LEVERAGING A COMMUNITY OF PRACTICE TO ADVANCE STEM EDUCATION REFORM AND PROMOTE TEACHER AND STUDENT SELF-EFFICACY

A Dissertation

by

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ABSTRACT

Colyer, Ruth R., Leveraging a Community of Practice to Advance STEM Education Reform and Promote Teacher and Student Self-Efficacy. Doctor of Education (EdD), December, 2024, 186 pp., 9 tables, 4 figures, 124 References.

This dissertation examined the impact of the CREST-MECIS community of practice on K-12 STEM teachers and undergraduate and graduate students, addressing the urgent need for innovative approaches in science education to meet the challenges of the 21st century. The study was grounded in response to three primary problem statements: 1) the significant learning losses and socio-emotional challenges stemming from the COVID-19 pandemic, 2) the inadequacy of traditional instructional methods in post-pandemic classrooms, and 3) the need for culturally relevant and inclusive teaching practices that acknowledge students' lived experiences. Data were collected through pre- and post-interviews, survey analyses, and qualitative feedback from program participants, offering a comprehensive look at the effects of the CREST-MECIS model.

The dissertation is organized into several key sections. Chapter One introduces the background and rationale for the study, situating it within the context of post-pandemic educational needs and the theoretical frameworks of culturally relevant pedagogy and constructivist learning. Chapter Two provides a literature review, examining foundational theories by Gloria Ladson-Billings, Lorsbach and Tobin, and Feldman, which advocate for community-based, reflective, and constructivist approaches in education. Chapter Three

describes the research methodology, detailing the community of practice model, data collection processes, and participant demographics. Chapter Four presents the study's findings, revealing that participation in CREST-MECIS significantly enhanced students' confidence, motivation, and engagement with STEM subjects and improved teachers' instructional efficacy and attitudes toward culturally relevant and innovative pedagogy. In the final chapter, conclusions were drawn about the program's effectiveness in fostering resilience, inclusivity, and socio-emotional support, aligning with Ladson-Billings' call for a "hard re-set" in education.

The study concluded that the CREST-MECIS program offered a replicable model for achieving a transformative shift in STEM education through collaborative, culturally responsive, and experiential learning environments. Recommendations include expanding such programs in diverse educational settings and further exploring the long-term impacts of community of practice models in education. This research contributes to the field by illustrating the potential for a re-imagined STEM curriculum that prepares both educators and students for the complex, interconnected demands of modern society.

DEDICATION

I dedicate this work to the Father Almighty, my sole source of inner strength, foresight, and perseverance, and my children, Maegan Rae Colyer, Joshua James Colyer, and Casey Arthur Colyer, my three sources of unwavering patience, support, and encouragement.

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CHAPTER I

INTRODUCTION

At the time this paper was written, the entire world was immersed in the unprecedented COVID-19 pandemic. Families, particularly our nation's youth, witnessed death without closure and sickness without solution. They endured the pangs of isolation and the ramifications of COVID confinement. Suffering through illness, grief, loneliness, job loss, and financial instability, bank accounts ran dry as families struggled to buy groceries, medication, and make ends meet. Changes in people's public behavior, created by regulations, restrictions, and personal and public health concerns, caused revenue from international and domestic air travel, in-store shopping, indoor dining, and participation in large in-person gatherings to fall by more than 50% during the first 30 months of the pandemic (Rose, 2021).

The current year is 2024, and the upheavals and devastation caused by the pandemic are still seen and felt daily worldwide. Aside from the economic effects of the pandemic, the world continues to endure consequences in other areas of human life, such as the sharp increases in anxiety and depression, drug overdose deaths, alcohol-induced deaths, suicide deaths, health complications in people who suffer from long-COVID (Horigian et al., 2020), family violence, psychological insecurities caused by social isolation and fear, ineffective coping mechanisms, and ramifications of ineffective remote education (Maison et al., 2021). Amidst it all is the educational system dedicatedto a COVID recovery discourse as though a pandemic never occurred. US classrooms will very soon become more diverse than ever before, and schools and educators must be prepared. To begin preparation, schools and educators must first understand a few immediate problems in education.

Problem Statements

Problem 1: COVID-19 and Disrupted Learning

For the 2021-2022 school year, Texas schools reopened for in-person, post-pandemic instruction with local social distancing and controversial masking requirements in place. Schools reopened only to discover that the declines in student learning resulting from the pandemic were dire, particularly in reading and math (Dorn et al., 2021). To address pandemic unfinished learning, Texas legislators passed bipartisan House Bill (HB) 4545 during the 87th Legislative Session on June 16, 2021, requiring Texas school districts and teachers to provide a minimum of thirty hours of both accelerated and supplemental instruction (tutoring) during or outside regular school hours for each returning student who either did not complete or did not pass a State of Texas Assessments of Academic Readiness (STAAR) in the Spring of 2021 or who is currently struggling in or failing classes (*Texas HB4545: 2021-2022: 87th legislature*). Teachers at my school district, however, have observed and reported that students are considerably more reluctant now, compared to previous years, to attend either accelerated and/or supplemental instructional sessions. Reasons, cited by students at my campus, for not attending such sessions include: 1) students are gainfully employed to help support their families, 2) students, especially females, must be home to care for siblings and/or other family members, 3) students lack timely transportation to before-school tutoring, particularly those who are transported via the school busses, 4) students lack transportation to Saturday tutorials on campus, 5) parental/guardian refusal, 6) student disinterest, and/or 7) student lack of motivation. Regardless of the reason, each contributes to student post-pandemic academic decline and the ever-growing disparities among the at-risk populations in 21st-century science education, and this is a major problem.

