage, Group 1 started to relate the real-life consequences of the solution developed via the model. Group 1 had the following dialogue regarding this stage:

> G1S1: *So, if the distance is 525 meters, what this guy says is not accurate. 525 minus 150 equals 375 meters. So, the driver noticed the other car and hit the brakes 375 meters before the vehicle. Had he really done so, why do we have this gap of 150 meters? So, looking at this, we understand that he did not hit the brakes as soon as he saw the car. The distance is 525 meters.*
>
> G1S3: *Maybe it is the driver of the first car who is not providing the correct information. How do you know that?*
>
> G1S1: *That man did not engage in any action. All he did was stop on the road. And he placed that thing as a safety measure.*
>
> G1S2: *In any case, the car that hits the other one, rather than the one that had stopped, is always deemed the faulty party.*

According to the results Group 1 reached through the interpretation of the incorrect solution they came up with, they commented that the driver of the second car is to blame. So, when they began to think about the real-life consequences of the solution they developed, G1S2 came up with the comment, "*In any case, the car that hits the other one, rather than the one that has stopped, is deemed the faulty party*". This can be considered an incomplete assessment of the real-life picture. According to the traffic rules, that comment can be applied only in cases where certain other requirements are met. Furthermore, the same student voiced the view that a car that hits another one from behind would always be considered the guilty party. G1S3, in turn, came up with the comment that the driver of the second car did not know how to drive the car as the actual reason for the accident in the real-life context. Such comments suggest that Group 1 failed at this stage.

### *Evaluation*

Group 1 had the most extensive discussions among other groups during the evaluation stage. They began with a quick return to the "understanding the problem" stage. They had the following conversation regarding that stage:

> G1S1: *Are we being asked how many seconds have passed? Are we supposed to find the second in which he applied the brakes?*
>
> G1S3: *We are going into a loop now.*
>
> G1S3: *The question is, at what point did he hit the brakes at this 150-meter distance? We just calculated the distance...*
>
> G1S2: *We calculated the distance he saw the reflector at.*

> G1S1: *I've got it here. The distance between the two vehicles when this one applied the brakes. It is shown in the camera footage. The distance from the time of hitting the brakes. Got it?*
>
> G1S3: *Nope. I still don't get it.*

Based on the preceding conversation, it is apparent that G1S3 encountered difficulties in comprehending the problem. Conversely, G1S1 made concerted efforts to decode the input provided in the problem to aid the other student's understanding. Eventually, G1S3 expressed comprehension by stating, "I see." Subsequently, the group members deliberated on the solutions they formulated during the problem-solving phase. However, the group failed to reach a consensus and resumed working on the solution. Furthermore, the group members employed mathematical elements based on disparate units (km/h vs m/s) in the same calculation. Although they arrived at a mathematically correct solution due to a fortuitous occurrence, they were able to make the correct determination. At this stage, they abandoned their initial belief that the second vehicle was at fault and concluded that the car that came to a stop on the road was responsible.

## The Mathematical Modelling Process of Group 2 Through the "Braking Distance of a Car" Activity

In this section, we closely looked through the problem-solving process of Group 2 by breaking down the whole group work with reference to the IMM process.

### *Understanding the Problem*

In this stage, Group 2 tried to interpret the problem through the following statements:

> G2S1: *The broken vehicle was hit by another vehicle, even though the latter applied the brakes. Furthermore, the velocity was falling at 15 km/h every two seconds.*
>
> G2S2: *We need to find out the distance at which the second car hit the brakes.*

In its bid to understand the problem, Group 2 did not make sufficient references to any other data provided in the problem. This observation suggests that the requirements applicable to the solution of the problem were expressed in an incomplete form by Group 2. The PSTs were, arguably, unable to meet the required level of competence for this first stage of the problem-solving process.

### *Internal Model Building*

Group 2 did not engage in any acts applicable to the separation/grouping and context building stages. They skipped these stages and moved on directly to the internal model-building stage. At this stage, the PSTs were expected to organize the data they had with respect to the problem, come up with assumptions regarding the solution, and clearly express what was provided and required for the problem. The dialogue regarding this stage is transcribed below.

> G2S2: *Let's write the input we are provided. We have the table here, and we are told that the car hit the brakes at some distance, and we are also provided with the velocity of the vehicle. I mean, we have the velocity-time data for the vehicle that hits the other one. We know that its initial velocity was 80 km/h.*
>
> G2S1: *We should also note that its velocity fell by 15 km/h every 2 seconds after hitting the brakes.*

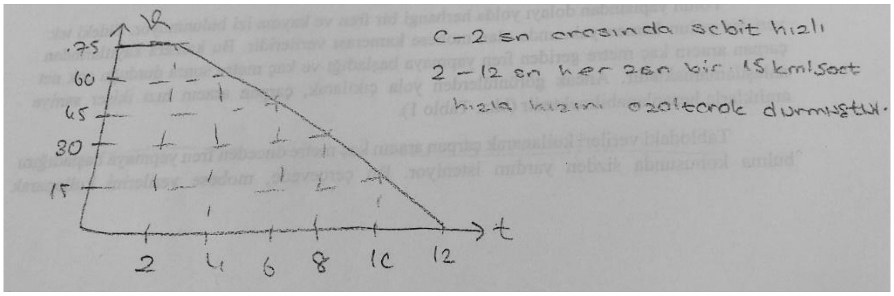
Group 2 was successful in naming one of the required variables with a specific reference to the velocity and time data. Nevertheless, they still fell short of the requirements by failing to come up with any assumptions. Group 2 accurately expressed the requirements but still failed to establish a connection between the data that was provided and the data that was required. Therefore, Group 2 cannot be considered the most effective at this stage.

### *Model Building*

At this stage, Group 2 opted for a velocity-time graph to help with the solution of the problem. See Figure 6 for the graph that Group 2 produced.

**Figure 6**

*The Mathematical Model that Group 2 Produced to Help With the Solution of the Problem*

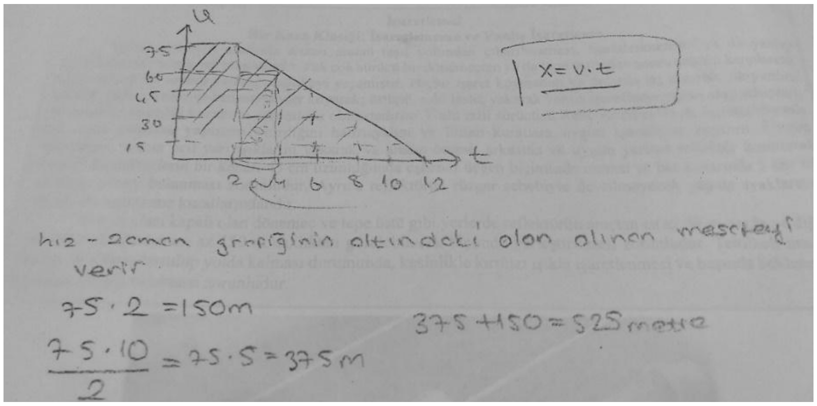


0-2 sn arasında sabit hızlı
2 – 12 sn her 2sn bir 15 km/saat
hızla hızını azaltarak durmuştur.

Upon examination of Figure 6, it is evident that Group 2 opted to employ a graph as a mathematical model, specifically a velocity-time graph for the second car. Although the selected mathematical models were deemed appropriate for the task at hand, they were constructed using an erroneous approach to the data. Notably, the data on the x-axis was presented in seconds, while the data on the y-axis was expressed in km/h. Additionally, this phase marked the first time that the PSTs referred to linear motion after constructing the graph. Following this, the group proceeded to solve the model and derived the subsequent solution, which was based on the x=vt formula. See Figure 7 for this information.

**Figure 7**

*Solution by Group 2*



$x = v \cdot t$

hız - zaman grafiğinin altındaki alan alınan mesafeyi verir

$75 \cdot 2 = 150m$

$\frac{75 \cdot 10}{2} = 75 \cdot 5 = 375m$

$375 + 150 = 525$ metre

The solution by Group 2 contains the accurate statement that "*the area below the velocity-time graph always represents the distance covered*." As they solved the problem, Group 2 employed the formula to calculate the area of triangles and rectangles and determined the area under the velocity-time graph. However, because the PSTs did not convert the km/h and m/s for uniformity in units while calculating the distance, they obtained the incorrect response.

### *Transformation*

At this stage, G2S1 voiced her opinion, ascribing the fault in the accident to the vehicle that hit the broken one. Her group mates also affirmed that view, and embraced the idea that the vehicle that hit the other from behind was at fault. However, this view was incorrect. As they later interpreted their mathematical solutions in a real-life context, they said, "*We saw that the vehicle decelerated smoothly after hitting the brakes. In daily life, we move with a given velocity, even if all we do is walk. And the distance we cover is a function of our velocity and the time we spend. So, in order to calculate the distance, we covered, we need to multiply the velocity with the time.*" Here, it is evident that the PSTs have been interpreting the models they used rather than the mathematical solution they produced. One can argue that if they really focused on interpreting the mathematical solution and the party was at fault, they could have noticed the shortcomings of their solution.

### *Evaluation*

At this stage, Group 2 said, "*We don't think we have been mistaken. Calculations about actual real-life cases also follow this route*" claiming that the solution they developed would lead to accurate results in real life as well. However, they did not engage in a discussion of the real-life applications of this case.

## Conclusions and Discussion

Linear motion, a foundational topic in physics, is typically instructed using traditional methods emphasizing formulas (Ropii et al., 2019). Unfortunately, this approach often results in the rote memorization of concepts and formulas, hindering meaningful learning and comprehension of the underlying principles (Reif, 1995). In this study, our objective was to address the challenges faced by students in a teacher education program taking an introductory physics course in grasping motion concepts and developing a mathematical understanding of physics. To achieve this goal, we employed an Interactive Multimedia (IMM) activity to analyze students' problem-solving processes and establish connections to real-life contexts.

Our focus on Pre-Service Teachers (PSTs) was twofold. Firstly, as future educators, they need to cultivate mathematical modeling skills to teach science from an interdisciplinary perspective. Secondly, many students perform poorly on exams due to a lack of understanding of fundamental concepts in physics and mathematics (Teodoro & Neves, 2011). Therefore, teaching physics concepts alongside their mathematical components has become increasingly important, particularly at the secondary level.

Upon analyzing the data based on the IMM stages, we observed a variety of common and unique issues at each stage. During the *understanding problem* stage, students frequently relied on their real-life experiences and common-sense knowledge to attribute meaning to the problem, resulting in misconceptions. This phenomenon is not uncommon, as physics concepts encountered in daily life can lead to non-normative ideas or models (Clement, 1982; DiSessa, 1982; Halloun & Hestenes, 1985). However, students should develop a scientific understanding of the problem and establish a connection with physics, rather than relying on preconceived notions.

Furthermore, existing misconceptions of linear motion among students impact their interpretation of the problem and, consequently, their ability to solve it. Motion, being a topic closely associated with students' preconceptions based on real-life experiences, is an easier topic to teach but also poses challenges in avoiding misconceptions (Bani-Salameh, 2016). Overall, our findings suggest that students require sufficient experience to interpret data realistically, highlighting the importance of teaching physics concepts in conjunction with their mathematical components.

In the *separation/grouping* stage, difficulties were observed among pre-service teachers (PSTs) in effectively linking mathematical and physical concepts within the context of the problem with their respective disciplines. Those who faced challenges in comprehending linear motion during the initial stages of problem understanding also encountered difficulties in connecting this idea with physics and categorization. However, some students did not explicitly reference this stage during the process. The accentuation of certain stages in the Integrating Mathematics and Physics (IMM) process may be attributed to insufficient experience within the study group. The third stage of the IMM process, context building, did not overtly occur in all groups, possibly due to the ineffective implementation of the preceding separation/grouping stage.

Gurbuz et al. (2018) reported that the separation/grouping and context-building stages were not explicitly performed by their participants, as they were experts in the physics topic and collaborated effectively. However, it cannot be conclusively asserted that the same reason led to the present study's participants bypassing these two stages. According to Chi et al. (1981), novices tend to categorize physics problems based on surface aspects, while professionals categorize them based on the physics ideas needed to solve them. Therefore, novice students may overlook the separation/grouping and context-building stages, which involve establishing connections between the concepts related to the relevant physics ideas. Moreover, despite the sequential listing of all stages of the IMM process on the provided worksheet, a flexible transition occurred between them, as affirmed by previous studies (Borromeo-Ferri, 2018; Doerr, 1997; Gurbuz et al., 2018).

The primary issue in the *internal model* stage concerned the limitations of the PSTs in developing assumptions. One of the main causes of these shortcomings was the students' misconceptions based on their daily life experiences. According to Aydin-Guc (2015), the students were only able to develop a limited number of new assumptions about the actual state of affairs through the mathematical modeling process. This lack of competence in assumption-making was linked to the students' insufficient knowledge and experience regarding the context of the activity. Similarly, when information about real-life cases was not explicitly provided in the problem context, individuals encountered difficulties in generating assumptions for mathematical modeling practices (Blum, 2011). Other studies have yielded similar findings regarding the development of this competency based on experience (Blum & Borromeo-Ferri, 2009; Bukova-Guzel, 2011). As the students regarded the input provided as assumptions, they experienced challenges in developing new ones. Consequently, one could argue that the perceived shortcomings were mainly due to the students' inability to comprehend the input as part of the problem. For instance, the students read and discussed the problem statement multiple times but still faced difficulties in developing a model. According to Maaß (2006), students often encounter difficulties in developing a model when they fail to comprehend the presented case through written statements.

Another issue observed in this stage was the students' inability to provide a scientific description of the motion of the vehicle that hit the other vehicle from behind. Consequently, they attempted to calculate the distance covered by the decelerating vehicle through the equation expressing the connection between velocity and time. This finding was consistent with Marshall and Carrejo's (2008) observations, as the students predominantly overlooked the change in the speed of the moving vehicle during the specified time frame, opting instead to solve the problem by applying the instantaneous velocity formula. At this stage, two groups failed to recall the linear motion formulas they had learned in class and were unable to apply them to the problem. Tuminaro and Redish (2004) assert that students' inability to apply their mathematical knowledge and skills in physics classes is a significant challenge in understanding physics. From this perspective, it is plausible to claim that the participants' mathematics performance levels were correlated with their physics performance levels in this study.

In the fifth stage of the study, it was observed that all participating groups chose applicable models, namely the velocity-time graph and the distance formula. However, it was found that simply drawing the velocity-time graph based on provided values did not necessarily lead the students to use the linear motion formula, rather than the instantaneous velocity formula. This finding is consistent with previous studies (McDermott et al., 1987; Nemirovsky & Rubin, 1992; Phage et al., 2017), which also reported difficulties in interpreting velocity-time graphs and building mathematical models based on them. Intra-group conversations suggested that students' limited mathematical skills contributed to their inability to interpret the graphics, as noted by Potgieter et al. (2008) and Scott (2012).

Although the students struggled with interpreting the graph on an individual basis, they were able to reach the correct conclusion that the area below the velocity-time graph represents displacement through group discussions and shared knowledge. However, the use of km/h instead of m/s as the unit of data during graph drawing led to an incorrect calculation of displacement and an inaccurate interpretation of the solution. Aydin-Guc (2015) observed that heuristic strategies, such as applying unit conversions, were used by students only in response to the researcher's suggestions. Moreover, the study found that guiding students to use a graph to represent one-dimensional motion through the stages of IMM led to a clearer understanding of the problem and facilitated problem-solving, as noted by Phage et al. (2017).

During the model-solving stage, it was observed that the students avoided using the formula to compute the trapezoid's area, as expected, instead dividing the area into smaller triangle and rectangle-shaped regions, which they were more comfortable with. Ozer-Keskin (2008) attributed this to students' inclination to utilize formulae they were familiar with. However, the utilization of incorrect units in the velocity-time graph, as highlighted in the model-building phase, resulted in incorrect outcomes at the end of the process. In the transformation stage, it was evident that students interpreted the models they utilized rather than the mathematical solution they derived. Group 1, for instance, connected their solution to a real-life context despite their incorrect assumptions. No group was observed to be successful in this stage. Other studies in literature have found that this stage is frequently disregarded or involves a superficial and inadequate consideration of the real-world implications of the solution (Hidiroglu et al., 2014).

During the evaluation stage, only one group (Group 1) engaged in a process to test the real-life applicability and accuracy of the solution. The literature is replete with studies indicating that students, confident in the accuracy of their solutions, do not feel the need to verify them, leading them to skip checking for the correctness of their solutions and calculation errors (Blum & Borromeo-Ferri, 2009; Maaß, 2006; Sen-Zeytun, 2013). Blum and Borromeo-Ferri (2009) and Sen-Zeytun (2013) note that this is due to students' conviction that the instructor's role is to verify the solutions. In conclusion, the utilization of the IMM stages to solve real-life physics problems proved to be an effective approach to engaging pre-service teachers' problem-solving skills. Although pre-service teachers typically find physics classes dull, they expressed enjoyment in applying their skills to tackle the problem at hand. Although the groups followed the recommended stages of IMM diligently, certain tasks such as parsing/grouping and generating context posed challenges. Nevertheless, the outcomes of this study present a promising avenue to stimulate and uphold pre-service teachers' interest in physics classes and their comprehension of the mathematical models used in physics.