Problem 2: Using the Same Methods and Expecting Different Outcomes

Science educators at my school district have also observed and reported that since students returned to school after eighteen months of COVID-19 pandemic isolation and virtual learning, the same instructional efforts, tools, and strategies that they used during previous school years to engage learners in science content currently seem to be inadequate and/or ineffective. Educators district-wide have concluded that the time is now to re-invent instructional strategies and tutoring programs to re-ignite student interest and motivation and accommodate students' very different learning needs. Today's student learning has morphed into something that even educators struggle to understand, and the strategies of yester years are not working (Shrestha and Hansen, 2021). Educators need new instructional strategies and tutoring programs to be compliant with Texas House Bill (HB) 4545 and to help students engage/re-engage in and recover unfinished post-pandemic learning, but what will those new strategies look like? What measures can educators take to re-ignite learning? Where do we begin?

Problem 3: Socio-emotional Support for Students

Piagetian and Vygotskian theories have taught us that learning is an active process that involves the social and cultural construction of knowledge within a learning environment (Goodman, 2014). However, the isolation and eighteen-month confinement to an electronic device may have potentially prevented many students from receiving the social and cultural components of their knowledge construction. This, consequently, may have stymied student socio-emotional development and learning (Loades et al., 2020) and contributed to the nationwide reported academic losses. This takes us to another problem: The new and improved instructional strategies and tutoring programs that educators need must also simultaneously and more effectively support students' socio-emotional needs, more so now than ever before.

The Relevancy

In her paper "I'm here for the hard re-set: Post pandemic pedagogy to preserve our culture", Gloria Ladson-Billings (2021) compares a soft re-set to a hard re-set and explains that the time is now in education, amidst COVID-19 post-pandemic recovery, for a hard re-set. Ladson-Billings describes the soft re-set as a measure taken to resolve minor issues on an electronic device that does not involve loss of data and the hard re-set as one that deletes all data on the device and restores it back to its original manufacturer settings. After a hard re-set, thus, the device user must start over, recollecting and replacing everything that previously lived on the device. Ladson-Billings calls for a hard re-set in education and curriculum but suggests that the data to be recollected now must be *new* and not like the *old*. For Ladson-Billings (2021), the old is what was normal and the new is the post-pandemic direction of education and curriculum for the future.

Ladson-Billings (2021) asserts that returning to normal is the worst thing that could happen in education because "normal is where the problems reside" (p. 68). The problems prior to the COVID-19 pandemic that she refers to are those associated with the oppression, suppression, and marginalization of the underrepresented and minority groups in US schools that have historically caused them to be unsuccessful. Examples of such problems include poverty, racism, and inequitable education. Other contributing factors that caused the pre-COVID problems are contextual mitigating factors, described by Gallard Martinez and colleagues (2020) as "a continuous set of socio-historical-political contextual constructs which are fluid and dynamic, simultaneously interweaving community, education, family, gender/identity, and other socially constructed places domains (p. 547)."   Such problems still exist today but have escalated to new heights as a result of the political, social, health, and economic devastation caused by the pandemic. Ladson-Billings' (2021) solution to post-pandemic recovery in education requires that schools and educators engage in culturally relevant pedagogy that considers the conditions of students' lives these occurrences set in motion" (Ladson-Billings, 2021, p. 73). She further suggests that a hard re-set in education and curriculum must occur around "technology, curriculum, pedagogy, assessment, and parent/community engagement that will support and promote students' culture" (Ladson-Billings, 2021, p. 73).

The day has arrived for curricular reform in 21st-century science education to mitigate the effects of antiquated instructional strategies and explore their replacement with new instructional tools and/or tutoring programs to enhance teacher instruction/tutorials. Curricular reform for 21st century science education should also consider how to help students engage/re-engage in and recover unfinished learning, while simultaneously and effectively supporting students' socio-emotional needs. The solution to post-pandemic recovery in Texas schools is mere instructional acceleration and supplementation, the mandates of HB 4545, which is a far cry from Ladson-Billings' (2021) hard re-set in education and curriculum, specifically one that occurs around technology integration and promotion of student culture. Obviously, the state is not prepared for a hard re-set in education and curriculum.

Before a technology re-set can be addressed, it is important to become familiar with the users of that technology in our classrooms, our students. Who are today's students in our classrooms? According to Beresford Research (Beresford Research, 2022), the current generational terms, birth years, and ages for 2022 are defined as follows: 1) the Generation X are born between the years 1965-1980 and range in ages from 42-57, 2) the Millennials are born between 1981-1996 and range in ages from 26-41, and 3) the Generation Z (Gen Z) are born between 1997-2012 and range in ages from 10-25. This means that nearly all students in K-12 and college classrooms today are members of Generation Z and, unlike Generation X and Millennials, have never known a non-digital world (Shrestha & Hansen, 2021). Their world revolves around cell phones, computers, tablets, free Wi-Fi, social media, and gaming systems (Carstens et al., 2021). They are described as being the most technologically proficient, a characteristic that keeps them highly connected to the social media web (Mahapatra et al., 2022). Understanding the characteristics and behaviors of this cohort and how to meet their educational needs are critical to the effectiveness of teaching and learning in 21st century science classrooms.

Gen Z's characteristics, behaviors, and engrossment into technology influences their expectations of education. Shrestha and Hansen (2021) describe these students as "digital natives" because "they are the 'native language speakers' of the digital language" and teachers as "digital immigrants" who speak "an old-fashioned, non-digital, language" (p. 5). The digital natives (students), thus, do not understand their digital immigrants (teachers) and "as a result, the educational strategies and methods utilized to educate such students have become obsolete" (p. 5). This is a very good reason why the practices, tools, and learning strategies that teachers have relied upon for years no longer seem to be effective in today's classrooms.