## Limitations of the Study and Recommendations for Researchers and Instructors

Despite the overall positive effects of IMM activities on all groups, individual student performance plays a significant role in determining group performance levels. In this study, groups were intentionally formed to include high-, medium-, and low-performing students, but groups consisting of PSTs with higher levels of personal interest and motivation demonstrated greater diversity of ideas and more extensive discussions. A member of Group 1, who displayed a more active stance and higher level of performance, was particularly effective in leading group discussions and implementing IMM stages as required. Consequently, group composition is essential for group dynamics and the success of IMM activities. Familiarity with IMM and internalizing the meaning and requirements of each stage also contributes to more effective implementation of these activities. PSTs' negative preconceptions about physics, resulting from prior experiences in physics courses, challenged them to complete all stages of IMM as required. Participants reported that they had never before experienced such a direct relation between physics and mathematics with real life. They appreciated working on a problem in a sequence that helped them to think, discuss, and revise their models. Additionally, they were more engaged in the activities and voiced their opinions more actively than in other sections of the same course. Instructors who intend to apply IMM activities in their classes could expect to demonstrate applied execution of each stage of this model and reinforce the insights gained through debates involving the entire class. Teaching physics content to science PSTs via modeling activities such as IMM, where students actively work on a real-life problem and apply their knowledge to more tangible models, can motivate and alleviate PSTs' prejudices against learning physics concepts. Our recommendations for future research are presented below:

- We strongly advise instructors who plan to use IMM activities to practice implementing such activities a few times before achieving satisfactory results. Novice students may need time to become familiar with some stages of IMM.
- Researchers should create an environment that allows for the implementation of multiple IMM activities to ensure that study groups are familiar with one another and the stages of IMM. This should focus on developing mental model-building competencies that will help students understand and solve the problem.
- The parsing/grouping stage requires students to associate the concepts of mathematics and physics involved in the problem with the relevant discipline. However, the groups in our study had difficulty making discipline-related separations or groupings. Therefore, we recommend that future researchers exercise this stage in different interdisciplinary contexts.
- Context building was another challenging stage because students did not complete the separating/grouping stage. Therefore, we recommend that each group establish a control mechanism before proceeding to the next stage of future research. Asking the right questions or establishing checkpoints may help these groups successfully complete each stage.
- PSTs in our study failed to test the real-world applicability and accuracy of their solutions. They were generally self-assured in their solutions. For future studies, another similar real-life problem may be provided to help students test their solutions. This way, they can confront their errors or incorrect approaches.

*The authors received no financial support for the research, authorship, and/or publication of this manuscript.*

**Demet Baran-Bulut** (demet.baran@erdogan.edu.tr) received her PhD degree in Mathematics Education at Karadeniz Teknik University, Turkey. She works as an assistant professor at Recep Tayyip Erdogan University and has taught several courses at the undergraduate and graduate level.

Her research focuses on geometry education, mathematical modeling, and mathematics teacher training.

**Tuğba Yüksel** (tugba.yuksel@erdogan.edu.tr) graduated with a PhD degree from the Curriculum and Instruction department at Purdue University, USA in 2017. Currently, she is an assistant professor in the Department of Mathematics and Science Education at Recep Tayyip Erdogan University in Turkey. Her research interests include investigating how individuals construct and utilize meta models for meaningful understanding of science; designing model-based learning environments, which are supported by physical, mathematical, and virtual manipulatives; learning in an out-of-school environment; and pre-service teachers' field experience practices.

## References

Aksit, O., & Wiebe, E. N. (2020). Exploring force and motion concepts in middle grades using computational modeling: A classroom intervention study. *Journal of Science Education and Technology*, *29*, 65-82. https://doi.org/10.1007/s10956-019-09800-z

Antonius, S., Haines, C., Jensen, T. H., Niss, M., & Burkhardt, H. (2007). Classroom activities and the teacher. In W. Blum, P. Galbraith, H. Henn, & M. Niss (Eds.), *Modelling and applications in mathematics education,* (pp. 295-308). Springer.

Aydin-Guc, F. (2015). *Matematiksel modelleme yeterliklerinin geliştirilmesine yönelik tasarlanan öğrenme ortamlarında öğretmen adaylarının matematiksel modelleme yeterliklerinin değerlendirilmesi [Examining mathematical modeling competencies of teacher candidates in learning environments designed to improve mathematical modeling competencies]* [Doctoral dissertation, Karadeniz Technical University]. National Thesis Center. https://tez.yok.gov.tr/UlusalTezMerkezi/

Bani-Salameh, H. N. (2016). How persistent are the misconceptions about force and motion held by college students? *Physics Education, 52*(1), 014003. https://doi.org/10.1088/1361-6552/52/1/014003

Basson, I. (2002). Physics and mathematics as interrelated fields of thought development using acceleration as an example. *International Journal of Mathematical Education in Science and Technology*, *33*(5), 679-690. https://doi.org/10.1080/00207390210146023

Berelson, B. (1952). *Content analysis in communication research*. The Free Press.

Berry, J., & Houston, K. (1995). *Mathematical modelling*. J.W. Arrowsmith Ltd.

Bing, T. J., & Redish, E. F. (2009). Analyzing problem solving using math in physics: Epistemological framing via warrants. *Physical Review Special Topics-Physics Education Research*, *5*(2), 020108-1-020108-15. https://doi.org/10.1103/PhysRevSTPER.5.020108

Blum, W. (2011). Can modelling be taught and learnt? Some answers from empirical research. In G. Kaiser, W. Blum, R. Borromeo Ferri, & G. Stillman (Eds.), *Trends in teaching and learning of mathematical modelling* (pp. 15-30). Springer.

Blum, W., & Borromeo-Ferri, R. (2009). Mathematical modelling: Can it be taught and learnt?. *Journal of Mathematical Modelling and Application, 1*(1), 45-58.

Borromeo-Ferri, R. (2006). Theoretical and empirical differentiations of phases in the modelling process. *The International Journal on Mathematics Education, 38* (2), 86- 95. https://doi.org/10.1007/BF02655883

Borromeo-Ferri, R. (2018). *Learning how to teach mathematical modeling in school and teacher education*. Springer International Publishing.

Bukova-Guzel, E. (2011). An examination of pre-service mathematics teachers' approaches to construct and solve mathematical modelling problems. *Teaching Modelling and Its Applications, 39*, 19-36.

Bybee, R., (2010). Advancing STEM education: A 2020 vision. *Technology And Engineering Teacher, 70* (1), 30–35.

Carrejo, D. J., & Marshall, J. (2007). What is mathematical modelling? Exploring prospective teachers' use of experiments to connect mathematics to the study of motion. *Mathematics Education Research Journal, 19*(1), 45-76. https://doi.org/10.1007/BF03217449

Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive science*, *5*(2), 121-152.

Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics*, *50*(1), 66-71. https://doi.org/10.1119/1.12989

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches* (2nd ed.). Sage Publications, Inc.

Dervisoglu, S., & Soran, H. (2003). Evaluation of interdisciplinary teaching approach in high school biology education. *Hacettepe University Journal of Education Faculty*, *25*(25), 48-57.

DiSessa, A. A. (1982). Unlearning Aristotelian physics: A study of knowledge based learning. *Cognitive Science, 6*(1), 37-75. https://doi.org/10.1016/S0364-0213(82)80005-0

Doerr, H. M. (1997). Experiment, simulation and analysis: An integrated instructional approach to the concept of force. *International Journal of Science Education*, *19*(3), 265-282. https://doi.org/10.1080/0950069970190302

Dogan, M. F., Gurbuz, R., Cavus Erdem, Z., & Sahin, S. (2018). STEM eğitimine geçişte bir araç olarak matematiksel modelleme [Mathematical modeling as a tool for transition to STEM education]. In R. Gurbuz ve & M. F. Dogan (Eds.), *Matematiksel modellemeye disiplinler arası bakış: Bir STEM yaklaşımı* [*An interdisciplinary view of mathematical modeling: A STEM approach]* (pp. 43-56). Pegem Academy.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107-115. https://doi.org/10.1111/j.1365-2648.2007.04569.x

English, L. D. (2015). STEM: Challenges and opportunities for mathematics education. In *Proceedings of the 39th Conference of the International Group for the Psychology of Mathematics Education* (Vol. 1, pp. 4-18). PME.

Erbas, A. K., Cetinkaya, P., Alacaci, C., Cakiroglu, E., Aydogan-Yenmez, A., Sen-Zeytun, A.,… Goz, M. (2016). *Günlük hayattan modelleme soruları [Modeling questions from everyday life]*. Türkiye Bilimler Akademisi.

Erickson, T. (2006). Stealing from physics: Modeling with mathematical functions in data-rich contexts. *Teaching Mathematics and its Applications*, *25*(1), 23-32. https://doi.org/10.1093/teamat/hri025

Goldberg, F. M., & Anderson, J. H. (1989). Student difficulties with graphical representations of negative values of velocity. *The Physics Teacher*, *27*(4), 254-260.

Gurbuz, R., Cavus Erdem, Z., Sahin, S., Temurtas, A., Dogan, C., Dogan, M. F.,… Celik, D. (2018). Bir disiplinler arası matematiksel modelleme etkinliğinden yansımalar [Reflections from an interdisciplinary mathematical modeling activity] [Special issue]. *Adıyaman University Journal of Educational Science, 8*(2), 1-22. https://doi.org/10.17984/adyuebd.463270

Halloun, I. A., & Hestenes, D. (1985). Common sense concepts about motion. *American Journal of Physics, 53*, 1056. https://doi.org/10.1119/1.14031

Hidiroglu, C. N., Tekin-Dede, A., Kula, S., & Bukova-Guzel, E. (2014). Öğrencilerin Kuyruklu Yıldız Problemi'ne ilişkin çözüm yaklaşımlarının matematiksel modelleme süreci çerçevesinde incelenmesi [Examining students' solutions regarding the comet problem in the frame of mathematical modeling process]. *Mehmet Akif Ersoy University Journal of Education Faculty, 31*, 1-17.

Julie, C., & Mudaly, V. (2007). Mathematical modelling of social issues in school mathematics in South Africa. In W. Blum, P. Galbraith, M. Niss & H. W. Henn (Eds.), *Modelling and* *applications in mathematics education* (pp. 503-510). Springer. https://doi.org/10.1007/978-0-387-29822-1_58

Lesh, R. A., & Doerr, H. (2003). Foundations of model and modelling perspectives on mathematic teaching and learning. In R. A. Lesh, & H. Doerr (Eds.), *Beyond constructivism: Models and modelling perspectives on mathematics teaching, learning and problem solving* (pp. 3-33). Lawrance Erlbauum.

Lyublinskaya, I. (2006). Making connections: Science experiments for algebra using TI technology. *Eurasia Journal of Mathematics Science and Technology Education, 2*(3), 144-157. https://doi.org/10.12973/ejmste/75471

Maaß, K. (2006). What are modelling competencies? *The International Journal on Mathematics Education, 38*(2), 113-142. https://doi.org/10.1007/BF02655885

Marshall, J. A., & Carrejo, D. J. (2008). Students' mathematical modeling of motion. *Journal of Research in Science Teaching, 45*(2), 153-173. https://doi.org/10.1002/tea.20210

McDermott, L. C., Rosenquist, M. L., & Van Zee, E. H. (1987). Student difficulties in connecting graphs and physics: Examples from kinematics. *American Journal of Physics*, *55*(6), 503-513. https://doi.org/10.1119/1.15104

Michaluk, L., Stoiko, R., Stewart, G., & Stewart, J. (2018). Beliefs and attitudes about science and mathematics in pre-service elementary teachers, STEM, and non-STEM majors in undergraduate physics courses. *Journal of Science Education and Technology, 27*(2), 99-113. https://doi.org/10.1007/s10956-017-9711-3

Morrison, J., & McDuffie, A. R. (2009). Connecting science and mathematics: Using inquiry investigations to learn about data collection, analysis, and display. *School Science and Mathematics*, *109*(1), 31-44. https://doi.org/10.1111/j.1949-8594.2009.tb17860.x

Munier, V., & Merle, H. (2009). Interdisciplinary mathematics–physics approaches to teaching the concept of angle in elementary school. *International Journal of Science Education*, *31*(14), 1857-1895. https://doi.org/10.1080/09500690802272082

Nemirovsky, R., & Rubin, A. (1992). Students' tendency to assume resemblances between a function and its derivative, TERC Working Paper 2-92, Cambridge, Massachusetts.

Niss, M., Blum, W., & Galbraith, P. L. (2007). Introduction. In W. Blum, P. L. Galbraith, W. Henn, & M. Niss (Eds.), *Modeling and applications in mathematics education* (pp. 3-32). Springer.

Ogunsola-Bandele, M. F. (1996). Mathematics in physics - which way forward: The influence of mathematics on students' attitudes to the teaching of Physics, Paper presented at the Annual Meeting of the National Science Teachers Association, Nigeria.

Ozer-Keskin, O. (2008). *Ortaöğretim matematik öğretmen adaylarının matematiksel modelleme yapabilme becerilerinin geliştirilmesi üzerine bir araştırma [A research of developing the pre-service secondary mathematics teachers? Mathematical modelling performance].* [Doctoral dissertation, Gazi University]. National Thesis Center. https://tez.yok.gov.tr/UlusalTezMerkezi/

Pendrill, A. M., & Ouattara, L. (2017). Force, acceleration and velocity during trampoline jumps-a challenging assignment. *Physics Education, 52*(6), 065021. https://doi.org/10.1088/1361-6552/aa89cb

Phage, I. B., Lemmer, M., & Hitge, M. (2017). Probing factors influencing students' graph comprehension regarding four operations in kinematics graphs. *African Journal of Research in Mathematics, Science and Technology Education*, *21*(2), 200-210. https://doi.org/10.1080/18117295.2017.1333751

Pollock, S. J. (2006). Transferring transformations: Learning gains, student attitudes, and the impacts of multiple instructors in large lecture courses. In P. Heron, L. McCullough, & J. Marx (Eds.), *AIP Conference Proceedings* (vol. 818, no. 1, pp. 141-144). College Park: American Institute of Physics.

Potgieter, M., Harding, A., & Engelbrecht, J. (2008). Transfer of algebraic and graphical thinking between mathematics and chemistry. *Journal of Research in Science Teaching, 45*, 197-218. https://doi.org/10.1002/tea.20208

Prins G., T., Bulte, A. M. W., Driel J. H. V., & Pilot, A. (2009). Students' involvement in authentic modelling practices as contexts in chemistry education. *Research Science Education*, *39*, 681-700. https://doi.org/10.1007/s11165-008-9099-4

Redish, E. F., & Gupta, A. (2010). Making meaning with math in physics: A semantic analysis. In D. Raine, C. Hurkett, & L. Rogers (Eds.), *Selected contributions from the GIREP-EPEC & PHEC 2009 International Conference* (pp. 244-260). Leicester: Lulu/The Center for Interdisciplinary Science, University of Leichester. http://arxiv.org/abs/1002.0472

Reif, P. (1995). Understanding and teaching important scientific thought processes. *Journal of Science Education and Technology, 4*(4), 261-282. https://doi.org/10.1007/BF02211259doi:10.1007/BF02211259

Ropii, N., Hardyanto, W., & Ellianawati, E. (2019). Guided inquiry Scratch increase students' critical thinking skills on the linear motion concept: Can it be?. *Jurnal Penelitian & Pengembangan Pendidikan Fisika, 5*(1), 63-68. https://doi.org/10.21009/1.05107

Scott, F. (2012). Is maths to blame? An investigation into high school students' difficulty in performing calculations in chemistry. *Chemistry Education Research and Practice 13*, 330-336. https://doi.org/10.1039/C2RP00001F

Sen-Zeytun, A. (2013). *An investigation of prospective teachers' mathematical modeling processes and their views about factors affecting these processes* [Doctoral dissertation, Middle East Technical University]. National Thesis Center. https://tez.yok.gov.tr/UlusalTezMerkezi/

Singh, C., & Schunn C. D. (2009). Connecting three pivotal concepts in K-12 science state standards and maps of conceptual growth to research in physics education. *Journal of Physics Teacher Education Online*, *5*(2), 16-42. https://doi.org/10.48550/arXiv.1603.06024

Takaoglu, Z. B. (2015). Matematiksel modelleme kullanılan Fizik derslerinin öğretmen adaylarının ilgi, günlük hayat ve diğer derslerle ilişkilendirmelerine etkisi [The effect of physics courses mathematical modelling used on prospective teachers' interests and how they associate physics with real life and other courses]. *Yüzüncü Yıl University Journal of Education*, *12*(1), 223-263.

Teodoro, V. D., & Neves, R. G. (2011). Mathematical modelling in science and mathematics education. *Computer Physics Communications, 182*(1), 8-10. https://doi.org/10.1016/j.cpc.2010.05.021

Tuminaro, J., & Redish, E. F. (2004). Understanding students' poor performance on mathematical problem solving in physics. In J. Marx, S. Franklin & K. Cummings (Eds.), *American Institute of Physics* (pp. 113-116). Physics Education Research Conference.

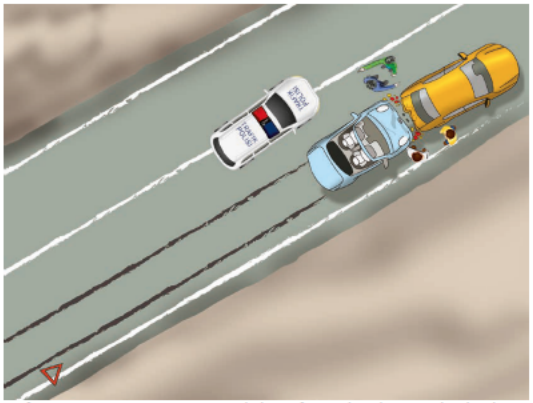
Weinberg, A. E., & Sample McMeeking, L. B. (2017). Toward meaningful interdisciplinary education: High school teachers' views of mathematics and science integration. *School Science and Mathematics*, *117*(5), 204-213. https://doi.org/10.1111/ssm.12224

# Appendix

## Braking Distance of a Car

*Marking!*
*An accident classic: wrong marking*

Among the causes of the accident, the failure to remove the broken vehicle from the road, not marking or incorrectly marking, has an important place. Many drivers have experienced the danger of a broken vehicle that suddenly appears after a bend or hilltop. Unfortunately, vehicle owners who make wrong markings by burning old tires, putting no signs or laying stones on the road, putting first aid kits, drums, jacks, and similar things on the road are responsible for fatal accidents. Let us remember that the famous rally driver Renç Koçibey also lost his life by crashing into an unmarked vehicle, and please make the markings according to the rules. Proper marking is done by turning on the vehicle's emergency warning lights and by placing a reflector in front of, behind, and in appropriate places. The reflector must be in the form of an equilateral triangle with a length of 45 cm and a reflective surface of 5 cm on each side. It is also among the marking rules that the reflector has legs that will not topple over due to the wind.



It is mandatory to place the reflector at least 30 m away from the vehicle and visible from a distance of at least 150 m by other drivers in places such as bends and hills with limited visibility. In the event that the vehicles carrying dangerous goods break down and stop on the road, they must be marked with a red light and kept under surveillance.