Researchers Carstens and colleagues (2021) note that "in today's classroom, technology is becoming a more prominent form of learning" (p. 105), causing teachers to be in constant search of the technological tools that work with and enhance student learning. They cite a referent stating:

> Today's educators are under great pressure to provide 21st-century students with a quality education based on 21st-century standards. Those standards include providing students with the technological and informational skills needed to compete in an ever-changing, technology-driven world (p. 105).

In addition to new instructional strategies, what types of technological tools will provide 21st-century students with a quality education based on 21st-century standards and accomplish the hard re-set in science education and curriculum?

The Centers of Research Excellence in Science and Technology (CREST) program at the University of Texas Rio Grande Valley (UTRGV) may potentially provide an answer to this question for equitable 21^{st}-century science education (Tarawneh, 2021). This program promotes the integration of education and research as key instructional strategies to construct new knowledge and expand the presence of students historically underrepresented in science, technology, engineering, and mathematics (STEM) disciplines. With National Science Foundation support, a Center for Multidisciplinary Research Excellence in Cyber-Physical Infrastructure Systems (MECIS) was established through the CREST program to: 1) provide undergraduate STEM students with cutting-edge cyber-physical infrastructure systems research experience, 2) integrate research and education and develop a pathway from high school through graduate programs in STEM, and 3) strengthen the institution's educational and research infrastructure to establish a platform for a doctoral program in engineering. It is expected for the Center's technological research and education activities to develop an underrepresented workforce that will be equipped with the knowledge and skills to address and remedy complex societal issues.

Purpose and Significance of the Study

This study is in response to Ladson-Billings' call for a hard re-set to improve STEM education in the 21st century. The goal is to advance scholarship in STEM education that replaces antiquated practices, which have created an education system in need of repair, with strategies that promote learning for all students. Specifically, I will investigate how a research community of practice supports K-12 STEM teachers, undergraduate and graduate college students, and engineering faculty to improve STEM education practices.

Researcher Positionality

Born in Monterrey, Mexico, in 1945, my father was a *mestizo* migrant worker who never made it past the 8th grade. He preached at Nations Gospel Tabernacle in Oregon, Ohio, during the seasons when he, his 10 brothers and sisters, and his parents migrated there to work. He met my mother at this church in 1965. My mother was born in 1946 in Toledo, Ohio, to a German man and a European Jewish woman. My parents were married on August 20th, 1965, and I was born in Toledo, Ohio, on July 3rd, 1966. I was the first-born of 7 children.

I graduated from a high school along the U.S.-Mexico border in 1984 with honors, scholarships, and dreams…...dreams of becoming a cardiac surgeon. During my 4 years in high school, I was concurrently enrolled in college courses through the Biomedical Sciences Program at Pan American University, now the University of Texas Rio Grande Valley. Unfortunately, it was also during my 4 years of high school that my family experienced hardships that "normal" families cannot imagine. It was my fixation on science and dreams of my future career that fueled my aspirations and motivated me to push forward through the mud.

My father chose a private Christian university in Oklahoma that I would attend after graduation. During the early summer of 1984, before leaving for Oklahoma at the age of 17, I read the biology textbook from cover to cover for the first semester biology course that I was enrolled in. When the first day of class arrived, I was dressed for the occasion. My first class was biology. Sporting the snappiest duds from my closet, I walked into class and noticed that all the students were male. Not thinking anything of it, I found a chair and sat down. Several other male students entered class and sat down. A tall, gray man walked over to me and asked why I was in his class. I showed him my schedule and explained that I was enrolled in the course. He said that it was a mistake and told me to go to the registrar's office to correct it. I asked him what the mistake was, and he told me that [I] "would find out." Off to the registrar's office I went. I was told that a new class schedule would be delivered to my dormitory room. When I received my new schedule, I saw that my biology, chemistry, and physics courses had been dropped. I thought a mistake was made, but I could not call because the registrar's office was closed for the day. So, I went to class again the next day. The tall, gray professor stopped me at the door and asked where I was going. I proceeded to explain to him that the registrar's office made a mistake on my schedule. He interrupted me and asked the male students what they thought the mistake was. One student stood up and said that there was no mistake…the paper said that I was dropped from class, which meant that I should not be there in class. I felt stupid, and I certainly did not know what was going on. The gray professor then asked me about my career aspirations. I told him that I wanted to be a doctor. He chuckled and announced to the class of only male students that I was dropped because "girls like [me] should be elementary teachers or stewardesses." I was never permitted to re-enroll in any science courses. Anger, resentment, and disappointment consumed me as I watched my *pre-med* status begin to fade away.

In another class at the same university, I corrected a Caucasian professor for mispronouncing my Spanish surname, *Rodriguez*. I did so respectfully, but the professor took offense and gave me a $50 fine, as monetary fines were a common form of punishment at this university. This happened frequently, but I did not care, nor did I pay any of the fines. My name was my identity, and I firmly believed that it was important for my professors to pronounce my name correctly.

I was fined for simply being *ME* at this university. For three long years while enrolled in this school, I received fines for the way I dressed and for my southern drawl that was laced with a Latin accent. I was fined for attending a church of my choice and not the one assigned by the school. I was fined for picking flowers from the prayer gardens and taking them to the science labs for observation under the stereo microscopes. I was even fined for the way I combed my hair. My grades were poor, and I was beyond unhappy. Anger, resentment, and disappointment consumed me further, and my dreams of a career in medicine were now disappearing.