An auto traveling at a speed of 80 km per hour slightly hits another vehicle from behind due to a breakdown on the road. The owner of the stationary vehicle claims that he placed a beacon reflector within 30 meters of his vehicle in a place where drivers could see it from 150 meters away, and therefore, the driver who hit his vehicle was one hundred percent guilty.

On the other hand, the owner of the vehicle that caused an accident blames the owner of the defective vehicle, saying that he could not stop despite pressing the brake when he saw the reflector. Knowing how many meters before the impacting car slams the brake will be a crucial parameter in calculating crime rates.

Due to the nature of the road, there are no signs of braking or slipping on the road. The only data available is the surveillance camera data, which is just near the road. From the surveillance camera recordings, it is not clearly understood how many meters behind the crashing vehicle started to brake and how many meters it stopped. However, the speed of the impacting car may be computed in two-second intervals using the photos (see Table 1).

Using the data in the table, you are asked to find out how many meters before the crashing vehicle started braking. In this context, using surveillance data, find out how many meters before the driver stepped on the brake and explain in detail in a way that the authorities will understand.

*Table 1 Speed-time data of the crashing vehicle*

| Time (h) | Speed (km/h) |
|---|---|
| 4:00:00 pm | 75 |
| 4:00:02 pm | 75 |
| 4:00:04 pm | 60 |
| 4:00:06 pm | 45 |
| 4:00:08 pm | 30 |
| 4:00:10 pm | 15 |
| 4:00:12 pm | 0 |

ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 27, NO. 4, 141-156

# Secondary School Students' Experiences in Online Physics Learning During the COVID-19 Pandemic: A Phenomenological Examination from Trinidad and Tobago

Rawatee Maharaj-Sharma
*The University of the West Indies, St Augustine, Trinidad & Tobago*

**ABSTRACT**

The world lived through a pandemic over the 2020-2022 period, which forced drastic changes in every sector and every aspect of our lives. One such change in the education sector was the immediate shift to online learning as educational institutions across the world responded to the pandemic. Educational institutions in Trinidad and Tobago, like everywhere else, shifted from face-to-face to online instruction in all courses and programmes, including physics. While the conduct of physics lessons through virtual classrooms may have several advantages, it is not without disadvantages. The latter resulted in challenges, especially for students, and it is important for us to understand how students experienced and managed their learning in the fully online environment. The aim of this phenomenological study is to capture and describe the experiences of students in online physics learning in a virtual classroom – specifically their experiences in preparing for online physics learning, managing learning in the virtual physics classroom, and benefiting from opportunities in online physics learning. Three major themes emerged from this study – students' readiness for online learning, students' challenges during online learning and the role of follow through facilitation after online lessons. Despite their preparations, students encountered challenges such as network connectivity, reliability of supporting systems, and distractions in their learning environment at home. However, they were optimistic that the reality presented opportunities to improve their technological competencies and to maximize their online learning experiences as they engaged in the learning of physics concepts in a non-traditional way.

*Keywords:* COVID-19 pandemic, online physics learning, phenomenology

## Introduction

The COVID-19 pandemic challenged educational systems across the world and forced most, if not all, educational institutions to shift from traditional pedagogical methods to online teaching and learning. This necessary shift in educational instructional delivery was critical to maintain continuity in teaching and learning that would otherwise have been severely compromised in the face of massive global shutdowns in every sector across the world. This sudden change meant that educators and students had to make immediate adjustments to adapt to this new normal in education. In making these adjustments, the existing inequity in education systems the world over, which had laid somewhat dormant for decades, became vulgarly apparent. In Trinidad and Tobago, this inequity in education is undeniably pronounced and the transition to online teaching and learning drastically amplified the reality in all disciplines inclusive of science.

Science education is one of the most critical subjects at the secondary school level due to its relevance to students' lives and the universally applicable problem-solving and critical thinking skills it uses and develops (Arrieta et al., 2020). These lifelong skills allow students, especially those intent on pursuing science at levels beyond secondary school, to generate ideas, weigh decisions intelligently, to understand concepts and theories behind natural phenomena, and to be able to share these understandings with others. Furthermore science education and specifically for the purposes of this study, physics education, is about teaching and learning that engages students in inquiry-based investigations in which they interact with teachers and peers to establish connections between current knowledge and scientific understanding, and to recognize how these apply to their everyday lives. Equally important in physics education is the cultivation of problem-solving, planning, and reasoning skills that students develop when they work in collaborative group settings to perform experiments, investigate phenomena, and evaluate evidence (Contant et al., 2018).

Prior to the onset of the pandemic, science classrooms, inclusive of physics classrooms and laboratories in Trinidad and Tobago, were dominated by peer-peer interactions and brainstorming so that all students, even those in disadvantageous circumstances, had good opportunity to develop those lifelong 21st century skills, and in the case of science education, those critical scientific skills. When education, inclusive of science education transitioned into a remote mode in March 2020, navigating the new reality to ensure a productive and meaningful learning experience for science students meant that teachers and educators had to rethink their practice to ensure that pre-pandemic learning outcomes remained attainable even in the pandemic reality (Brown, 2020). The apprehension to teach science entirely online was a phenomenon that teachers the world over had to confront (Brown, 2020; Gilles & Britton, 2020; Graham et al., 2020). Students too were intimidated by the new reality, even more so than teachers were, as online methods for most of them had been limited to emails, web-surfing, and gaming applications. Teaching and learning had not been previously thought of, in the fully online context, for most students and teachers (Arietta et al., 2020; Brown, 2020). Reasonable adaptations to delivery methods, assessments, and modes of interaction between students and teachers for all courses had to be made quickly and responsibly (Vasquez, 2020). Teachers in Trinidad and Tobago responded as they were best able to, but with the transition to online learning, it remained difficult to ascertain the extent to which all students were able to manage their learning in the context of what they were accustomed. There was speculation that students were challenged in the online environment and that those with inequitable resources were most disadvantaged. At that time, it was unclear how science students in Trinidad and Tobago were coping with remote learning, how they were experiencing online learning, and what challenges they were encountering in the online environment. These are the concerns which prompted the conceptualization of the current work, which reports on data collected over the period from March 2020 to December 2021.

## Literature and Theoretical Framework – Online Learning

Online education and e-learning are not new in the field of education. The versatility offered by Information and Communication Technology (ICT) resources and capabilities, presents educators with attractive options to address many of the issues that, in the past, made instructional opportunities for students difficult and even impossible in some cases. ICT is defined as a diverse set of technological tools and resources used to transmit, store, create, share, or exchange information. These technological tools and resources include computers, the Internet (websites, blogs, and emails), live broadcasting technologies (radio, television, and webcasting), recorded broadcasting technologies (podcasting, audio and video players, and storage devices) and telephony (fixed or mobile, satellite, visio/videoconferencing, etc., (UIS, 2009; UNESCO, 2017). Prior to the influx of online education, which was further triggered by the pandemic, delivery of instruction was limited by factors such as geographical remoteness, limited offerings by institutions, and the complex lives of students (Dziuban et al., 2018). Today, learning in an online environment offers the convenience of an "anytime and anywhere" education for both students and teachers. This provides students with increased opportunities for flexibility, collaboration, and interaction through the use of educational technologies that allow for the design, delivery, and management of learning at anytime and anywhere (Gedera et al., 2015; Obbink & Wheeler, 1993). While this new dispensation is different from face-to-face learning, and it may challenge the efforts of some teachers, the reality is that it has found acceptance with a notable cross section of the current generation of technophobes in our classrooms. Science classrooms have become virtual labs, simulation stations, and computer aided demonstration centers. The use of devices such as computers, cellphones, and tablets together with numerous online video conferencing platforms and applications enabled students to continue to learn, practice, and experience science even during the pandemic. Many students have embraced the novelty of technology supported science and have easily adapted to this new way of learning science, but this new mode of instructional delivery is not without its challenges for many other students.

Research on the nature of online science learning, including the benefits, challenges, and implications of this new approach was well underway even before the onset of the pandemic but gained much more traction soon after in early 2020 (Furtak & Penuel, 2019; Linn et al., 2016). At the onset of the pandemic, experts in science education were curious to find out what works, and what were the experiences of the stakeholders in this paradigm. Questions seeking students' views and perceptions on the successes and the challenges of online science learning have been targeted and available findings have revealed that while online learning has allowed for science education in the global context to continue through the pandemic, it has been problematic for both students and teachers in significant ways. In fact, in science education in particular, the transformation of hands-on practical activities and experimentation into virtual experiences through simulations and online demonstrations has significantly subtracted from the nature of the science experience that characterizes the scientific process (Dorn et al., 2020). The face-to-face investigative collaborations, which define the scientific approach, were lost when the online transition occurred. But, perhaps the most telling revelation arising from the consequences of online learning in all subject disciplines, including science, is that online learning has exposed more clearly than ever before the inequities in education systems across the world (Borup et al., 2020). While there is acknowledgement of the fact that inequities existed in education systems long before the pandemic and the transition to remote learning, the necessity for online learning brought on by the pandemic served to amplify these inequities (Rempel, 2020).

In a pre-pandemic study of online learning, Blackmon and Major (2012), reported that students were highly displeased with online learning for several reasons, but primary among them were loss of connectivity, instructor inaccessibility, autonomy in learning, and lesser peer interactions. Other pre-pandemic research on online learning have suggested that for learners who had access to devices and ICT resources, many were also fortunate to have access to reliable and stable connectivity and for them, the transition to online learning was quite easy (Salamat et al., 2018). Their access to resources also meant that the transition from traditional face-to-face learning to synchronous participation in online classes was smooth. The reality though, is that as much as 70% of learners globally did not have ready access to devices or Wi-Fi connectivity at the onset of the pandemic (Rempel, 2020).

Existing research suggests that online learning has worked well in some contexts and for some students and teachers, but several published works have highlighted places where, and circumstances under which, online learning has not worked very well. In non-science disciplines, Demirkol and Kazu (2014) found that the online mode of instruction led to improved academic performance and positive changes in attitudes and habits for students. Conversely, Zhu et al. (2013) reported that despite noted positive effects of e-learning on academic performance, students' perceptions towards online learning were unpredictable and students displayed undesirable learning habits in many instances. Blackmon and Major (2012) evaluated the pre-pandemic online learning experiences of students and reported that students who took online distance learning experienced device and Internet connectivity challenges as well as feelings of isolation from their peers and their teachers, both of which led to high levels of frustration associated with the online learning experience. Similar findings were reported by Loades et al. (2020) and Miller (2021) when the online learning experiences of science students during the pandemic were analyzed. Furthermore, while many students in those works suggested that human interactions needed to establish peer support and the ability to facilitate profound discussions in the online environment were inadequate and distant, some indicated that online learning made them more responsible and accountable for their learning. The latter was found to be the case primarily for students with access and support as reported in works by Singh et al. (2020).

In the science disciplines, the findings were similar – several reports of positive views of online science learning from students with access and resources, but many reports which highlight students' displeasure with online science learning (Gedera et al., 2015; Kalloo et al., 2020). In later work, in the pandemic era, in which Chen et al. (2021) interviewed groups of science students in early 2020, the findings noted that the displeasure with online science learning expressed by science students were linked mainly to the disconnect they felt from the live scientific process. Students suggested that the virtual environment cannot replicate the scientific process no matter how user-friendly or sophisticated it may be. Also emerging from research in both the early-pandemic and mid-pandemic eras are the challenges experienced by science students after online learning had occurred (Kalloo et al., 2020; Lapitan et al., 2021).

The pandemic disrupted the familiar structure of science learning for many students. The sequence of science lessons was no longer familiar to students. The familiar whole class discussions, collaborative experimental work, and real time idea sharing were disrupted. Monitoring students' progress by way of these engagements became an inconsistent exercise for teachers (Brown, 2020). It was difficult for teachers to maintain consistent classroom oversight in the traditional way given the numerous and sometimes lengthy online disruptions that students experienced in teaching sessions. Sometimes, teachers too experienced connectivity challenges. Disruptions and inconsistencies, coupled with the intangibility of hands-on learning, made online science learning less engaging for students to the extent that many science students expressed sentiments of rejection in response to the unrealistic feel virtual labs and simulations gave to the traditional experimentation and investigation they had become accustomed to (Mercado, 2021). Many science students and teachers experienced high levels of frustration and dissatisfaction with the online delivery of science instruction (Barrot et al., 2021).

## Context

Classes in all subjects, for the latter part of the 2019-2020, all of 2020–2021 as well as the initial semester of the 2021-2022 academic years, for secondary schools in Trinidad and Tobago, were conducted virtually. Physics teachers and students yielded to the hastened change in 2020 almost willingly, mainly because they recognized that physics learning had to continue but perhaps also with the expectation that the pandemic would have been short-lived. While the transition must have been challenging for teachers, it seems that students were the hardest hit stakeholders in the sudden shift to online physics learning. For students and teachers in the Trinidad and Tobago context, the transition to online learning was not a smooth or easy one. Many students had no access to digital learning devices and reliable online connectivity. Some teachers as well had connectivity challenges and many teachers were not trained in online delivery methods. The mandate to continue classroom learning in an online environment had parents scurrying to secure devices for their children, which, in a lock down mode was a slow, costly, and painstaking endeavor. Many students were therefore out of school for periods of up to eight weeks, while they took steps to secure devices, connectivity, and study space in the home environment. Despite the lack of confidence by many teachers to deliver online classroom instruction, most proceeded bravely; learning along the way, and adapting as they learned. The shift meant that both teachers and students had to rely on the strengths of each other and to adapt to the limitations of each other while learning in an uncertain and evolving context.

This study sought to explore and gain insights from a group of secondary school physics students about their experiences in learning physics during the time of the pandemic. The experiences and perceptions of students drawn from this study will provide a reflective evaluation of online physics learning during the pandemic and will be instructive for general teaching and learning of physics using online platforms.

## Purpose of the Study

The main purpose of this study was to explore, describe, and gain insights from the experiences of secondary school physics students in learning physics through online platforms. In seeking to achieve this purpose, the following research question guided the approach adopted in this work: What were students' perceptions of online physics learning as gleaned from their lived experiences over the period from March 2020 to December 2021?

## Methodology

### Research Design

To explore the experiences of the students in learning physics in what was called the new normal during the pandemic; this study utilized a Descriptive Phenomenological Research Design. Phenomenological design is a type of qualitative research that focuses on the commonality of a lived experience within a particular group. It emphasizes experiential, lived aspects of a construct, that is, how the phenomenon is experienced at the time that it occurs, rather than what is thought about the experience or the meaning of it subsequently (Creswell, 2013; Gibbs, 2018). In this work the intent was to unveil students' perceptions of their present lived experiences of online physics learning, in the context of an ongoing pandemic, and to interrogate these perceptions for patterns and themes to arrive at general understandings. With that intent in mind, the descriptive phenomenological research design was deemed suitable.

### Sampling

The participants in this work were a group of fourth-year secondary school physics students who were undertaking a course of physics study which was to culminate in sitting for an external standardized examination in June 2022. It was a mixed group comprised of 21 males and 23 females ranging in age from 14 – 16 years. The school was located in a semi-urban area in south Trinidad and was classified as an average performing school based on the Ministry of Education's classification of schools (Ministry of Education Trinidad & Tobago, 2012). The group was conveniently selected in response to an explicit request from the group's physics teacher, who was very interested in finding out her students' perceptions of online physics learning (Etikan et al., 2016).

### Data Collection and Instrumentation

Given the phenomenological research design adopted herein, a targeted interview protocol was deemed the most suitable data collection instrument that would allow for gathering of relevant and rich data to adequately and meaningfully answer the research question. The interview protocol was designed with three sections. Questions in section one of the protocol were explored in the period

March 2020 to July 2020. The intent with these items was to ascertain students' initial perceptions of online physics learning. Questions in section two targeted students' perceptions having been engaged in online physics learning for an extended period and were administered during the period September 2020 to December 2020. The final section of the interview protocol focused on students' perceptions having been engaged in online physics learning for more than one school year and was administered in the period January 2021 to June 2021. The initial interview protocol was designed by the researcher in consultation with the class teacher. The teacher's input was important to ensure that the items aligned with the context, circumstances, experiences, and realities of the students. The initial version went through two iterations over the period February 2020 in which both researcher and class teacher reviewed the instrument individually in the first instance, and then collaboratively, to ensure that the items were context relevant and unambiguous. Following this phase of review, experts in curriculum and assessment were asked to validate the interview protocol. After this validation process, the instrument was modified for further clarity and focus.

Once the validation was complete, the researcher wrote to the principal of the school seeking permission to conduct the study at the institution with the selected group of students and class teacher. Correspondence, by way of consent letters, was also sent to all participants, using their email addresses, inviting them to participate in the study. In the email, they were informed of the nature and purpose of the research, their right to participate voluntarily, their right to withdraw from the study at any time if they so desired and that their participation was in no way linked to their final grades. Participants were also informed that the findings of the study will be kept confidential and will be used only for the purposes of the current work. They were asked to sign and return the letters of consent within one week.

Once all the briefing and consent protocols were met, arrangements were made to begin conducting interviews with the 44 students in the group. Students were interviewed individually, at a date and time that was mutually convenient. The interviews were done online, and students were asked to turn on their cameras so that the researcher could observe facial expressions as they responded. This was to allow for probing in the event that the interviewee appeared confused, fatigued, or anxious when questions were asked. An average of three interviews per week were conducted (in light of issues such as scheduling and connectivity), so that data from questions in section one of the protocol were collected over the initial three-month period students were engaged in online physics learning. Interviews were audio recorded to facilitate subsequent transcription of the interview for data analysis. Sections two and three of the interview protocol were administered in the respective periods and with similar duration as described above. Interviews were similarly audio recorded and transcribed for analysis.

## Data Analysis

### *Analysis Approach*

The transcribed interview data were analyzed using Colaizzi's phenomenological method, as described by Wirihana et al. (2018), which is the preferred method used by researchers to reliably understand people's experiences. Colaizzi's method depends on rich first-person accounts of experiences and provides a rigorous analysis, with each step staying close to the data. The end result is a concise yet all-encompassing description of the phenomenon, validated by the participants. Colaizzi's seven-step method involves careful review by reading and rereading of transcripts, extracting and summarizing significant statements, formulating meanings from significant statements, categorizing statements with common or similar meanings into clusters of themes (validating with original text), describing the clusters of themes, returning to the participants for member checking/cross-checking, and finally incorporating changes based on participants feedback.