It was at this time that I decided to take matters into my own hands. One evening, after two years of no family contact, I was finally able to speak to my father. After our lengthy conversation and the river of tears that flowed down my cheeks subsided, my father left me with three words…*You Are Rodriguez.* A hell-raising Rodriguez I then became. For the next year at that university in the stairwell of my dormitory, I read the books and taught myself college algebra, calculus, and chemistry. My roommate told the professors what I was doing. The professors sent the course assignments via my roommate for me to complete. That is how I earned credit for those particular courses. I received instruction for other courses from members of my church who were ex-professors from other universities. I guess you could say I was mostly *church-schooled.*

This last story is the cherry on this cake. I was prepared to take the medical college admission test, or the MCAT as we know it. I did this on my own and without university involvement. My church professors made the arrangements. I received a score of 36, which was considered a score in the 95th percentile. With this score, I confidently applied for an internship with a renowned cardiac surgeon at a Texas university. Unfortunately, the university officials informed me that I did not qualify for the internship and advised me to retake the MCAT.

So much for honors, scholarships…..and dreams. Much time and many, many experiences later, I returned home to complete my schooling, but I wasn't the same person who left. When I left, I was a confident powerhouse. When I returned, I was rebellious, broken, and powerless. My undergraduate school records reflect that tormented chapter in my life, but what they do not show is that…. *I succeeded*. I am now a high school science teacher, and in my classroom my message is loud and clear - people can only see the SELF as it appears but they cannot see the appearance of the SELF. My students, thus, learn the importance of connecting their experiences - the good, the bad, and the ugly - to education to build their best SELF.

My personal teaching style is fashioned from the constructs of cultural relevance and social justice pedagogies described by authors such as Ladson-Billings and Andrade. I share the central tenet of these authors that teachers and teacher educators should consider engaging students in dialogue that enables them to learn science through controversial issues and apply their science learning in ways to help them move beyond their personal, ideological, social, emotional, cultural, and political injustices. This is very possible to accomplish, even considering the standards-based movement, but not without its challenges. To achieve the level of relevancy that students need to be able to connect their lives to science content, I believe that teachers and teacher educators should be aware of the contextual mitigating factors that cause students to be unsuccessful and be able and willing to remove themselves from the scrutiny and constraints of the educational system. In so doing, teachers and teacher educators should be prepared for any degree of resistance because, as Lynn Bryan and Kenneth Tobin (2018) very accurately point out, sometimes things really are so politicized that science instruction taught from the socioemotional and cultural spheres can be too controversial for the common good, even though the benefactors are the students.

Research Questions

The University of Texas Rio Grande Valley's (UTRGV) CREST-MECIS program has assembled a research community of practice that brings together K-12 teachers from school districts across the Rio Grande Valley with undergraduate students, graduate students, and higher education engineering and education faculty currently from UTRGV. The research questions for this project are guided by the overarching question, "How does the CREST-MECIS program affect participants' desire to pursue or continue in a STEM field?" Specifically, the research questions guiding this study are:

1. How does the CREST-MECIS community of practice influence undergraduate and graduate students' participation in and completion of the CREST-MECIS program, including interest in and pursuit of a STEM career?
2. How does the CREST-MECIS community of practice influence K-12 STEM teachers' efficacy, attitudes, and beliefs toward teaching a CREST developed curriculum?

Definition of Terms

Community of Practice: a group of people who have an interest, passion, or concern for something and join together to learn more about it (Lave & Wenger, 1991).

Culturally Relevant Pedagogy: a theoretical model around three fundamental elements: 1) student achievement and learning, 2) cultural competence, and 3) socio-political or critical consciousness (Ladson-Billings, 1995).

Research Experience for Teachers (RET): an experience that immerses teachers in authentic research experiences. In this case, alongside CREST faculty and students to explore the design and application of innovative projects involving automation, sensors, and artificial intelligence into implementable STEM curricula and activities for their classroom (Chapman, 2023).

Gen Z Motivators to Learn: Include approaches that include, but are not limited to, 1) interactive and engaging content, 2) integration of technology, 3) real-world relevance, 4) collaborative learning, 5) flexible and personalized learning, 6) regular feedback, 7) an inclusive and diverse classroom environment, and 8) balanced and challenging tasks with resources and supports that mostly revolve around technology.

Teacher self-efficacy: beliefs of one's own abilities to engage and teach students. (Bandura et al., 1999)

Underrepresentation in STEM: those whose representation in STEM employment as well as science and engineering education is lower than their representation in the U.S. population (NCSES, 2023).

Conclusion

This study was inspired by Gloria Ladson-Billings' (2021) recommendations for a re-set in education and curriculum for student post COVID-19 pandemic learning and psychosocial recovery. The pandemic has spotlighted the strengths and weaknesses of schools and educators and has forced the need for curricular and pedagogical reform and re-set in education. The world now realizes that a teacher is not only essential in a pandemic, but a teacher is also essential in the everyday wellbeing of children. Additionally, this research provides suggestions for reform in curriculum and pedagogy generally, in science curriculum and pedagogy specifically, with emphasis on a re-set around technology, science, and the incorporation of engineering strategies in science learning.

The day has arrived for such reform in 21st century science education to mitigate the effects of antiquated instructional strategies and explore their replacement with creative, innovative, equitable, and culturally relevant instructional tools and tutoring programs. This can enhance teacher tutorials, help students engage/re-engage in and recover unfinished learning, and simultaneously and effectively support students' socio-emotional needs. While the nation awaits the impending cultural diversity explosion in our classrooms and Texas reconsiders just 'tutoring' to remedy students' post-pandemic learning loss and socio-emotional revitalization, educators can begin re-thinking not only what to teach but *how* to teach it. The time is now for what Gloria Ladson-Billings has called a *hard re-set.* This study has taken heed of this call and seeks to explore how a research community of practice can innovate how we conceptualize STEM learning spaces.

CHAPTER II

LITERATURE REVIEW

On March 11, 2020, after more than 118,000 cases in 114 countries and 4,291 deaths, the World Health Organization (WHO) declared COVID-19 a pandemic (*CDC Museum Covid-19 Timeline* 2023, Centers for Disease Control and Prevention, 2023). Less than a month later, more than 1 million COVID-19 cases were confirmed worldwide. Today, four years later, the WHO reports 768,187,096 confirmed cases, 6,945,714 confirmed deaths, and 13,461,344,203 vaccine doses administered (*WHO coronavirus (COVID-19) dashboard*). The upheavals and devastation caused by the COVID-19 pandemic are still seen and felt daily worldwide. The COVID-19 era has altered human existence's political, environmental, financial, economic, health, and social fronts, which have affected living standards, quality of life, psychological growth, and sustainability (Naseer et al., 2023). There are currently wars in high gear on Russian, Ukrainian, Israeli, and Palestinian borders, the outcomes of which are uncertain for the world. To make matters more complicated, the US borders are down, and the nation runs amok in chaos. While generational research is not an exact science, what is known is that individuals within a generation, e.g. Baby Boomers, Millennials, Generation Z, etc., who experience events of the time related to war, culture, politics, technology, and economics develop shifts in shared generational values and behaviors (Pichler et al., 2021).

Our nation's youth have witnessed death without closure and sickness without solution. They have endured the pangs of isolation and the ramifications of COVID confinement, effects of which are still uncertain but we know are coming. In a rapid systematic review of observational, longitudinal, and cross-sectional studies published between 1946 and March 29, 2020, assessing the impact of loneliness and anxiety on depression, it was found that in children and adolescents: 1) the duration, rather than the intensity, of loneliness was more strongly correlated with future mental health issues, such as depression, anxiety, acute stress disorder, adjustment disorder, grief, and post-traumatic stress disorder, up to 9 years later, 2) loneliness was more strongly associated with depression, 3) some research showed that loneliness was more strongly correlated to elevated depression symptoms in females and elevated social anxiety in males, and 4) social anxiety was more strongly associated with loneliness than other anxiety subtypes (Loades et al., 2020). Here we are four years after COVID-19 surfaced, and the research predictions are more real than what anyone anticipated. According to a YouthTruth (2022) student survey in the 2021-2022 school year, results of data collected from 222,837 elementary, middle, and high school students at 845 schools across 20 US states reported several mental health concerns:

a) LGBTQ youth report suicidal ideation 30% more often than their peers,
b) Black, Latino, and Asian youth access to school counselors and therapists 7-10% less than their white peers,
c) depression, stress, and anxiety as an obstacle to their learning:
    i.) 58% of female middle school students
    ii.) 67% female high school students
    iii.) 83-85% of trans and non-binary middle school students
    iv.) 81-87% high school students

Even more concerning is that the P-12 education system is following a COVID-19 recovery discourse as though a pandemic never occurred. Schools reopened and resumed with broken and antiquated systemic and pedagogical practices that existed pre-COVID-19. For post-COVID-19 recovery, the field of education today is poised to reform, repair, and reset the broken system.

The Hard Re-Set: An Opportunity to Transform a Broken System

In her paper "I'm here for the hard re-set: Post pandemic pedagogy to preserve our culture", Gloria Ladson-Billings (2021) uses an analogy between a soft re-set and a hard re-set in education to explain that the time is now, amidst COVID-19 post-pandemic recovery, for a hard re-set. Ladson-Billings describes the soft re-set as a measure taken to resolve minor issues on an electronic device that does not involve loss of data and the hard re-set as one that deletes all data on the device and restores it back to its original manufacturer settings. After a hard re-set, thus, the device user must start over, recollecting and replacing everything that previously lived on the device. Ladson-Billings calls for a hard re-set in education and curriculum but suggests that the data to be recollected now must be *new* and not like the *old*. For her (2021), the old is what was normal and the new is the post-pandemic direction of education and curriculum for the future.

Ladson-Billings (2021) asserts that returning to normal is the worst thing that could happen in education because "normal is where the problems reside" (p. 68). Examples of the problems in education prior to the COVID-19 pandemic that she refers to include poverty, racism, inequitable education. Other problems include what Gallard and colleagues (2020) refer to as contextual mitigating factors (CMF), which include the cultural, economic, historical, and social factors that continually influence and position people in society and are associated with the oppression, suppression, and marginalization of underrepresented and minority groups seen in US schools. Such problems still exist today but have escalated to new heights as a result of the political, social, health, and economic devastation caused by the pandemic. Ladson-Billings' solution to post-pandemic recovery in education requires that schools and educators "engage in culturally relevant pedagogy that takes into account the conditions of students' lives these occurrences set in motion" (Ladson-Billings, 2021, p. 73).

Ladson-Billings' (1995) original culturally relevant pedagogical model revolves around three fundamental elements: 1) student achievement and learning, 2) cultural competence, and 3) socio-political/critical consciousness. Her descriptions of each element are as follows: 1) student achievement and learning are the difference between what students know and can do at the beginning of school and what they know and can do at the end of the school year, 2) cultural competence refers to students' in-depth awareness of his or her own culture as well as that of another, e.g., the mainstream culture, and 3) socio-political/critical consciousness refers to the intellectual tools that educators should provide to students to address present-day concerns, specifically tools that come from "culturally relevant teachers [who] know how to weave the elements of the curriculum into these concerns" (Ladson-Billings, 2021, p. 72). In addition to these fundamental elements of culturally relevant pedagogy, Ladson-Billings (2021) suggests that a hard re-set in education and curriculum must occur around "technology, curriculum, pedagogy, assessment, and parent/community engagement that will support and promote students' culture" (p. 73).