### *Analysis Procedure*

Data collection for this work was completed in September 2021. Audio recordings were transcribed over the period September 2021 to November 2021. Once this was completed, the researcher engaged in the familiarization process by reading through the accounts of all 44 participants several times. This familiarization was done in three phases corresponding to transcripts from the three sections of the interview protocol. In each phase, the final reading was a deliberate exercise in which the researcher highlighted all statements in the accounts that were of direct relevance to the phenomenon being investigated – students' perceptions about online physics learning.

The researcher then proceeded to carefully study the highlighted statements to attach emerging meanings relevant to students' perceptions of online physics learning to these statements. While complete bracketing may not be possible according to Colaizzi (1978), the researcher made every effort to set aside her presuppositions and to stick closely to the phenomenon as revealed from the data. The identified meanings were subsequently clustered into themes that reflected commonality of meanings across all accounts and meanings in each theme. Again, bracketing was ensured to avoid any potential influence of existing theories the researcher may possess. Once the clusters of themes were determined, the researcher proceeded to write, in the first instance, a full and inclusive description of the phenomenon which incorporated all the themes that emerged, and then later to condense the exhaustive description down to short, dense statements that captured just those aspects deemed to be essential to the structure of the phenomenon. This fundamental structure of dense statements was returned to all participants to inquire from them if it captured the experiences they reported on during the interviews. Participants' feedback was used to modify interpretations if necessary.

## Findings

Colaizzi's (1978) treatment of the data led to the emergence of three overarching themes into which students' perceptions of online physics learning could be placed. These were: *readiness for online learning, challenges during online learning and follow-through after online classes.* Each overarching theme contained subsets of perceptions, which in turn, were supported directly by the raw data. Each theme will now be discussed.

### Phase 1 – March 2020 to July 2020

### *Readiness For Online Learning*

In phase one of the research, students indicated that the sudden need to shift from face-to-face instruction to online instruction, imposed by the pandemic, met them highly unprepared for online physics learning. While online learning was not completely new to them, they admitted that the idea of all learning happening in a virtual environment was something they never thought seriously about simply because they never imagined it would be a reality they would have to experience. Their unpreparedness was partially a mental state, but mainly it was in terms of support systems, resources, and ICT competency. Lack of support in the form of not having internet access was perhaps the most common among the students. While some students had internet access at the start of the pandemic, 48% of the students in this group did not, and they attributed this to their low socio-economic livelihoods. For those who had access at that time, many indicated that connectivity was either weak or unreliable. Many students also spoke about power outages being quite common in the areas they lived – as much as three times per week lasting up to an hour in some instances. In addition, almost all the students in this work indicated that their homes were not well-fitted for online school, pointing out that they did not have a fixed conducive work area for extended online learning. Responses from students, which captured their level of unpreparedness, included the following:

> "… I did not know what I had to do …"
> "… having classes on the computer was like … weird … miss was not nearby"
> "I had no wifi … but we had to get it for class …"
> "When electricity went in the past I did not bother … but for my class it was a big problem … and I had no desk at home …"

Access to resources to facilitate online physics learning such as devices inclusive of laptops, tablets, and smartphones, as well as items such as desks and chairs, were immediate requirements to facilitate online learning, which many students did not have. In fact, 66% of the students in this work indicated that they were 'out-of-school' for at least two weeks and up to eight weeks in some cases, after the pandemic started, while their parents tried to secure devices and desks for them to engage in online classes. The following verbatim responses further summarizes the challenges students had in terms of access:

> "My mom had to find the money to get me a desk and a chair"
> "…the old iPad was okay for games…but it was not good for my class...it was cutting-off…"

While some students had a functional level of ICT competency, which included basic skills such as navigating interactive online teaching platforms, these were in the minority. In fact, only about 25% of the students indicated that when online classes started in March – April 2020, they were able to follow instructions and use their devices to access the teaching sessions. Things like sharing videos, uploading artifacts, participating in online activities through simulation applications and sharing their screens to make presentations were skills required to participate meaningfully in online learning. However, 75% of the students in this work simply did not have those skills at the start of fully remote learning. The following excerpts summarize the situation for the majority (75%) of students in this work at the start of the pandemic:

> "I did not know which box to press to share my screen"
> "I did not have my friends around to ask for help … I was alone …"

### *Challenges During Online Learning*

Interview data from phase one of the research revealed that in the initial months following the onset of the pandemic, students experienced much frustration in their online physics classes. Online demonstrations, virtual labs, and simulated inquiry activities replaced the hands-on, collaborative real-time approach they were familiar with. Considering their high levels of unpreparedness, particularly in the terms of support systems and ICT competencies in this phase of the study, meaningful participation in the physics activities in the virtual environment was extremely difficult for many students and impossible for some. Students missed peer interactions, with 52% of students citing group work in the physical setting as the interaction they missed most. They acknowledged the fact that online group work continued to be part of their online classes but were adamant that it *'will never be like in the real classrooms'*. Students agreed that simulations and virtual labs were *'less messy'* and *'visually appealing'* but were unhappy that they could no longer *'touch and hold'* physical manipulates, for example to connect circuits or perform experiments like investigating elastic limit applying Hooke's Law. As much as 80% of the students indicated that this was the most frustrating part of online physics learning for them. They noted however that their teacher would sometimes ask them to gather manipulates from their homes to perform certain activities and experiments while the simulations were presented, but lamented that *'it could never be the same thing…'*

Feeling isolated during learning from teachers as well as peers was another aspect of online learning that students said they missed. In fact, 90% of the students in this work discussed this explicitly during the interview. Many indicated that they were not motivated to ask questions in their online classes in the same way they did in the pre-pandemic classroom. Even when prompted by the teacher, students said that they preferred to stay quiet. At least six of the students interviewed said that *'the screen/computer/device was a like a barrier from miss.'* Some students admitted that they were usually quite *'talkative in physics classes'* but would only rarely volunteer responses or ask questions during online physics learning. For reasons that were uncertain to the students themselves, the online environment was somewhat *'discomforting'*. Sharing ideas with and learning from their peers were experiences they had to engage with in a different way in online classes. While they praised their teacher for efforts made to facilitate online class discussions and to include teacher feedback and peer input in these discussions, 32% of the students said that they still did not feel as if they were *'part of the class.'* Many students also said that even though the interactions were happening as the class progressed, it still did not feel like they were engaged in *'real-time participation'* in their online physics classes. Many students shared sentiments similar to those captured below:

> "I could not ask my friend for help with my work … I missed that"
> "…doing the lab by myself … on my home table was not interesting … like in school"
> "… knowing where to send my work was hard … miss said there was a folder … I could not find it and I did not want to ask again"
> "I got into the thing that showed how light bended, but I could not move to the next thing to see how it reflected"

### *Follow-through After Online Learning*

Students indicated in their phase one interview responses that after online physics lessons ended, their teacher was very careful to insist that they complete and submit assigned tasks in a timely manner. She had email addresses for all students and would send reminders about due dates and would inquire if assistance was needed to complete the assigned tasks. She was also very prompt with guidance and clarification when students asked and was prompt with marking assignments and providing feedback. Students admitted though that for them personally, managing their time to complete the tasks was a bit new to them because even though they were required to manage time in pre-pandemic times, the '*more loose*' pandemic circumstances, made it easy for them to procrastinate. They appreciated their teacher's persistence with them outside of official online teaching time and credited her attention as a major factor in reducing their procrastination. In fact, 43% of students indicated that had it not been for the extra attention shown by their teacher, they would have *'easily procrastinated'* their '*homework and lab reports*'. Students also indicated that in pre-pandemic times, collaboration with peers to complete assignments and homework during recess and lunchtime, as well as after school, was very helpful to them both in terms of building further understanding while completing tasks and in providing encouragement and motivation to them personally. The latter they lament, was '*the most missed experience'* after an online class ended. Overall, 82% of the students said that there was meaningful follow-through and monitoring of their progress after online lessons, as indicated below:

> "I did not feel I had to do my homework … like when miss gave us it in class … and asking for it the next day …"
> "miss sent us reminders on our phones to do the revision so I went and did it"

## Phase 2 - September 2020 to December 2020

### *Readiness For Online Learning*

Interview data from phase two revealed that students were still experiencing levels of unpreparedness for online learning. However, many of them indicated that they either were much more aware of issues that may arise and had taken steps to address them or knew how to resolve or to prepare proactively to deal with them when they arose. For example, many students who did not have Internet access initially had access by phase two of the research, and those who had access took steps to improve connectivity strength. Some students indicated that their parents made arrangements with relatives and friends to accommodate them in the event of power outages at home. One parent even installed a home generator to ensure that his daughter would have power for her classes in the event of a power outage. Several students said that while it was a financial strain on their parents, many parents tried to outfit an area in their home for them to do their online classes. By the time phase two of the research was done, 70% of the students indicated that they had the required resources to effectively participate in online learning. Students also reported that their teacher made extra efforts to help them develop the required ICT competencies so they could engage in the online sessions. Notwithstanding, it seemed to take longer for some students to grasp the required skills; by phase two, 48% of the students indicated that they were *'comfortable'* learning in the online environment through interactions with the various online resources. Responses, which support this transition, include:

> "I can use the computer better now … but some things still hard …"
> "I now understand how to share my work with my friends on the computer"
> " when the current go … I know how to get back my work now"

### *Challenges During Online Learning*

While students admitted that their levels of frustration were somewhat reduced in phase two of the research, which they hinted may be attributed to increased familiarity with the applications, activities, and demonstration used in online physics learning, their responses seem to suggest that they surrendered to online learning out of an overall sense of complacency rather than acceptance of reality. Many students responded with sentiments such as *'I'm learning to do the simulations because that's the only way to do them now'*, or *'I still don't like it but if I don't do it I will not learn the physics.'* So, while the data showed that the number of students responding with explicit expressions of frustration reduced from 80% to just over 50% in phase two of the research, that did not necessarily mean that more students embraced online physics learning. Furthermore, even after exposure to online physics learning for well into eight months, responses from students in phase two of the research showed that most students continue to insist that the online learning experience remained an isolated and lonely one for them personally. By the end of phase two, 84% of students continue to describe their engagement in online physics learning with words and phrases such as*, 'alone', 'away from my friends', 'distant', 'by myself'* and *'why only me.'* Comments, which suggest that students were becoming more comfortable, learning in the online environment even though they continued to feel isolated, include:

> "I am not so confused as when we first started to use the computer for class"
> "I still prefer to be in class … but I am okay with online now …"
> "I feel lonely while learning … I miss my friends …"

### *Follow-through After Online Learning*

In phase two of the research, students' responses were very similar to those provided in phase one, in terms of follow-through. Aided by the teacher's guidance, students felt they received adequate support to complete lab reports, homework, and out-of-class assignments. In fact, the data showed very little difference in students' perceptions of supportive follow-through to keep them on track with their work. Students continue to acknowledge the important role their teacher's supportive oversight had on compelling them to manage their out of class time to submit assignments on time. Very interesting were responses which indicated that even though they had teacher guidance during class, they missed the out-of-class collaboration when working on 'out-of-class' tasks and assignments. The data showed that in phase two, 64% of students indicated that they missed this type of collaboration, as compared to 40% in phase one who explicitly indicated that they missed 'out-of-class' collaboration. Students' comments, which captured their views and feelings in respect of follow-through in phase two include:

> "it is good that miss keeps messaging to remind me to do my work when I am home"
> "I wish I could do my homework with my friends … to talk about the homework"

## Phase 3 – January 2021 to June 2021

### *Readiness For Online Learning*

In phase three of the research, students reported low levels of unpreparedness citing their over eight months experience with online learning. In fact, all students indicated that they felt prepared for online learning except for bouts of anxiety associated with the occasional internet drop or disconnection from the classes, which sometimes happened and which they simply had no control over. There was however, less panic and feasible contingency plans when these occurred, so they did not take away much from the online experience. Students admitted though that they continue to feel a sense of *'unease'* knowing that such disruptions can happen at any time and that they are entirely out of their control. By phase three of this work, 76% of students said they felt 'well-prepared' for online learning in spite of unforeseen interruption. The following two excerpts capture the sentiments expressed by most students.

> 'I am really good with the online things now"
> "It is easy for me now … I am not stressed … even when current goes…"

### *Challenges During Online Learning*

While levels of frustration appeared to have dropped in phase three, feelings of isolation did not. Interview data in phase three of the research revealed that 93% of the students used the words *'lonely'* or *'isolated'* in their responses to challenges experienced during online learning. Probing students' responses seem to suggest that they came to the shocking realization that their anticipation that online physics learning would be short-lived was in fact unrealistic and the likelihood that learning will continue like this for an indefinite period, was a reality they must accept. The thought of no physical interaction with peers and their teacher seemed to have further amplified their feelings of isolation; so much so that students, who did not explicitly share their feelings of loneliness in the earlier phases of the research, did so in phase three. The following captures students' sense of isolation:

> "…online is okay now but it is going on for too long…I really…really miss my classmates…"

> "I feel better when I talk about the work with my friends…I am fed-up of doing it by myself"

### *Follow-through After Online Learning*

In phase three of the research however, responses about follow-through after online lessons suggested that things had changed. Students indicated that there was reduced follow-through from the teacher, even though the demand to complete and submit assignments, lab reports, and homework remained. Students reported that their teacher was not as meticulous in following through with reminders or with providing guidance and feedback in a timely manner. Furthermore, assignments including homework tasks were not always marked and returned promptly. While students did not openly voice their views on why they felt this change occurred, their responses seem to implicitly suggest that the change may be associated with teacher burn-out. This change in teacher follow-through directly affected students to the extent that 68% of students said that they were procrastinating more than they had done in phases one and two. Increased procrastination, coupled with their existing discontent about out-of-class collaborations, resulted in a situation where at the end of phase three students were vocally disappointed with the effort made by their teacher to facilitate meaningful follow-through learning. The reasons for this view held by the students were not explicitly solicited, nor were they ascertained herein. While it would be interesting to know these reasons, the aspect was deemed to be outside the scope of the current work. The following sentiment, expressed by one student, captures the view of many students in the class and is telling in this regard:

> "…it is like miss [is] too fed-up with online … and maybe with us … she is not sending us reminders on the phone like she did before …"

Table 1 summarizes the excerpts from students' responses for the themes in phase one of the study. Table 2 summarizes the excerpts from students' responses for themes in phases two and three.

**Table 1**

*Excerpts From Students' Responses During Phase One*

| Study Phase | Emerging Theme | Students (verbatim) comments |
|---|---|---|
| 1 | Readiness for online learning | • *"… I did not know what I had to do …"*<br>• *"… having classes on the computer was like … weird … miss was not nearby"*<br>• *"I had no wifi … but we had to get it for class …"*<br>• *"When electricity went in the past I did not bother … but for my class it was a big problem … and I had no desk at home …"*<br>• *"My mom had to find the money to get me a desk and a chair"*<br>• *"I did not know which box to press to share my screen"*<br>• *"I did not have my friends around to ask for help … I was alone …"* |
| | Challenges during online learning | • *"I could not ask my friend for help with my work … I missed that"*<br>• *"…doing the lab by myself … on my home table was not interesting … like in school"*<br>• *"… knowing where to send my work was hard … miss said there was a folder … I could not find it and I did not want to ask again"*<br>• *"I got into the thing that showed how light bended but I could not move to the next thing to see how it reflected"* |
| | Follow-through after online learning | • *"I did not feel I had to do my homework … like when miss gave us it in class … and asking for it the next day …"*<br>• *"miss sent us reminders on our phones to do the revision so I … did it"* |

**Table 2**

*Excerpts From Students' Responses During Phases Two and Three*

| Study Phase | Emerging Theme | Students (verbatim) comments |
|---|---|---|
| 2 | Readiness for online learning | • *"I can use the computer better now … but some things still hard …"*<br>• *"I now understand how to share my work with my friends on the computer"*<br>• *" when the current go … I know how to get back my work now"* |
| | Challenges during online learning | • *"I am not so confused as when we first started to use the computer for class"*<br>• *"I still prefer to be in class … but I am okay with online now …"*<br>• *"I feel lonely while learning … I miss my friends …"* |
| | Follow-through after online learning | • *"it is good that miss keeps messaging to remind me to do my work when I am home"*<br>• *"I wish I could do my homework with my friends … to talk about the homework"* |
| 3 | Readiness for online learning | • *"I am really good with the online things now"*<br>• *"It is easy for me now … I am not stressed … even when current goes…"* |
| | Challenges during online learning | • *"…online is okay now but it is going on for too long … I really miss my classmates …"*<br>• *"I feel better when I talk about the work with my friends … I am fed-up of doing it by myself"* |
| | Follow-through after online learning | • *"…it is like miss [is] too fed-up with online … and maybe with us … she is not sending us reminders on the phone like she did before …"* |

## Conclusions

This work revealed that at the onset of the pandemic, physics students in this group were unprepared for online learning in several ways and mostly because of the unfamiliar learning pathway that lay ahead for them. Many did not have a functional online work area, and most did not have access to reliable internet and Wi-Fi connectivity even though they may have had access to devices. These elements of unpreparedness, however, were addressed as online physics learning continued through the pandemic. By the end of phase three of this work, students were well equipped to engage in online learning, except for the looming sense of unease many claim to continue to experience in respect of disconnectivity or electrical power failure.

Regarding the challenges during online learning, students experienced high levels of frustration at the onset of the pandemic. These frustration-driven challenges were mainly a result of not being able to engage in the scientific process in the traditional way through engagement in real-time, live laboratory experiments and hands-on learning activities in the familiar collaborative setting. Linked to the absence of face-to-face peer collaboration, students indicated that peer sharing, input, and feedback were not the same as in pre-pandemic learning. The pandemic arrangement had transformed their personal learning into a very isolated and lonely exercise. Elevated levels of isolation and loneliness only served to intensify their levels of frustration as online physics learning continued through the pandemic. By phase three of the study, students had become complacent and surrendered themselves to online learning, though frustration levels and feelings of isolation remained high.

Teacher support and attention to follow-through after online lessons were helpful to students in terms of keeping them engaged, motivated, and on track with the completion of homework, lab reports, and other assignments. They were very appreciative of this effort from their teacher and reported that it made online learning 'workable' for them. Unfortunately, this level of support was not sustained through this work. By phase three, students indicated that they were not receiving the same kind of support from their teacher as in phases one and two. While the reason for this remains largely uncertain, there was implicit speculation arising from students' responses, that it may be linked to 'teacher burn-out.' Notwithstanding, students were unanimous in their views that this occurrence had a negative impact on their online physics learning which led to higher levels of procrastination and increased feelings of frustration. The latter unfortunately being a reality in phase three in spite of the fact that students were better prepared and had fewer challenges than in phases one and two.

## Recommendations

The concept of teacher burnout has been a concerning one even before the pandemic. This study seems to suggest that it continues to be a troubling educational issue during the pandemic and in fact may have become a more critical issue in the online teaching and learning environment. In that regard, future work on the prevalence and nature of teacher burn-out in the online teaching environment and how it impacts online learning for students is worthy of pursuit. In addition, this work looked at online learning in a physics class and while some aspects of the findings here may be applicable to online learning in other science subjects, it may not be generalizable for online learning in other subject areas. It will therefore be useful to interrogate students' online learning experiences in other disciplines and compare those findings with that of the online physics learning experiences revealed in this work.

## Implications

This study is instructive for online learning in general but particularly for online learning in science disciplines. It highlights students' concerns, their challenges, preparedness, and their expectations in the online learning environment. Science teachers now have a view of students' experiences and feelings and may be better able to understand students' behavior and levels of participation during online lessons. While teachers, for the most part, may have been facilitating learning in the online environment in the best way they know, they now have at their disposal students' perspectives, in the form of formative feedback, which can be used to further inform their online practice.

Technology in teaching is here to stay and while the pandemic has ushered in online teaching and learning in a hastened manner, it is something that teachers and students would have eventually had to contend with. While this work pointed out some of the pitfalls with online learning, it showed that it is an approach that can be adopted post-pandemic. Furthermore, this work revealed some of the common considerations that should be taken into account when planning for online instruction so as to alleviate the challenges and shortcomings highlighted herein. No one knows if or when we will experience another pandemic or other pandemic-like situations. Even now, circumstances remain uncertain. The pandemic has shown us the importance of preparing our students for a world in which remote learning, partially or entirely, is a likely option. One way students in the Trinidad and Tobago context can prepare is to reflect on the experiences, views, and feelings revealed by students in this work who took an online physics course for over one year. The experiences of these students can shed light on the concerns, challenges, and learning opportunities of remote learning. The insights gleaned from this work might help students to better prepare to navigate the challenges of online learning and may be helpful to them succeeding in learning science in an online platform.

*The author received no financial support for the research, authorship, and/or publication of this manuscript.*

**Rawatee Maharaj-Sharma** (rawatee.maharaj-sharma@sta.uwi.edu) is the current Director and a Senior Lecturer in Science Education (Physics) at the School of Education, UWI, St. Augustine Trinidad and Tobago. She also served as the Coordinator of the Bachelor of Education Programme

for ten years prior to her appointment as Director. Her research interests include novel approaches in science education, science students' voices, and students' conceptions and misconceptions in science.

## References

Arrieta, G., Dancel, J., & Agbisit, M.J. (2020). Teaching science in the new normal: Understanding the experiences of junior high school science teachers. *MIPA Journal of Education*, *2*(2), 146-162.

Barrot, J. S., Llenares, I. I., & Del Rosario, L. S. (2021). Students' online learning challenges during the pandemic and how they cope with them: The case of the Philippines. *Education Information Technology*, *26*(6), 7321-7338.

Blackmon, S., & Major, C. (2012). Student experiences in online courses: A qualitative synthesis. *The Quarterly Review of Distance Education*, *13*(2), 2012, 77–85.

Borup, J., Walters, S., & Call-Cummings, M. (2020) Student perceptions of their interactions with peers at a cyber charter high school. *Online Learning*, *24*(2). http://dx.doi.org/10.24059/olj.v24i2.2015.

Brown, S. (2020). Teaching science methods online during COVID-19: Instructor's segue into online learning. *Electronic Journal for Research in Science and Mathematics Education*, *24*(3), 14-18.

Chen, L. K., Dorn, E., Sarakatsannis, J., & Wiesinger, A. (2021). *Teacher survey: Learning loss is global—and significant*. McKinsey & Company. https://www.mckinsey.com/industries/public-and-social-sector/our-insights/teacher-survey-learning-loss-is-global-and-significant.

Colaizzi, P. F. (1978) Psychological research as the phenomenologist views it. In R. S. Valle, & K. Mark (Eds.), *Existential Phenomenological Alternatives for Psychology* (pp.48-71). Oxford University Press.

Contant, T. L., Tweed, L., Bass, J. E., & Carin, A. A. (2018). *Teaching inquiry through inquiry based instruction*. Pearson.

Creswell, J.W. (2013). *Research design: Qualitative approach, quantitative and mixed.* Sage.

Demirkol, M., & Kazu, I. Y. (2014). Effect of blended environment model on high school students' academic achievement. *The Turkish Online Journal of Educational Technology*, *13*(1), 78–87.

Dorn, E., Hancock, B., Sarakatsannis, J., & Viruleg, E. (2020). *COVID-19 and learning loss—disparities grow and students need help*. McKinsey & Company. https://www.mckinsey.com/industries/public-and-social-sector/our-insights/covid-19-and-learning-loss-disparities-grow-and-students-need-help.

Dziuban, C., Graham, C.R., Moskal, P.D., Norberg, A., & Sicilia, N. (2018). Blended learning: The new normal and emerging technologies. *International Journal of Educational Technology in Higher Education*, *15*(1), 1-16.

Etikan, I., Musa, S. A., & Alkassim, R .S. (2016). Comparison of convenience and purposive sampling. *American Journal of Theoretical and Applied Statistics, 5*(1), 1-4.

Furtak, E. M., & Penuel, W. R. (2019). Coming to terms: Addressing the persistence of "hands-on" and other reform terminology in the era of science as practice. *Science Education*, *103*(1), 167–186. https://doi.org/10.1002/sce.21488

Gedera, D., Williams, J., & Wright, N. (2015). Identifying factors influencing students' motivation and engagement in online courses. In C. Koh (Ed.), *Motivation, Leadership and Curriculum Design* (pp. 13-23). Springer.

Gibbs, G. (2018). Thematic coding and categorizing. In U. Flick (Ed.), *Analyzing qualitative data* (pp. 53-74). Sage. https://dx.doi.org/10.4135/9781526441867.n4.

Gilles, B., & Britton, S. (2020). Moving online: Creating a relevant learning experience for preservice teachers in the time of COVID-19. *Electronic Journal for Research in Science and Mathematics Education*, *24*(3), 19-28.

Kalloo, R. C., Mitchell, B., & Kamalodeen, V. J. (2020). Responding to the COVID-19 pandemic in Trinidad & Tobago: Challenges and opportunities for teacher education. *Journal of Education for Teaching*, *46*(4), 452-462. https://doi.org/10.1080/02067476.2020.1800407.

Lapitan, L. D. S., Tiangco, C. E., Sumalinog, D. A. G., Sabarillo, N. S., & Diaz, M. J. (2021). An effective blended online teaching and learning strategy during the COVID-19 pandemic. *Education for Chemical Engineers*, *35*, 116-131.

Linn, M. C., Gerard, L., Matuk, C., & McElhaney, K. W. (2016). Science education: From separation to integration, *Review of Research in Education*, *40*(1), 529- 587.

Loades, M. E., Chatburn, E., Higson-Sweeney, N., Reynolds, S., Shafran, R., Brigden, A., Linney, C., McManus, M. N., Borwick, C., & Crawley, E. (2020). Rapid systematic review: The impact of social isolation and loneliness on the mental health of children and adolescents in the context of COVID-19. *Journal of the American Academy of Child & Adolescent Psychiatry*, *59*(11), 1218–1239.

Mercado, J. (2021). A phenomenological study on students' experiences in learning physics in an online class. *Science Education International*, *32*(4), 384-389.

Miller, K. E. (2021). A light in students' lives: K-12 teachers' experiences (re)building caring relationships during remote learning. *Online Learning*, *25*(1), 115-134.

Ministry of Education, Trinidad and Tobago (2012). Education sector strategic plan 2011–2015. Port of Spain, Trinidad: Author.

Obbink, K., & Wheeler, G. (1993). *Teaching and learning via the network: National teacher enhancement network*. Network Coalition for Networked Information. https://www.cni.org/projects/netteach/1993/prop33.html

Rempel, D. (2020). Scientific collaboration during the COVID-19 pandemic: N95DECON.org. *Annals of Work Exposures and Health, 64*(8), 775–777.

Salamat, P., Ahmad, L., Bakht, G., & Saifi, I. (2018). Effects of e-learning on students' academic learning at university level. *Asian Journal of Social Sciences and Humanities*, *2*(2), 1-12.

Singh, S., Roy, D., Sinha, K., Parveen, S., Sharma, G., & Joshi, G. (2020). Impact of COVID-19 and lockdown on mental health of children and adolescents: A narrative review with recommendations. *Psychiatry Research*, *293*, 113429. https://doi.org/10.1016/j.psychres.2020.113429.

UIS (2009). *Guide to measuring information and communication technologies (ICT) in education*. UIS.

United Nations Educational, Scientific and Cultural Organization. 2017. *Leveraging information and communication technology to achieve Education 2030: Report of the UNESCO 2017 International Forum on ICT and Education 2030, 10-11 July 2017, Qingdao, the People's Republic of China***.** ED/PLS/ICT/2017/03. UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000259587

Vasquez, S. (2020). Developing an online learning environment for community college students enrolled in human anatomy & physiology and microbiology courses amid COVID-19. *Electronic Journal for Research in Science and Mathematics Education*, *24*(3), 53-59.

Wirihana, L., Welch, A., Williamson, M., Christensen, M., Bakon, S., & Craft, J. (2018). Using Colaizzi's method of data analysis to explore the experiences of nurse academic teaching on satellite campuses. *Nurse Research*, *25*(4), 30-34.

Zhu, C., Kintu, M. J., & Kagambe, E. (2013) Blended learning effectiveness: The relationship between student characteristics, design features and outcomes. *International Journal Educational Technology High Education*, *14*, 7. https://doi.org/10.1186/s41239-017-0043-4

ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 27, NO. 4, 157-175

# How the Perception of the Inclusiveness of the Learning Environment Predicts Female and Male Students' Physics Self-efficacy, Interest, and Identity in an Introductory Course for Bioscience Majors

Sonja Cwik
*University of Pittsburgh*

Chandralekha Singh
*University of Pittsburgh*

**ABSTRACT**

Students' physics self-efficacy, interest, and identity in introductory courses can influence their outcomes in that course and their future career aspirations. A lot of work has focused on the role these motivational beliefs play in students' outcomes without attention to the role the perception of the inclusiveness of the learning environment plays in shaping these beliefs. This study used a validated survey instrument to probe the motivational outcomes of 873 students at the end of a two-semester mandatory introductory physics course primarily for bioscience majors, in which women make up 62% of the class. We investigated how the perception of the inclusiveness of the learning environment (perceived recognition, peer interaction, and belonging) predicts male and female students' motivational outcomes, including their physics self-efficacy, interest, and identity. We found that these motivational beliefs were lower for women and the perception of the inclusiveness of the learning environment plays a major role in explaining these motivational outcomes. These findings can be useful in providing support and creating an equitable and inclusive learning environment to help all students excel in algebra-based physics courses for bioscience majors.

*Keywords:* undergraduate, identity, equity and inclusion, motivational beliefs, gender, physics

## Introduction and Theoretical Framework

Studies have shown that motivational factors, such as a student's identity, self-efficacy, and interest in a particular field are important for students' career interests (Correll, 2004; Hazari et al., 2013; Ketenci et al., 2020; Stets et al., 2017), learning (Han et al., 2021; Vincent-Ruz & Schunn, 2017), and continuation in science, technology, engineering, and math (STEM) fields (Britner, 2008; Kosiol et al., 2019; Mujtaba & Reiss, 2014; Robinson et al., 2019). For example, students were more likely to take courses or pursue a career in science if they had higher competency belief or self-efficacy (Britner, 2008; Correll, 2001, 2004; Eccles, 1994; Wang & Degol, 2013), display higher interest in science (Benbow & Minor, 1986), or have a higher science identity (Chemers et al., 2011; Robinson et al., 2019; Stets et al., 2017). A gender gap favoring men in motivational factors (Cwik & Singh, 2023; Maries et al., 2020; Maries et al., 2022; Louis & Mistele, 2012; Marshman et al., 2018; Nissen & Shemwell, 2016; Santana & Singh, 2023; Stewart et al., 2020) and conceptual tests (Traxler et al., 2018) have been studied in STEM courses. Specifically, in physics, many studies have been done on calculus-based physics courses, where women are underrepresented, to understand and address the low diversity in the courses.

However, stereotypes about who can excel in physics could affect women even in these physics courses in which they are not underrepresented, e.g., mandatory two-semester physics course sequence for bioscience majors. One common stereotype is that genius and brilliance are important factors in success in physics (Leslie et al., 2015). However, genius is often associated with boys (Upson & Friedman, 2012), and girls from a young age shy away from fields associated with innate brilliance or genius (Bian et al., 2017). Studies have found that by the age of six, girls are less likely than boys to believe they are *really smart* and less likely to choose activities that are made for *brilliant people* (Bian et al., 2017). As these students get older, norms in the science curriculum hold less relevance for girls, since they tend not to represent the interest and values of girls (Archer et al., 2017). All these stereotypes and factors can influence female students' perceptions about their ability to do physics before they enter the classroom. Thus, it is possible that although women are the majority in algebra-based physics courses primarily for bioscience majors, these societal stereotypes can still influence their outcomes in the physics class unless instructors attempt to create a fair and inclusive learning environment.

Students' identity in STEM disciplines has been shown to play an important role in their participation in classes and professional choices (Carlone & Johnson, 2007; Gee, 2000; Hazari et al., 2010; Stets et al., 2017; Tonso, 2006; Vincent-Ruz & Schunn, 2018). However, prior studies have shown that it can be more difficult for women to form a physics identity than men (Archer et al., 2017; Godwin et al., 2016; Lock et al., 2013; Monsalve et al., 2016). Students' physics identity is influenced by their self-efficacy, interest, and perceived recognition (Flowers III & Banda, 2016; Godwin et al., 2016; Li & Singh, 2022; Lock et al., 2013; Potvin & Hazari, 2013; Sawtelle et al., 2012).

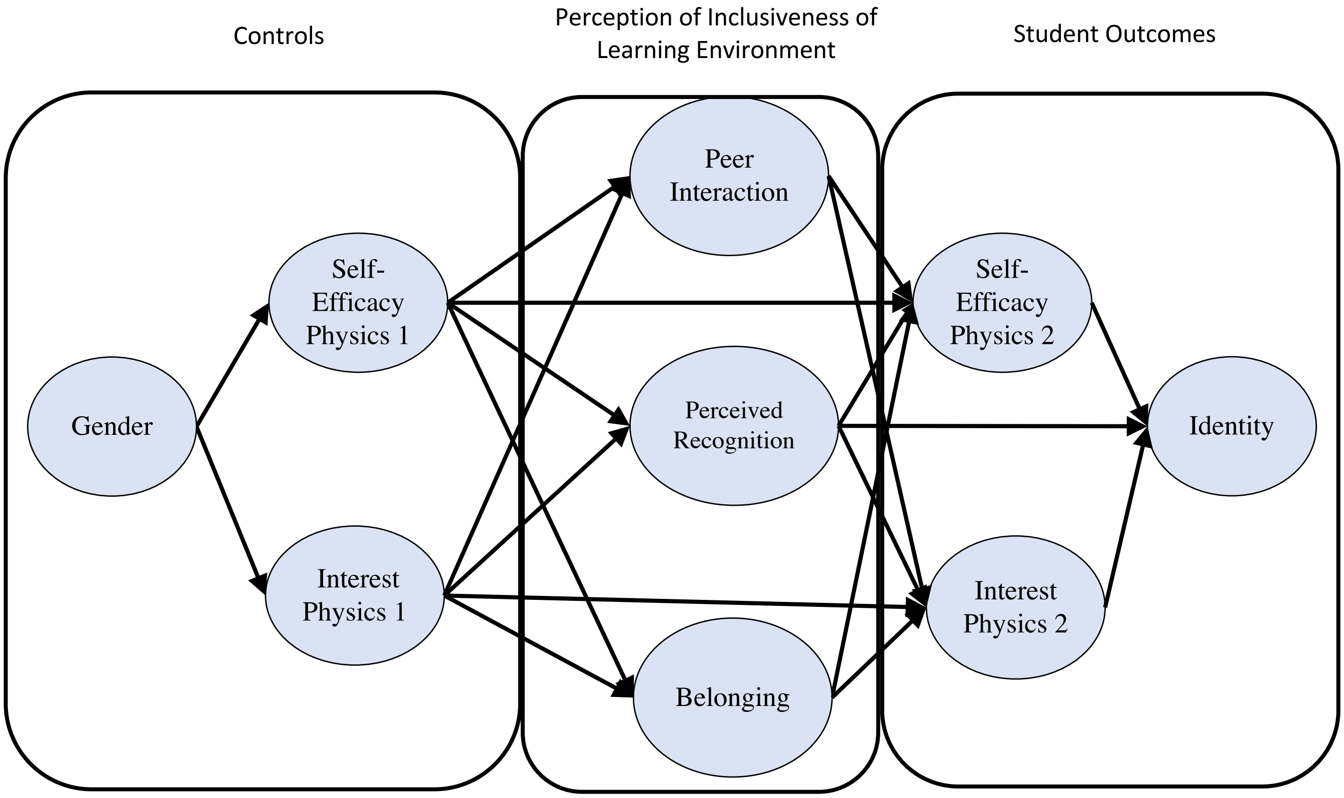
Self-efficacy is a person's belief that they can succeed in a particular activity or course (Bandura, 1977, 1994). Students' self-efficacy in academic courses may be influenced by the classroom environment (Britner & Pajares, 2006; Dou et al., 2018; Gao, 2020; Schunk & Pajares, 2002) and different teaching strategies (Bailey et al., 2017; Fencl & Scheel, 2005; Nissen & Shemwell, 2016). Self-efficacy has been shown to impact students' engagement, learning, and persistence in science courses (Bouffard-Bouchard et al., 1991; Britner, 2008; Cavallo et al., 2004; Correll, 2004; Felder et al., 1995; McKinney et al., 2021; Sawtelle et al., 2012; Dale H Schunk & Frank Pajares, 2002; Vincent-Ruz & Schunn, 2017; Zimmerman, 2000). Similarly, interest in a particular discipline may affect students' STEM career orientation (Lichtenberger & George-Jackson, 2013; Uitto, 2014) and persistence in STEM courses and majors (Harackiewicz et al., 2002; Hidi, 2006; Strenta et al., 1994). One study showed that changing the curriculum to stimulate the interest of female students helped improve all the student's understanding. the end of the year (Häussler & Hoffmann, 2002).