Re-setting around technology, curriculum, pedagogy, assessment, and parent/community engagement for post-pandemic recovery in education is now vital to the culturally relevant pedagogical framework. According to Ladson-Billings (2021), re-setting around technology means that schools must provide the technology, and educators must provide the digital instructional resources to enable their students to work at their own pace and under conditions that are more personally suitable for them. A re-set around curriculum means that "the curriculum will need to be deconstructed and re-constructed to more accurately reflect the culture of our students" (Ladson-Billings, 2021, p. 73) and "meet the social-emotional needs of students" (p. 74) as well. Ladson-Billings (2021) envisions a pedagogical re-set as one in which educators incorporate innovation to "pull on youth culture" (p. 74) and make students the center of teaching and learning. Assessments, she adds, must be varied, innovative, and culturally relevant, and parents and caregivers need to be more involved in teaching and learning. Classrooms will continue to become more diverse, and schools and educators must be prepared. This paper offers insight into a curriculum and pedagogy re-set for Texas schools and educators with specific focus on science curriculum and pedagogy.

The Broken System

In Texas, the solution to post-pandemic recovery in education is mere instructional acceleration and supplementation. During the 87th Legislative Session on June 16, 2021, Texas legislators passed bipartisan House Bill (HB) 4545 requiring Texas school districts and educators to provide a minimum of thirty hours of both accelerated and supplemental instruction during or outside regular school hours for each returning student who either did not complete or did not pass a State of Texas Assessments of Academic Readiness (STAAR) in the Spring of 2021 or who is currently struggling in or failing classes (*Texas HB4545: 2021-2022: 87th legislature*). The Bill stipulates that accelerated instruction provided by a district, per Section 28.0211, Education Code, amended Subsections (a-1), (a-2), and (a-3) of HB 4545, must: 1) be provided to the student before or after normal school hours, 2) ensure the student's participation in and exposure to the grade level content and curriculum that is available to other students at the same grade level who are not receiving accelerated instruction, and 3) provide the student the option of either receiving supplemental instruction as described by Subsection (a-3) or being placed with a teacher who is designated a recognized, exemplary, or master teacher under Section 21.3521 to deliver accelerated instruction (*Texas HB4545: 2021-2022: 87th legislature*, pp. 2 - 3). Supplemental instruction, as described by Subsection (a-3) of the bill, must:

> (1) include targeted instruction in the essential knowledge and skills; (2) be provided in addition to instruction normally provided to students in the grade level in which the student is enrolled; (3) be provided for no less than 30 total hours during the following summer and school year, and include instruction no less than once per week unless the instruction is provided fully during summer; (4) be designed to assist the student in achieving grade level performance in the applicable subject area; (5) include effective instructional materials designed for supplemental instruction; (6) be provided to a student individually or in a group of no more than three students, unless the parent or guardian of each student in the group authorizes a larger group; (7) be provided by a person with training in the instructional materials used for supplemental instruction and who receives ongoing oversight while providing supplemental instruction; and [The last item of the Subsection is also identified as (7).] (7) to the extent possible, be provided by the same person for the student for the entirety of the supplemental instruction period. (p. 4)

For high school students, Section 28.0217 of the bill states that students may also be required to participate in accelerated instruction at times outside of normal school operations, e.g., on Saturdays (*Texas HB4545: 2021-2022: 87th legislature*, p. 8). In short, the HB 4545 requirements of both accelerated and supplemental instructions describe the 'tutoring' that students are to receive until they successfully pass an assessment instrument.

The house bill's mandate for 'tutoring' is a far cry from Ladson-Billing's (2021) education and curriculum hard re-set. This, however, is what the state of Texas has passed down to districts, schools, and teachers as its plan for post-pandemic recovery, and obviously, the state is not prepared for a hard re-set in education and curriculum. A culturally relevant pedagogical framework may offer the best solution for curriculum and pedagogy in general, science curriculum and pedagogy specifically.

The Curriculum

But the curricula that we are required to follow comes from the state! is what educators will exclaim, but this is only partly true. The following describes the writer's definition of curriculum. In Texas public schools, the curriculum requirements for every K-12 course are detailed as a set of state standards, referred to as the Texas Essential Knowledge and Skills or TEKS (Texas Education Agency, 2022). Arthur Ellis (2004) would refer to this curriculum as the overt - planned, formal - curriculum and would compare it to a doctor's written prescription to his or her patient for something that should be followed. In this sense, Ellis would also refer to the TEKS as the *prescriptive* curriculum. This prescriptive curriculum along with several pedagogical and instructional strategies provided from that year's district curriculum writers are provided to all district educators to follow throughout the school year. Using this prescriptive curriculum, educators then become the creators and writers of their weekly lesson plans, which essentially comprise a 'sub-prescriptive' curriculum. Ellis would argue that teacher lesson plans are the prescriptive curriculum, but those lesson plans bridge much more than just content standards and, therefore, function on a completely different dimension than just the prescriptive.

Teacher lesson plans bridge the prescriptive curriculum to its juxtaposed cousin, the *descriptive* curriculum (Ellis, 2004). He refers to the descriptive curriculum as the "*experienced* curriculum" (Ellis, 2004, pg. 5), which reflects student experiences of the prescriptive curriculum when it is implemented. In the descriptive curriculum is where teachers can also identify what Gallard Martinez and colleagues (2020) refer to as contextual mitigating factors that contribute to student successes and failures. Student experiences, thus, are descriptive of the prescriptive curriculum, which implies that teachers must be vigilant of both the prescriptive and descriptive dimensions of their state and district prescriptive curricula when they prepare their lesson plans, or 'sub-prescriptive curriculum.' Student experiences can be anticipated in the descriptive curriculum via what Ornstein and Hunkins (2013) refer to as the hidden curriculum (the actual content of student experiences characterized by activities and interactions that are profoundly different from the prescriptive dimensions) and the null curriculum (the content that is not taught, per se, but influences the shaping of attitudes and beliefs). Ladson-Billings (2021) notes that "the point of the hard re-set is to reconsider what kind of human beings/citizens we are seeking to produce" (p. 72), and in the hidden and null curricula is where that planning can occur.