Therefore, it is important to investigate factors that influence students' physics identity, self-efficacy, and interest. Our framework posits that factors in the learning environment can influence students' motivational outcomes including their physics self-efficacy, interest, and identity. Specifically, we investigated students' perception of the inclusiveness of their learning environment, which in this study consists of their interactions with their peers, their sense of belonging, and perceived recognition by others (including friends, family, and their instructors/teaching assistants) and how it predicts their physics self-efficacy, interest, and identity. We investigated these three perceptions of the inclusiveness of the learning environment factors since instructors can influence these factors to help improve the experiences of students in their classes. Additionally, the selection of SEM model is guided by interviews with students (Li & Singh, 2023a; Li & Singh, 2023b). Furthermore, students' sense of belonging in science has been shown to correlate with retention as well as their self-efficacy (Goodenow, 1993; Masika & Jones, 2016); so it is important to investigate how students' sense of belonging predicts their self-efficacy at the end of the semester. Students' positive interactions with peers have been shown to enhance their understanding and engagement in courses (Meltzer & Manivannan, 2002; Rockinson-Szapkiw et al., 2021). Moreover, perceived recognition has been shown to play an important role in a student's identity (Hazari et al., 2010; Kalender et al., 2019; Vincent-Ruz & Schunn, 2018) as well as being an important factor in women's motivation (Goodenow, 1993).

While many studies have investigated gender differences in motivational factors in introductory physics courses where women are underrepresented, most have not taken into account the factors in the students' learning environment. This study examined the difference between male and female students' perceptions of the inclusiveness of the learning environment on their motivational beliefs at the end of the algebra-based introductory physics sequence for bioscience majors in which women are not underrepresented. The perception of the inclusiveness of the learning environment is shaped by experiences students have in the classroom as well as interactions outside of the classroom like office hours, email correspondence with the instructor or TA, and students studying or doing homework together. We control for students' self-efficacy and interest at the end of physics 1 since these are students' beliefs about physics when they enter the class based on prior experiences. The perception of the inclusiveness of the learning environment includes students' perception of their peer interaction, sense of belonging, and perceived recognition (from instructors, TAs, friends, and family). Lastly, we investigated the students' outcomes of physics self-efficacy, interest, and identity at the end of physics 2. An example of our final model is shown in Fig. 1. All paths were considered from left to right in our model, however, only some of the paths are shown in Fig. 1 for clarity.

**Figure 1**

*Schematic representation of the model based on the theoretical framework. From left to right, all possible regression paths were considered. However, only some (not all) of the regression paths are shown.*



## Research Questions

**RQ1** Are there gender differences in students' motivational characteristics including physics self-efficacy, interest, and identity at the end of the course?

**RQ2** How does the perception of the inclusiveness of the learning environment (including peer interaction, perceived recognition, and belonging) predict motivational factors at the end of the course?

**RQ3** What is the effect of controlling for high school factors (e.g., high school GPA and SAT Math scores) on the motivational factors at the end of the course?

## Methodology

### Participants

In this study, we analyzed results from 873 students who completed a motivational survey at the end of the semester in introductory algebra-based physics 1 and physics 2 over two years. These courses are typically taken by students primarily on the bioscience track in their junior or senior year of undergraduate studies, with approximately 50%-70% of students expressing a desire to pursue future careers in health professions. The university provided demographic information such as age, gender, and ethnic/racial information using an honest broker process by which the research team received the information without knowledge of the identities of the participants. From the university data, the participants were 38% male and 62% female students. The gender data provided by the university include only binary options of *male* and *female*. We recognize gender as a socio-cultural and nonbinary construct; however, the data provided by the university only included binary options (less than 1% of the students did not provide this information and thus were not included in this study).

### Instrument Validity

This study measured students' physics identity, self-efficacy, interest, sense of belonging, perceived recognition, and interaction with their peers for students enrolled in introductory algebra-based physics courses for bioscience majors. The survey items were constructed from items validated by others (Adams et al., 2006; Glynn et al., 2011; *PERTS Academic Mindsets Assessment*, 2020) and re-validated in our context using one-on-one student interviews (Marshman et al., 2018), exploratory factor analysis (EFA), confirmatory factor analysis (CFA) (Cohen, 2013), analyzing the Pearson correlation between different constructs (Cohen, 2013), and using Cronbach alpha (Cronbach, 1951). The *physics identity* questions evaluated whether the students see themselves as a physics person (Hazari, Potvin, et al., 2013). The *physics self-efficacy* questions measure students' confidence in their ability to answer and understand physics problems (Glynn et al., 2011; Hazari, Potvin, et al., 2013; Learning Activation Lab, 2017; Schell & Lukoff, 2010). The *interest in physics* questions measured students' enthusiasm and curiosity about learning physics and ideas related to physics (Learning Activation Lab, 2017). The *sense of belonging* questions evaluated whether students felt like they belonged in the introductory physics classroom (Goodenow, 1993; *PERTS Academic Mindsets Assessment*, 2020). The *perceived recognition* questions measured the extent to which the students thought other people see them as physics persons (Hazari et al., 2013). Lastly, the *peer interaction* questions measured whether students thought that working with their peers was beneficial, e.g., for increasing their confidence and enthusiasm to do physics (Sayer et al., 2016; Singh, 2005). The physics identity instrument only included one question, which is consistent with past studies since it has been difficult to make other questions that factor in this category in exploratory factor analysis (Godwin et al., 2021; Godwin et al., 2016; Hazari et al., 2013; Hazari et al., 2010). The questions in the study were designed on a Likert scale of 1 (low endorsement) to 4 (high endorsement) except for the sense of belonging questions which were designed on a scale of 1 to 5 to keep them consistent with the original survey (Likert, 1932). A lower score was indicative of a negative endorsement of the survey construct while a higher score was related to a positive belief in the construct. Some of the items were reverse-coded.

After performing an EFA to ensure that the items were factored according to different constructs as envisioned, a CFA was conducted to establish a measurement model for the constructs and used in SEM. The squares of the CFA factor loadings (lambda) indicate the fraction of variance explained by the factors. The model fit indices were good and all the factor loadings (lambda) were above 0.6, which indicates good loadings (Cohen, 2013). The results of the CFA model which include the factor loadings are shown in Table 1.

**Table 1**

*Survey questions for each of the motivational constructs along with factor loadings from the Confirmatory Factor Analysis (CFA) result for all students (N = 873). The rating scale for most of the self-efficacy and interest questions was NO! no yes YES! while the rating scale for the physics identity, peer interaction, and perceived recognition questions was strongly disagreed, disagree, agree, strongly agree. The rating scale for the physics belonging questions was not at all true, a little true, somewhat true, mostly true, and completely true. All p-values (of the significance test of each item loading) are $p < 0.001$.*

| Construct and Item | Lambda |
|---|---|
| **Physics Identity** | |
| I see myself as a physics person | 1.00 |
| **Physics Self-Efficacy** | |
| I can help my classmates with physics in the laboratory or recitation | 0.64 |
| I understand concepts I have studied in physics | 0.71 |
| If I study, I will do well on a physics test | 0.73 |
| If I encounter a setback in a physics exam, I can overcome it | 0.66 |
| **Physics Interest** | |
| I wonder about how physics works | 0.70 |
| I find physics† | 0.81 |
| I want to know everything I can about physics | 0.76 |
| I am curious about recent discoveries in physics | 0.71 |
| **Physics Perceived Recognition** | |
| My family sees me as a physics person | 0.91 |
| My friends see me as a physics person | 0.91 |
| My physics instructor and/or TA sees me as a physics person | 0.68 |
| **Physics Belonging** | |
| I feel like I belong in this class | 0.80 |
| I feel like an outsider in this class | 0.68 |
| I feel comfortable in this class | 0.85 |
| I feel like I can be myself in this class | 0.69 |
| Sometimes I worry I do not belong in this class | 0.61 |

| | |
|---|---|
| **Physics Peer Interaction** | |
| My experiences and interactions with other students in this class… | |
| Made me feel more relaxed about learning physics | 0.75 |
| Increased my confidence in my ability to do physics | 0.95 |
| Increased my confidence that I can succeed in physics | 0.94 |
| Increased my confidence in my ability to handle difficult physics problems | 0.85 |

† the rating scale for this question was very boring, boring, interesting, very interesting.

Zero-order pair-wise Pearson correlations are given in Table 2. These Pearson's *r* values signify the strength of pairwise relationships between variables. The inter-correlations vary in strength, but none of the correlations are so high that the constructs cannot be separately examined. The only high inter-correlations were between post-interest in physics 1 and post-interest in Physics 2 (0.89) and between physics identity in physics 2 and perceived recognition in physics 2 (0.82). Prior research has shown there is a high correlation in interest throughout the introductory physics classes (Kalender et al., 2017; Marshman et al., 2018). Perceived recognition questions ask about external identity, whereas physics identity asks about internal identity so there tends to be a high correlation between these constructs. Both correlations are low enough that they should be separate constructs.

**Table 2**

*Pearson inter-correlations are given between all the predictors and outcomes. All p-values are < 0.001.*

| Pearson Correlation Coefficient | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Observed Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1. Post Self-Efficacy in physics 1 | -- | -- | -- | -- | -- | -- | -- | -- |
| 2. Post Interest in physics 1 | 0.58 | -- | -- | -- | -- | -- | -- | -- |
| 3. Perceived Recognition in Physics 2 | 0.39 | 0.51 | -- | -- | -- | -- | -- | -- |
| 4. Peer Interaction in physics 2 | 0.36 | 0.28 | 0.36 | -- | -- | -- | -- | -- |
| 5. Belonging in physics 2 | 0.53 | 0.38 | 0.45 | 0.62 | -- | -- | -- | -- |
| 6. Post Self-Efficacy in physics 2 | 0.72 | 0.46 | 0.58 | 0.67 | 0.79 | -- | -- | -- |
| 7. Post Interest in physics 2 | 0.45 | 0.89 | 0.58 | 0.39 | 0.47 | 0.60 | -- | -- |
| 8. Physics Identity in physics 2 | 0.46 | 0.52 | 0.82 | 0.37 | 0.45 | 0.58 | 0.57 | -- |

## Analysis

Initially, we compared female and male students' mean scores of the predictors and outcomes for statistical significance using *t*-tests and for the effect size using Cohen's *d* (Cohen, 2013). Cohen's *d* is $d = (\mu_m - \mu_f)/\sigma_{pooled}$, where $\mu_m$ is the average score of male students, $\mu_f$ is the average score of female students, and$\sigma_{pooled}$ is the pooled standard deviation for all students. In general, $d = 0.20$ indicates a small effect size, $d = 0.50$ indicates a medium effect size, and $d = 0.80$ indicates a large effect size (Cohen, 2013).

To quantify the statistical significance and relative strength of our framework's path links, we used Structural Equation Modeling (SEM) as a statistical tool by using R (lavaan package) with a maximum likelihood estimation method (Team, 2013). SEM is a statistical method comprising two parts that are completed together; a measurement part that consists of CFA and a structural part that consists of path analysis. Path analysis can be considered an extension of multiple regression analysis, but it allows one to conduct several multiple regressions simultaneously between variables in one estimation model and allows us to predict multiple outcomes simultaneously. SEM also allows us to calculate the overall goodness of fit and for all estimates to be standardized simultaneously so there can be a direct comparison between different structural components. Thus, we can test more complicated models than we would with multiple regression analysis. A full SEM model combines this path analysis with CFA, allowing researchers to test the validity of their constructs (using CFA) and the connections between these constructs (using path analysis) in a single model with a single set of fit indices. We report the model fit for SEM by using the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residuals (SRMR). Commonly used thresholds for the goodness of fit are: CFI and TLI > 0.90, and RMSEA and SRMR < 0.08 (MacCallum et al., 1996).

Initially, we performed gender moderation analysis by conducting multi-group SEM, i.e., the model estimates were performed separately for men and women to check whether any of the relations between variables show differences across gender by using "lavaan" [56]. In particular, our moderation analysis was similar to our mediation model in Fig. 1 but there was no link from gender, instead, multi-group SEM was performed separately for women and men simultaneously.

To explain what moderation analysis means, we start with a simple moderation analysis example. In a simple moderation analysis involving the predictive relation between only two variables, the predictive relationship (the regression path) between those two variables is tested for two or more different groups (e.g., men and women) simultaneously. If the predictive relationship is different for the groups (i.e., the values of the regression coefficients (β) are not the same for the correlation between the two constructs for different groups), then there is a moderation effect in the model. For example, in a study focusing on how smoking predicts lung cancer, if there was a moderation effect by gender, the predictive relation (regression coefficient) between smoking and lung cancer would be different for women and men. However, if the regression coefficients for how smoking predicts lung cancer were the same for women and men, then there is no moderation by gender and one can just focus on mediation analysis by gender (in other words, we need not separately calculate the regression coefficients for women and men since they are equal, and we can introduce gender as an additional categorical variable in the model to do mediation by gender).

When the model is more complex than the preceding example of smoking and lung cancer as in our SEM model (which has a measurement part involving CFA and a structural part involving path analysis), checking to make sure there are no gender moderation effects involves checking that there are no gender moderation effects for both the measurement and structural parts. For the measurement part, to check for measurement invariance in each step of gender moderation analysis, we fixed different elements of the measurement part of the model to equality across gender and compared the results to the previous step when they were allowed to vary between groups (i.e., for women and men) separately using the Likelihood Ratio Test (Tomarken & Waller, 2005). A non-significant *p*-value at each step indicates that the fit of this model is not appreciably worse than that of the model in the previous step, so the more restrictive invariance hypothesis (when the parameters are set to the same values for women and men) is retained. Therefore, setting those different elements of the measurement part of the model to equality across gender is valid, which means that estimates are not statistically significantly different across groups (i.e., women and men).

First, we tested for *weak* measurement invariance, which determines if survey items have similar factor loadings for men and women. We compared two models, one in which the factor loadings (which represent the correlation between each item and its corresponding construct) for women and men were predicted independently, and the other in which the factor loadings were forced to be equal between the groups (i.e., for women and men). Next, we tested for *strong* measurement invariance, which determines if survey items have similar factor loadings as well as similar intercepts (which represent the expected value of an observed variable when its associated latent variable is equal to zero) for men and women. Similar to weak invariance testing, we compared the models in which these factors were allowed to vary between groups separately for women and men and when they were set equal for women and men. If measurement invariance passes the weak and strong invariance test, i.e., there is no statistically significant difference between models when those parameters for women and men are set equal, then we must check for differences in the path analysis part, i.e., regression coefficients (β) among different latent variables in the model between women and men. This is because differences between the groups could occur at the factor (latent variable) level in regression coefficients (β).

Similar to *weak* and *strong* measurement invariance for the measurement part, when testing the moderation effect in path analysis, the predictive relationship (regression path) between two variables is tested for the two groups (e.g., women and men) simultaneously. If the predictive relationship is different for the groups (i.e., the values of the regression coefficients (β) are not the same for the predictive relationship between the two constructs for women and men), then there is a gender moderation effect in the model. If moderation does not show differences by gender in any of these steps (measurement invariance holds and testing for regression coefficients shows that they can be set equal for women and men), we can utilize a gender mediation model (see Fig. 1). In other words, we can interpret our model the same way for both men and women, and any gender differences can be modeled using a separate gender variable.

In our multi-group SEM model, we found a non-significant *p*-value in each step, and thus measurement invariance holds and the regression coefficients for women and men can be set equal, i.e., there are no moderation effects by gender (for men and women) in our models. Thus, we concluded that our SEM model can be interpreted similarly for men and women and we can use gender mediation analysis (instead of doing moderation by gender). Therefore, we tested the theoretical model in mediation analysis, using gender as a variable (1 for male and 0 for female) directly predicting items to examine the resulting structural paths between constructs (a schematic representation of the path analysis for the gender mediation model is shown in Fig. 1). In the mediation analysis, if there are paths from gender to any of the constructs as we found in our results (Figs. 2 and 3) discussed in the next section, it implies that women and men did not have the same average value for those constructs controlling for all constructs to the left. However, it is important to note that all of the item factor loadings and regression coefficients between the constructs are the same for women and men (as found from the gender moderation analysis which preceded the mediation analysis).

## Results and Discussion

### Gender Differences in Predictors and Outcomes

We find statistically significant differences in all predictors and outcomes in favor of male students (Table 3). This pattern is similar to what we find in calculus-based physics courses (Kalender et al., 2019) by the end of physics 2 even though in our investigation, women are the majority in the algebra-based courses for bioscience majors (62%). Since a student's physics self-efficacy, interest, and identity can impact not only their performance in that course but also impact students' future career plans, more should be done in the physics classroom to eliminate the gender gap in these motivational factors by creating an equitable and inclusive learning environment.

**Table 3**

*Mean predictor and outcome values by gender and effect sizes (Cohen's d) by gender. The p-values are indicated by no superscript for $p < 0.001$ and superscript "a" for $p = 0.001$.*

| Predictors and Outcomes (Score Range) | Mean | | Cohen's *d* |
|---|---|---|---|
| | Male | Female | |
| Post Self-Efficacy in physics 1 (1-4) | 2.98 | 2.73 | 0.49 |
| Post Interest in physics 1 (1-4) | 2.81 | 2.38 | 0.71 |
| Perceived Recognition in physics 2 (1-4) | 2.24 | 1.98 | 0.39 |
| Peer Interaction in physics 2 (1-4) | 2.94 | 2.79 | $0.24^a$ |
| Belonging in physics 2 (1-5) | 3.69 | 3.45 | 0.28 |
| Post Self-Efficacy in physics 2 (1-4) | 2.94 | 2.73 | 0.40 |
| Post Interest in physics 2 (1-4) | 2.77 | 2.32 | 0.73 |
| Physics Identity in physics 2 (1-4) | 2.19 | 1.85 | 0.45 |

## SEM Path Model

We initially tested moderation analysis between variables using multi-group SEM between female and male students to investigate if any of the relationships between the variables were different across gender. There were no group differences between female and male students at the level of weak, and strong measurement invariance at the level of regression coefficients, so we proceeded to mediation analysis.

Then we used mediation analysis to investigate the extent to which gender differences in students' outcomes at the end of the introductory physics courses (self-efficacy, interest, and physics identity) were mediated by differences in students' initial self-efficacy, interest, and perception of the inclusiveness of the learning environment of the course.

## Model 1

In Model 1 (Fig. 2), the students' perceived recognition, peer interaction, and sense of belonging were part of the learning environment in the class that mediated student outcomes. The model fit indices indicate a good fit to the data: CFI = 0.937, TLI = 0.929, RMSEA = 0.051, SRMR = 0.047. In this model, we found no direct effects from the gender on any of the student outcomes: self-efficacy, interest, and identity in physics 2. We found that gender only had direct connections to self-efficacy ($\beta = 0.27$) and interest ($\beta = 0.37$) in physics 1. To expand further, the statistically significant path from gender to self-efficacy in physics 1 means that men are predicted to have higher mean values in their self-efficacy than women. The reason that there is no direct path from gender to students' identity in physics 2 is that the gender differences in students' physics identity (Table 3) are statistically non-significant when controlling for the other constructs in the model.

In this model self-efficacy, interest, and perceived recognition influence physics identity at the end of physics 2 directly, with perceived recognition having the largest direct effect ($\beta = 0.70$). This is consistent with past models in calculus-based physics courses (Hazari et al., 2010; Kalender et al., 2019). In addition, the total indirect path for physics identity was found by adding all of the indirect paths together. For example, there are two indirect paths from peer interaction to identity. The first path goes from peer interaction → self-efficacy physics 2 →to identity ($0.26*0.13 = 0.03$). The second path goes from peer interaction →interest physics 2 →to identity ($0.15*0.10 = 0.02$). So the total indirect path from peer interaction to identity is $0.03 + 0.02 = 0.05$. Additionally, identity has a total indirect path from belonging of 0.02 and a total indirect effect from perceived recognition of 0.03.

Women may have negative experiences in perceived recognition from instructors and TAs. In Table 3, we observe that both women and men have a mean recognition below the positive threshold (score of 3). Furthermore, women also have lower scores in identity than men.

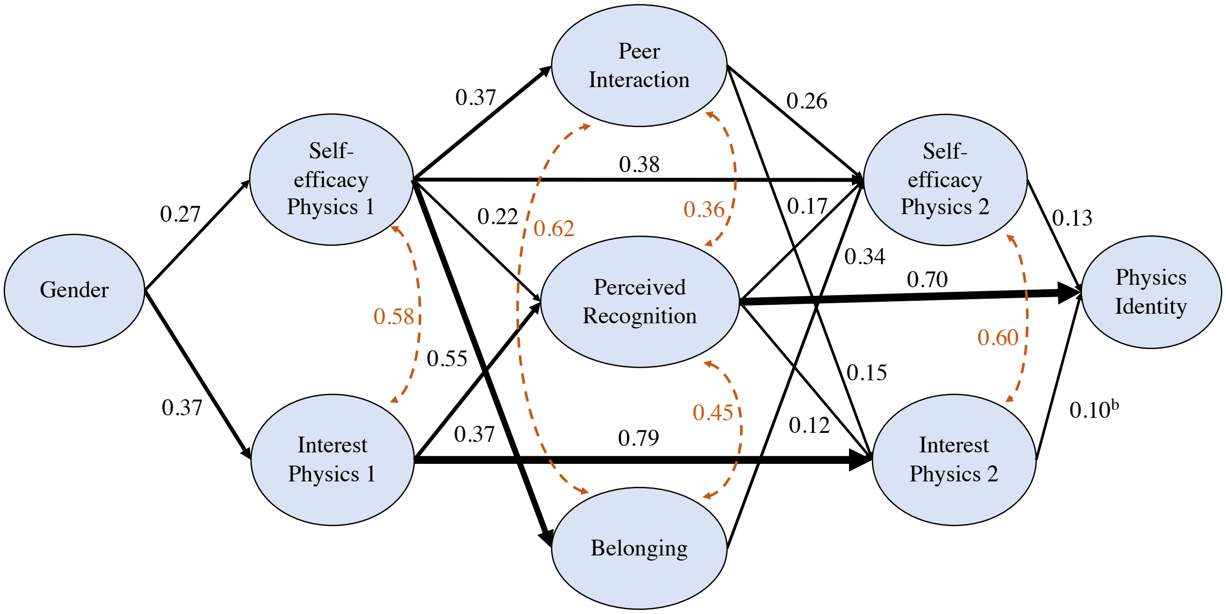
Interest in physics 2 has the largest direct from an interest in physics 1 (β = 0.79) with smaller direct effects from peer interaction (β = 0.15) and perceived recognition (β = 0.12). Although interest in physics 2 is mainly correlated with interest in physics 1, it does not mean that interest can not be changed throughout these courses. Instructors may be able to positively influence students' peer interaction and perceived recognition, which predict students' interest in physics at the end of the course. One possibility to improve students' interest in physics is to provide more problems in class that relate to students' interests and career paths.

Self-efficacy in physics 2 has direct effects from self-efficacy in physics 1 (β = 0.38), belonging (β = 0.34), peer interaction (β = 0.26), and a small effect from perceived recognition (β = 0.17). Self-efficacy is important for students' persistence in class and future careers. Since the learning environment can influence students' self-efficacy, it is important for an instructor to try and improve student belonging, peer interaction, and perceived recognition.

While many studies have investigated gender differences in students' self-efficacy, interest, and identity in introductory physics courses where women are underrepresented (Hazari et al., 2010; Kalender et al., 2019), most have not taken into account the factors in the student's perception of the inclusiveness of their learning environment. From the model, we find that students' perceived recognition directly predicts students' identity, self-efficacy, and interest at the end of the physics 2 courses. Additionally, students' belonging and peer interaction directly predict students' self-efficacy and interest while indirectly predicting students' identity. Thus instructors may be able to improve this perception of the inclusiveness of the learning environment factors in the classroom that predict student motivational outcomes.

**Figure 2**

*Result of the path analysis part of the SEM showing mediation between gender and motivational outcomes in physics through various mediating factors. The line thickness is a qualitative measure of the relative magnitude of β values. All p-values are indicated by no superscript for p <0.001 and superscript "a" for p = 0.003.*

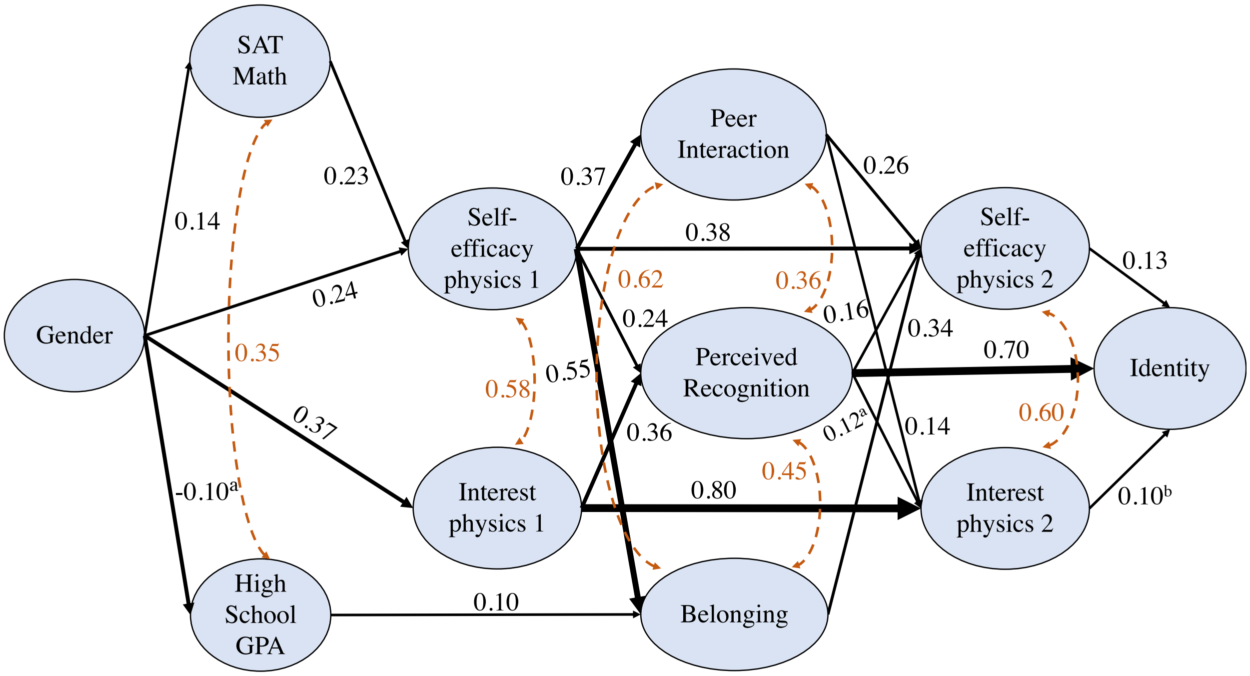


## Adding in High School Factors

We also analyzed a model to investigate if additional aspects of student motivational outcomes can be explained by their prior high school academic measures provided during college admissions. In this model visually represented in (Fig. 3), we added students' SAT math scores and high school GPA as control factors. Gender has a small direct effect on both SAT Math ($\beta = 0.15$), and high school GPA ($\beta = -0.11$), which means women have a slightly higher high school GPA than men while men have a slightly higher SAT Math score than women. SAT Math only has a direct effect on self-efficacy in physics 1 ($\beta = 0.23$) whereas high school GPA only has a small direct effect on belonging in physics 2 ($\beta = 0.10$). Almost all other direct effects (and indirect effects) stayed the same from the first model with some minor changes in the value of the direct effect (for instance, the line from self-efficacy in physics 1 → perceived recognition went from 0.24 in the first model to 0.22 in this model). Thus, we conclude that these additional academic factors do not have a significant influence on student motivational outcomes. We can analyze it more clearly when we look at the variance explained in each outcome (Table 4).

**Figure 3**

*Result of the path analysis part of the SEM showing mediation between gender and motivational outcomes in physics through various mediating factors. The line thickness is the relative magnitude of β values. All p-values are indicated by no superscript for $p < 0.001$, superscript "a" for $p = 0.002$, and superscript "b" for $p = 0.003$.*



## Variance explained by the models

After constructing the models, we calculated the coefficient of determination (adjusted $R^2$), which allows us to analyze the proportion of variance explained by each factor (Table 4). This allows us to analyze if adding additional academic outcomes explains more variance in the student outcomes for self-efficacy, interest, and identity in physics 2. We found that adding high school factors explained the same amount of variance in post-self-efficacy in physics 1 (from 0.06 to 0.11), perceived recognition (0.26 to 0.27), and belonging (0.29 to 0.31). It did not explain any more of the variance in any of the student outcomes (self-efficacy, interest, or identity in physics 2). This is important since these motivational factors could not only influence students' performance in the course but also their future career choices. Since high school academic measures don't predict student motivational outcomes, the learning environment factors that instructors can influence are central in predicting the outcomes.

**Table 4**

*Adjusted coefficients of determination (Adjusted $R^2$) for all variables in the two models on the impact of the learning environment. Model 1 is from part an above and the other model (+ H.S. Factors) is from part b above. H.S. refers to high school. All p-values are < 0.001*

| Variable | Adjusted $R^2$ | |
|---|---|---|
| | Model 1 | + H.S. Factors |
| High School GPA | - | 0.00 |
| SAT Math | - | 0.01 |
| Post Self-Efficacy in physics 1 | 0.06 | 0.11 |
| Post Interest in physics 1 | 0.12 | 0.12 |
| Perceived Recognition in Physics 2 | 0.26 | 0.27 |
| Peer Interaction in physics 2 | 0.12 | 0.13 |
| Belonging in physics 2 | 0.29 | 0.31 |
| Post Self-Efficacy in physics 2 | 0.82 | 0.82 |
| Post Interest in physics 2 | 0.82 | 0.82 |
| Physics Identity in physics 2 | 0.69 | 0.69 |

## Implications and Future Directions

In this research involving both descriptive and inferential quantitative analyses, we find gender gaps in physics motivational beliefs disadvantaging women in mandatory introductory physics courses for bioscience majors in which women are not outnumbered by men, similar to what has been found earlier in introductory calculus-based courses in which women are severely underrepresented (Hazari et al., 2010; Kalender et al., 2019). Our SEM models show that perception of the inclusiveness of the learning environment factors (perceived recognition, peer interaction, and belonging) are important to help explain student outcomes of physics self-efficacy, interest, and identity at the end of physics 2. Instructors can influence these learning environment factors to help improve the experiences of women in their classes. These factors influence each other as well, so if an instructor can improve students' peer interaction, possibly by allowing students to work in groups during class such that there is positive interdependence, it could influence students' sense of belonging as well. Thus, if instructors can provide support for the factors they can control, they have the potential to change student outcomes for the better and make their classrooms more equitable and inclusive in the process.

The motivational belief gaps may at least partly be due to physics instructors and teaching assistants unwittingly reinforcing gender stereotypes about physics and communicating lower expectations for women. They must recognize that what is important is not what their intentions are but the impact they are having on the students. Therefore, professors, instructors, and TAs need to create a learning environment that emphasizes recognizing their students positively, allowing for positive peer interactions, and providing a space where all students can feel like they belong in physics.

From our results, each of these factors plays an important role in predicting students' self-efficacy, interest, and identity in physics. We note that the learning environment does not only consist of what happens in the classroom. Student interactions with each other while their doing homework, students' experiences in an instructor or TA's office hours, interactions between students and the instructor over email, and other circumstances all contribute to students' learning environment. All of those interactions can affect students' identity, self-efficacy, and interest in physics by the end of the semester.

There are a variety of ways that TAs/instructors can improve student interactions and the learning environment in the courses. Instructors can influence students' peer interaction with each other by providing time for the students to work together in class and making sure all voices are heard equally when discussing problems as a whole group. One strategy physics instructors can use to encourage equal contribution in group work is to assign each student a role that rotates throughout the course. It is also important for instructors to emphasize that struggling is normal during the learning process, and it is the stepping-stone to learning new things. Therefore, students should embrace their struggles. Additionally, short interventions, e.g., sense of belonging and mindset interventions, have been shown to eliminate gender performance gaps (Kalender et al., 2020; Walton et al., 2015) and have lasting effects beyond the class in which they are implemented (Yeager & Walton, 2011).

The courses in this study were traditionally taught lecture-based courses. It would be important to investigate these models in evidence-based active-engagement courses (e.g., studio courses). In the future, it will also be useful to investigate other student outcomes, e.g., whether students' perceptions of their peer interaction depend on the groups they were interacting with (same-sex groups vs mixed groups vs working alone) and how different evidence-based active engagement classes affect these findings.

*This work was supported by the National Science Foundation Grant DUE-1524575.*

**Sonja Cwik** (Sonja.cwik@pitt.edu) is an Assistant Professor in the Physics Department at Chapman University. She received her bachelor's degree from Wellesley College and her master's and Ph.D. from the University of Pittsburgh. Her research interests include understanding women's motivational beliefs in introductory physics courses.

**Chandralekha Singh** (clsingh@pitt.edu) is a Distinguished Professor in the Department of Physics and Astronomy and the Founding Director of the Discipline-based Science Education Research Center (dB-SERC) at the University of Pittsburgh. She is a Past President of the American Association of Physics Teachers. She obtained her bachelors and masters degrees from the Indian Institute of Technology Kharagpur and her Ph.D. in theoretical condensed matter physics from the University of California Santa Barbara. She was a postdoctoral fellow at the University of Illinois Urbana Champaign, before joining the University of Pittsburgh. She has been conducting research in physics education for more than two decades. She co-led the US team to the International Conference on Women in Physics in Birmingham UK in 2017. She is a Fellow of the American Physical Society, American Association for the Advancement of Science and American Association of Physics Teachers. More information about her can be found at
https://sites.google.com/site/professorsinghswebpage/

## References

Adams, W. K., Perkins, K. K., Podolefsky, N. S., Dubson, M., Finkelstein, N. D., & Wieman, C. E. (2006). A new instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey. *Physical Review Special Topics - Physics Education Research*, *2*(1), 010101. https://doi.org/10.1103/PhysRevSTPER.2.010101

Archer, L., Moote, J., Francis, B., DeWitt, J., & Yeomans, L. (2017). The "exceptional" physics girl: A sociological analysis of multimethod data from young women aged 10–16 to explore gendered patterns of post-16 participation. *American Educational Research Journal*, *54*(1), 88-126. https://doi.org/10.3102/0002831216678379

Bailey, J. M., Lombardi, D., Cordova, J. R., & Sinatra, G. M. (2017). Meeting students halfway: Increasing self-efficacy and promoting knowledge change in astronomy. *Physical Review Physics Education Research*, *13*(2), 020140. https://doi.org/10.1103/PhysRevPhysEducRes.13.020140

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological review*, *84*(2), 191. https://doi.org/10.1037/0033-295X.84.2.191

Bandura, A. (1994). Self-efficacy. In R. J. Corsini (Ed.), *Encyclopedia of Psychology* (2nd ed., Vol. 3, pp. 368-369). Wiley. https://doi.org/10.1002/9780470479216.corpsy0836

Benbow, C. P., & Minor, L. L. (1986). Mathematically talented males and females and achievement in the high school sciences. *American Educational Research Journal*, *23*(3), 425-436.