Thus, by the definitions described here, it is the hidden and null curricula that can function as the portals to the experienced curriculum because these are the curricula where teachers generally, culturally relevant teachers specifically, can intentionally integrate moral, ethical, personal, social, cultural, ethnic, and language landscapes in ways that students' culture and social conditions are used to connect academic learning (Ladson-Billings, 2021) to their experiences (Ellis, 2004; Ladson-Billings, 2021). If teachers, the sole creators of their 'sub-prescriptive curriculum,' could plan their experienced curriculum being mindful of a hidden and null curricular agenda, teachers would be able to anticipate student experiences of the prescriptive curriculum to more adequately advance culturally relevant pedagogical practices to reduce education debt (Ladson-Billings, 2006) and to begin closing the achievement and socioemotional gaps created by the COVID-19 pandemic.

The Issues with Tutoring

For the 2021-2022 school year, Texas schools reopened for in-person post-pandemic instruction with local social distancing and controversial masking requirements in place. Schools reopened only to discover that the declines in student learning resulting from the pandemic were dire, particularly in reading and math (Dorn et al., 2021). To address pandemic unfinished learning, schools and teachers in Texas must comply with the bipartisan House Bill (HB) 4545 and provide a minimum of thirty hours of both accelerated and supplemental instruction (tutoring) during each semester of the school year. However, teachers at my school district have observed and reported that students are considerably more reluctant to attend either accelerated and/or supplemental instructional sessions. Reasons, cited by students at my campus, for not attending such sessions include: 1) students are gainfully employed to help support their families, 2) students, especially females, must be home to care for siblings and/or other family members, 3) students lack timely transportation to before-school tutoring, particularly those who are transported via the school busses, 4) students lack transportation to Saturday tutorials on campus, 5) parental/guardian refusal, 6) student disinterest, and/or 7) student lack of motivation. This is supported by the literature (McWhirter et al., 2019). Ladson-Billings (2021) notes that "for some students, most instruction may have to occur on the weekends" (p. 75), but this does not happen. Regardless of the reason or the contextual landscape in which our students have been positioned, each contributes to student post-pandemic academic decline and the ever-growing disparities among the at-risk populations in 21st century science education.

Old School* is No Longer *Cool School

Science educators at my school district have also observed and reported that since students returned to school after eighteen months of COVID-19 pandemic isolation and virtual learning, the same instructional efforts, tools, and strategies that they used during previous school years to engage learners in science content currently seem to be inadequate and/or ineffective. Science educators district-wide have concluded that the time is now to re-invent instructional strategies and tutoring programs to ignite student interest and motivation and accommodate students' very different learning needs because today's student learning has morphed into something that even educators struggle to understand, and the strategies of yester years are not working. Science educators need new creative, innovative, equitable, and culturally relevant instructional strategies, tools, and tutoring programs to be compliant with HB 4545 and to help students engage/re-engage in and recover unfinished post-pandemic learning because *old school* is no longer *cool school*.

Teacher Workforce in Crisis

Teachers and schools are challenged to re-think their instructional strategies and tutoring programs, but, as a result of the COVID-19 era, the US teacher workforce is still in crisis (Duncan, 2022). Educational organizations, such as the Texas Association of School Boards (*TASB News and Insights*, n.d.), the National Education Association (Walker, 2021), and the Association of Texas Professional Educators (2021), reported that the COVID-19 pandemic took its toll on teachers' mental and physical health causing them to leave the profession. Additionally, teachers reported being spread thin and not having the extra time or motivation to invent new creative, innovative, equitable, and culturally relevant instructional strategies that are desperately needed right now. Results of the 2023 State of the American Teacher Survey published by Rand Corporation show that American teachers report better well-being and lower job-related stress, however their well-being is worse than the general population of working adults (Doan et al., 2023).

Student Mental Health Stigma

Piagetian and Vygotskian theories have taught us that learning is an active process that involves the social and cultural construction of knowledge within a learning environment (Goodman, 2014). However, the isolation and eighteen-month confinement to an electronic device may have potentially prevented many students from receiving the social and cultural components of their knowledge construction. This, consequently, may have stymied student socio-emotional development and learning (Loades et al., 2020) and contributed to the nationwide reported academic losses. Those new and improved creative, innovative, equitable, and culturally relevant instructional strategies and tutoring programs that educators in general need must also simultaneously and more effectively support students' socio-emotional needs, more so now than ever before. This aligns with Ladson-Billings (2021) hard re-set for curriculum, in which she states, "in addition to content, the curriculum will need to expand to meet the social-emotional needs of students" (p. 74).

21st Century Science Education

In 21st century science education, a curriculum re-set could include: 1) the promotion of scientific literacy and application of moral and ethical reasoning to activities of science, as seen in lessons based on Socioscientific Issues (SSI) (Zeidler et al., 2019), 2) the bridging of science and technology with society and the environment, as seen in SSIs brethren eco-justice frameworks, Science, Technology, Society, and Environment (STSE), or 3) Socially-Acute Questions (SAQ) (Bencze et al., 2020), which pertain to acute societal issues that require socio-epistemological reflexivity in the processes of scientific knowledge production (Bencze et al., 2020) and align with the basic premises of the culturally relevant pedagogical framework. Each of these theoretical approaches in science education provides planning opportunities for the hidden and null curricular components of science educators' 'sub-prescriptive curriculum' (lesson-plans) to advance culturally relevant pedagogical practices in a science curriculum re-set, provided educators understand the foundational underpinnings of the learning theories upon which each approach was constructed.