Bian, L., Leslie, S.-J., & Cimpian, A. (2017). Gender stereotypes about intellectual ability emerge early and influence children's interests. *Science*, *355*(6323), 389-391. https://doi.org/10.1126/science.aah6524

Bouffard-Bouchard, T., Parent, S., & Larivee, S. (1991). Influence of self-efficacy on self-regulation and performance among junior and senior high-school age students. *International Journal of Behavioral Development*, *14*(2), 153-164.

Britner, S. L. (2008). Motivation in high school science students: A comparison of gender differences in life, physical, and earth science classes. *Journal of Research in Science Teaching*, *45*(8), 955-970.

Britner, S. L., & Pajares, F. (2006). Sources of science self-efficacy beliefs of middle school students. *Journal of Research in Science Teaching*, *43*(5), 485-499. https://doi.org/10.1002/tea.20131

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187-1218. https://doi.org/10.1002/tea.20237

Cavallo, A. M. L., Potter, W. H., & Rozman, M. (2004). Gender differences in learning constructs, shifts in learning constructs, and their relationship to course achievement in a structured inquiry, yearlong college physics course for life science majors. *School Science and Mathematics*, *104*(6), 288-300. https://doi.org/10.1111/j.1949-8594.2004.tb18000.x

Chemers, M. M., Zurbriggen, E. L., Syed, M., Goza, B. K., & Bearman, S. (2011). The role of efficacy and identity in science career commitment among underrepresented minority students. *Journal of Social Issues*, *67*(3), 469-491.

Cohen, J. (2013). *Statistical Power Analysis for the Behavioral Sciences*. Routledge.

Correll, S. J. (2001). Gender and the career choice process: The role of biased self-assessments. *American Journal of Sociology*, *106*(6), 1691-1730.

Correll, S. J. (2004). Constraints into preferences: Gender, status, and emerging career aspirations. *American Sociological Review*, *69*(1), 93-113.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, *16*(3), 297-334.

Cwik, S., & Singh, C. (2023). Framework for and Review of Research on Assessing and Improving Equity and Inclusion in Undergraduate Physics Learning Environments. S. Cwik and C.

Singh, in International Handbook of Physics Education Research: Special Topics, edited by M. F. Taşar and P. R. L. Heron (AIP Publishing, Melville, New York, 2023), pp. 2-1–2-26 https://doi.org/10.1063/9780735425514_002

Dou, R., Brewe, E., Potvin, G., Zwolak, J. P., & Hazari, Z. (2018). Understanding the development of interest and self-efficacy in active-learning undergraduate physics courses. *International Journal of Science Education*, *40*(13), 1587-1605. https://doi.org/10.1080/09500693.2018.1488088

Eccles, J. S. (1994). Understanding women's educational and occupational choices: Applying the Eccles et al. model of achievement-related choices. *Psychology of Women Quarterly*, *18*(4), 585-609. https://doi.org/10.1111/j.1471-6402.1994.tb01049.x

Felder, R. M., Felder, G. N., Mauney, M., Hamrin Jr., C. E., & Dietz, E. J. (1995). A longitudinal study of engineering student performance and retention. III. Gender differences in student performance and attitudes. *Journal of Engineering Education*, *84*(2), 151-163. https://doi.org/https://doi.org/10.1002/j.2168-9830.1995.tb00162.x

Fencl, H., & Scheel, K. (2005). Research and Teaching: Engaging students - An examination of the effects of teaching strategies on self-efficacy and course climate in a nonmajors physics course. *Journal of College Science Teaching*, *35*(1), 20.

Flowers III, A. M., & Banda, R. (2016). Cultivating science identity through sources of self-efficacy. *Journal for Multicultural Education*, *10*(3), 405-417.

Gao, J. (2020). Sources of mathematics self-efficacy in Chinese students: a mixed-method study with Q-sorting procedure. *International Journal of Science and Mathematics Education*, *18*(4), 713-732.

Gee, J. P. (2000). Chapter 3: Identity as an analytic lens for research in education. *Review of Research in Education*, *25*(1), 99-125.

Glynn, S. M., Brickman, P., Armstrong, N., & Taasoobshirazi, G. (2011). Science motivation questionnaire II: Validation with science majors and nonscience majors. *Journal of Research in Science Teaching*, *48*(10), 1159-1176. https://doi.org/10.1002/tea.20442

Godwin, A., Geoff, P., & Zahra, H. (2021). The development of critical engineering agency, identity, and the impact on engineering career choices. 2013 ASEE Annual Conference & Exposition,

Godwin, A., Potvin, G., Hazari, Z., & Lock, R. (2016). Identity, critical agency, and engineering: An affective model for predicting engineering as a career choice. *Journal of Engineering Education*, *105*(2), 312-340. https://doi.org/10.1002/jee.20118

Goodenow, C. (1993). Classroom belonging among early adolescent students: Relationships to motivation and achievement. *The Journal of Early Adolescence*, *13*(1), 21-43. https://doi.org/10.1177/0272431693013001002

Han, J., Kelley, T., & Knowles, J. G. (2021). Factors Influencing Student STEM learning: Self-efficacy and outcome expectancy, 21st century skills, and career awareness. *Journal for STEM Education Research*, *4*(2), 117-137. https://doi.org/doi:10.1007/s41979-021-00053-3

Harackiewicz, J. M., Barron, K. E., Tauer, J. M., & Elliot, A. J. (2002). Predicting success in college: A longitudinal study of achievement goals and ability measures as predictors of interest and performance from freshman year through graduation. *Journal of educational Psychology*, *94*(3), 562-575. https://doi.org/10.1037/0022-0663.94.3.562

Häussler, P., & Hoffmann, L. (2002). An intervention study to enhance girls' interest, self-concept, and achievement in physics classes. *Journal of Research in Science Teaching*, *39*(9), 870-888. https://doi.org/10.1002/tea.10048

Hazari, Z., Potvin, G., Lock, R. M., Lung, F., Sonnert, G., & Sadler, P. M. (2013). Factors that affect the physical science career interest of female students: Testing five common hypotheses. *Physical Review Special Topics-Physics Education Research*, *9*(2), 020115.

Hazari, Z., Sadler, P. M., & Sonnert, G. (2013). The science identity of college students: Exploring the intersection of gender, race, and ethnicity. *Journal of College Science Teaching*, *42*(5), 82-91.

Hazari, Z., Sonnert, G., Sadler, P. M., & Shanahan, M.-C. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. *Journal of Research in Science Teaching*, *47*(8), 978-1003. https://doi.org/10.1002/tea.20363

Hidi, S. (2006). Interest: A unique motivational variable. *Educational Research Review*, *1*(2), 69-82. https://doi.org/10.1016/j.edurev.2006.09.001

Kalender, Z. Y., Marshman, E., Nokes-Malach, T. J., Schunn, C. D., & Singh, C. (2017). Motivational characteristics of underrepresented ethnic and racial minority students in introductory physics courses. Proceedings of the 2017 Physics Education Research Conference, Cincinnati, OH. http://dx.doi.org/10.1119/perc.2017.pr.046

Kalender, Z. Y., Marshman, E., Schunn, C. D., Nokes-Malach, T. J., & Singh, C. (2019). Why female science, technology, engineering, and mathematics majors do not identify with physics: They do not think others see them that way. *Physical Review Physics Education Research*, *15*(2), 020148. https://doi.org/10.1103/PhysRevPhysEducRes.15.020148

Kalender, Z. Y., Marshman, E., Schunn, C. D., Nokes-Malach, T. J., & Singh, C. (2020). Damage caused by women's lower self-efficacy on physics learning. *Physical Review Physics Education Research*, *16*(1), 010118. https://doi.org/10.1103/PhysRevPhysEducRes.16.010118

Ketenci, T., Leroux, A., & Renken, M. (2020). Beyond student factors: A study of the impact on STEM career attainment. *Journal for STEM Education Research*, *3*(3), 368-386. https://doi.org/doi:10.1007/s41979-020-00037-9

Kosiol, T., Rach, S., & Ufer, S. (2019). (Which) mathematics interest is important for a successful transition to a university study program? *International Journal of Science and Mathematics Education*, *17*(7), 1359-1380.

Learning Activation Lab. (2017). *Activation lab tools: Measures and data collection instruments*. Retrieved 4 February 2019 from http://www.activationlab.org/tools/.

Leslie, S.-J., Cimpian, A., Meyer, M., & Freeland, E. (2015). Expectations of brilliance underlie gender distributions across academic disciplines. *Science*, *347*(6219), 262-265. https://doi.org/10.1126/science.1261375

Li, Y., & Singh, C. (2021). Effect of gender, self-efficacy, and interest on perception of the learning environment and outcomes in calculus-based introductory physics courses. *Physical Review Physics Education Research*, *17*(1), 010143. https://doi.org/10.1103/PhysRevPhysEducRes.17.010143

Li, Y., & Singh, C. (2022). Inclusive learning environments can improve student learning and motivational beliefs. *Physical Review Physics Education Research*, *18*(2), 020147.

Li, Y., & Singh, C. (2023a). Impact of perceived recognition by physics instructors on women's self-efficacy and interest. *Physical Review Physics Education Research*, *19*(2), 020125. https://doi.org/10.1103/PhysRevPhysEducRes.19.020125

Li, Y., & Singh, C. (2023b). Sense of belonging is an important predictor of introductory physics students' academic performance. *Physical Review Physics Education Research*, *19*(2), 020137.

Lichtenberger, E., & George-Jackson, C. (2013). Predicting high school students' interest in majoring in a STEM field: Insight into high school students' postsecondary plans. *Journal of Career and Technical Education*, *28*(1), 19-38.

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, *22*(140), 55. https://legacy.voteview.com/pdf/Likert_1932.pdf

Lock, R. M., Hazari, Z., & Potvin, G. (2013). Physics career intentions: The effect of physics identity, math identity, and gender. *AIP Conference Proceedings*, *1513*(1), 262-265. https://doi.org/10.1063/1.4789702

Louis, R. A., & Mistele, J. M. (2012). The differences in scores and self-efficacy by student gender in mathematics and science. *International Journal of Science and Mathematics Education*, *10*(5), 1163-1190.

MacCallum, R. C., Browne, M. W., & Sugawara, H. M. (1996). Power analysis and determination of sample size for covariance structure modeling. *Psychological Methods*, *1*(2), 130. https://doi.org/10.1037/1082-989X.1.2.130

Maries, A., Karim, N., & Singh, C. (2020). Active learning in an inequitable learning environment can increase the gender performance gap: The negative impact of stereotype threat. *The Physics Teacher*, *58*, 430-433. https://doi.org/10.1119/10.0001844

Maries, A., Whitcomb, K., & Singh, C. (2022). Gender inequities throughout STEM. *Journal of College Science Teaching*, *51*(3), 27-36. https://www.nsta.org/journal-college-science-teaching/journal-college-science-teaching-januaryfebruary-2022/gender

Marshman, E., Kalender, Z. Y., Schunn, C., Nokes-Malach, T., & Singh, C. (2018). A longitudinal analysis of students' motivational characteristics in introductory physics courses: Gender differences. *Canadian Journal of Physics*, *96*(4), 391-405. https://doi.org/10.1139/cjp-2017-018

Masika, R., & Jones, J. (2016). Building student belonging and engagement: Insights into higher education students' experiences of participating and learning together. *Teaching in Higher Education*, *21*(2), 138-150. https://doi.org/10.1080/13562517.2015.1122585

McKinney, J., Chang, M.-L., & Glassmeyer, D. (2021). Why females choose STEM majors: Understanding the relationships between major, personality, interests, self-eficacy, and anxiety. *Journal for STEM Education Research*, *4*(3), 278-300. https://doi.org/doi:10.1007/s41979-021-00050-6

Meltzer, D. E., & Manivannan, K. (2002). Transforming the lecture-hall environment: The fully interactive physics lecture. *American Journal of Physics*, *70*(6), 639-654.

Miller, K., Schell, J., Ho, A., Lukoff, B., & Mazur, E. (2015). Response switching and self-efficacy in Peer Instruction classrooms. *Physical Review Special Topics-Physics Education Research*, *11*(1), 010104.

Monsalve, C., Hazari, Z., McPadden, D., Sonnert, G., & Sadler, P. M. (2016). Examining the relationship between career outcome expectations and physics identity. Proceedings of the Physics Education Research Conference, Sacramento, CA.

Mujtaba, T., & Reiss, M. J. (2014). A survey of psychological, motivational, family and perceptions of physics education factors that explain 15-year-old students'aspirations to study physics in post-compulsory English schools. *International Journal of Science and Mathematics Education*, *12*(2), 371-393.

Nissen, J. M., & Shemwell, J. T. (2016). Gender, experience, and self-efficacy in introductory physics. *Physical Review Physics Education Research*, *12*(2), 020105. https://doi.org/10.1103/PhysRevPhysEducRes.12.020105

*PERTS Academic Mindsets Assessment.* (2020). Retrieved 3 February 2019 from https://www.perts.net/orientation/ascend

Potvin, G., & Hazari, Z. (2013). The development and measurement of identity across the physical sciences. Proceedings of the 2013 Physics Education Research Conference, Portland, OR.

Robinson, K. A., Perez, T., Carmel, J. H., & Linnenbrink-Garcia, L. (2019). Science identity development trajectories in a gateway college chemistry course: Predictors and relations to achievement and STEM pursuit. *Contemporary Educational Psychology*, *56*, 180-192.

Rockinson-Szapkiw, A., Wendt, J. L., & Stephen, J. S. (2021). The efficacy of a blended peer mentoring experience for racial and ethnic minority women in STEM pilot study: Academic, professional, and psychosocial outcomes for mentors and mentees. *Journal for STEM Education Research*, *4*(2), 173-193. https://doi.org/doi:10.1007/s41979-020-00048-6

Santana, L. M., & Singh, C. (2023). Effects of male-dominated physics culture on undergraduate women. *Physical Review Physics Education Research*, *19*(2), 020134.

Sawtelle, V., Brewe, E., & Kramer, L. H. (2012). Exploring the relationship between self-efficacy and retention in introductory physics. *Journal of Research in Science Teaching*, *49*(9), 1096-1121. https://doi.org/10.1002/tea.21050

Sayer, R., Marshman, E., & Singh, C. (2016). The impact of peer interaction on the responses to clicker questions in an upper-level quantum mechanics course. Proceedings of the Physics Education Research Conference, Sacramento, CA.

Schell, J., & Lukoff, B. (2010). Peer instruction self-efficacy instrument [Developed at Harvard University] (unpublished).

Schunk, D. H., & Pajares, F. (2002). The Development of Academic Self-Efficacy. In A. Wigfield & J. S. Eccles (Eds.), *Development of Achievement Motivation: A Volume in the Educational Psychology Series* (pp. 15-31). Academic Press. https://doi.org/https://doi.org/10.1016/B978-012750053-9/50003-6

Schunk, D. H., & Pajares, F. (2002). The development of academic self-efficacy. In *Development of achievement motivation* (pp. 15-31). Elsevier.

Singh, C. (2005). Impact of peer interaction on conceptual test performance. *American Journal of Physics*, *73*(5), 446-451. https://doi.org/10.1119/1.1858450

Stets, J. E., Brenner, P. S., Burke, P. J., & Serpe, R. T. (2017). The science identity and entering a science occupation. *Social Science Research*, *64*, 1-14.

Stewart, J., Henderson, R., Michaluk, L., Deshler, J., Fuller, E., & Rambo-Hernandez, K. (2020). Using the Social Cognitive Theory Framework to Chart Gender Differences in the Developmental Trajectory of STEM Self-Efficacy in Science and Engineering Students. *Journal of Science Education and Technology*, *29*(6), 758-773.

Strenta, A. C., Elliott, R., Adair, R., Matier, M., & Scott, J. (1994). Choosing and leaving science in highly selective institutions. *Research in Higher Education*, *35*(5), 513-547. www.jstor.org/stable/40196139

Team, R. C. (2013). *R: A language and environment for statistical computing.*

Tomarken, A. J., & Waller, N. G. (2005). Structural equation modeling: Strengths, limitations, and misconceptions. *Annual Review of Clinical Psychology*, *1*(1), 31-65. https://doi.org/10.1146/annurev.clinpsy.1.102803.144239

Tonso, K. L. (2006). Student engineers and engineer identity: Campus engineer identities as figured world. *Cultural Studies of Science Education*, *1*(2), 273-307. https://doi.org/10.1007/s11422-005-9009-2

Traxler, A., Henderson, R., Stewart, J., Stewart, G., Papak, A., & Lindell, R. (2018). Gender fairness within the force concept inventory. *Physical Review Physics Education Research*, *14*(1), 010103. https://doi.org/10.1103/PhysRevPhysEducRes.14.010103

Uitto, A. (2014). Interest, attitudes and self-efficacy beliefs explaining upper-secondary school students' orientation towards biology-related careers. *International Journal of Science and Mathematics Education*, *12*(6), 1425-1444.

Upson, S., & Friedman, L. F. (2012). Where are all the female geniuses? *Scientific American Mind*, *23*(5), 63-65.

Vincent-Ruz, P., & Schunn, C. D. (2017). The increasingly important role of science competency beliefs for science learning in girls. *Journal of Research in Science Teaching*, *54*(6), 790-822. https://doi.org/10.1002/tea.21387

Vincent-Ruz, P., & Schunn, C. D. (2018). The nature of science identity and its role as the driver of student choices. *International Journal of STEM Education*, *5*(1), 48.

Walton, G. M., Logel, C., Peach, J. M., Spencer, S. J., & Zanna, M. P. (2015). Two brief interventions to mitigate a "chilly climate" transform women's experience, relationships, and achievement in engineering. *Journal of educational Psychology*, *107*(2), 468-485.

Wang, M.-T., & Degol, J. (2013). Motivational pathways to STEM career choices: Using expectancy–value perspective to understand individual and gender differences in STEM fields. *Developmental Review*, *33*(4), 304-340.

Yeager, D. S., & Walton, G. M. (2011). Social-psychological interventions in education: They're not magic. *Review of Educational Research*, *81*(2), 267-301.

Zimmerman, B. J. (2000). Self-efficacy: An essential motive to learn. *Contemporary Educational Psychology*, *25*(1), 82-91.