Of significant importance in a science curriculum re-set for 21st century science education is the integration of constructivist pedagogies. In Chapter 1 of *Educational Psychology Reader: The Art and Science of How People Learn*, Greg Goodman (2014) offers a description of constructivism, which he bases on the work of Jean Piaget and Lev Vygotsky, stating that constructivist theory is "our ability to create and construct our own lives through the multifaceted and experientially based existence that we continuously evolve and participate in" (p. 10). He further notes that "constructivists believe that individuals restructure the chaos of life to create meaning and order within their own worlds" (Goodman, 2014, p. 10). In the work of Michael R. Matthews (1992), progressive constructivist pedagogies in science should: 1) foster communal student engagement, 2) encourage discourse, argumentation, conversation, and the formation and appreciation of opinion, 3) stress the importance of understanding as a goal of education and science instruction, and 4) make educators aware of the human dimension of science: its fallibility, its connection to culture and interests, scientific convention and theory, the historical authenticity of concepts, and the complex procedures of theory appraisal.

In their paper "Constructivism as a Referent for Science Teaching" (1992), Anthony Lorsbach and Kenneth Tobin wrote of the importance of a constructivist-oriented curriculum, the learning environment, and the cooperative learning strategy in science education, which the authors describe as key instructional strategies that are used by constructivists because of the belief that learning involves the community of others to help make sense of their experiential world. Ladson-Billings in 2021, 29 years later, shares Lorsbach and Tobin's appreciation of cooperative learning and emphasizes that in a pedagogical re-set, "teachers must move beyond lectures and telling as teaching. Teachers must become skilled in using authentic discussion and debate strategies, cooperative grouping, and small group activities" (p. 74). What is constructivism, what do teachers really know about constructivism, and why is it important in 21st century science education?

Constructivism as a Referent for Science Teaching

The article "Constructivism as a Referent for Science Teaching," by Anthony Lorsbach and Ken Tobin (1992), explores how constructivism, an epistemology of knowledge acquisition, can inform and enhance science teaching practices. The authors begin by questioning why educators seldom focus on *how* students learn, despite this being critical to effective teaching. They suggest that constructivism, which emphasizes the active role of learners in constructing their understanding based on personal experiences, offers a valuable perspective for teachers.

Constructivist Epistemology and Learning. According to the authors, the epistemological perspective of constructivism asserts that knowledge is seen as residing in individuals, not as an objective reality that can be transmitted from teacher to student. Instead, it is built by individuals through their sensory experiences and interactions with the world. Constructivism connotes that students cannot passively absorb information; they must actively engage with it, making connections to their prior knowledge and experiences. Lorsbach and Tobin (1992) contrast this with the traditional objectivist view, where knowledge is seen as an external truth that students must learn through memorization and repetition, and transitioning from objectivist to constructivist-oriented thoughts leads to radical changes in classroom practices.

In a constructivist classroom, Lorsbach and Tobin note that learning is seen as a deeply personal, adaptive process where students continuously adjust their understanding to fit new experiences either independently and/or with others. Words and concepts are not universal containers of meaning but are shaped by individual experiences. The authors use the term "negotiation of meaning" (p. 4) to describe the process through which students actively engage with new information, compare it with their prior knowledge, and resolve any discrepancies to make sense of what they are learning. Negotiation of meaning, thus, is important in a constructivist-oriented curriculum and classroom, and Lorsbach and Tobin suggest that cooperative learning is a primary teaching strategy because this strategy enables students to explore their experiential world with the community of others. Hence, in a constructivist learning environment, teachers provide opportunities for students to engage in problem-solving and inquiry, enabling them to adapt and refine their understanding.

Cooperative Learning: The Role of Social Interaction. Teaching science from a constructivist perspective involves active, social processes, and it is this active engagement of students in science that Lorsbach and Tobin (1992) affirm "is the goal of most science education reform" (p. 2). Social interaction plays a crucial role in constructivist learning, where students work together to test and refine their ideas. Lorsbach and Tobin note that through collaboration, students are exposed to different perspectives, which can challenge their existing beliefs and lead to deeper understanding. The cooperative approach, thus, encourages students to negotiate meaning, helping them to resolve conflicts between their preconceptions and new information, it fosters social interactions, and it encourages students to share and debate their ideas. This is a significant shift from traditional classrooms, where the focus is often on individual work and quiet compliance.

Constructivism Applied in Science Teaching. Lorsbach and Tobin (1992) contrast two science teachers to illustrate the difference between objectivist and constructivist teaching approaches. "Bob," an objectivist teacher, views science as a set of facts to be transmitted to students. His classroom is organized for passive learning, with students sitting in rows and listening to lectures. Bob's approach emphasizes covering content efficiently, with little regard for whether students truly understand the material. The example used was when Bob was teaching about friction, he had his students complete a worksheet and then provided them with the correct answers, leaving little room for deeper exploration or connection to personal experiences.

In contrast, "John," a constructivist teacher, creates a more student-centered and inquiry-based learning environment. John introduces concepts with brief lectures or readings, but he then encourages students to explore topics that interest them through experiments and group work. When teaching about friction, John allows students to conduct hands-on activities and relate the concept to everyday experiences, such as rubbing their hands together or watching a cartoon to discuss friction. This approach gives students more time to engage with the material and construct their own understanding, leading to deeper comprehension.

The Shift from Objectivism to Constructivism. Lorsbach and Tobin (1992) address the challenges teachers face when transitioning from an objectivist to a constructivist approach. Changing long-standing teaching practices is difficult, as both teachers and students are often accustomed to traditional methods where teachers control the flow of knowledge, and students are passive recipients. However, the authors contend that as teachers adopt constructivist practices, they begin to see significant changes in their classrooms. Students become more engaged and take more responsibility for their learning, and traditional classroom management strategies, such as maintaining silence and order, are replaced by a focus on creating environments conducive to exploration and collaboration.

Teachers who shift to constructivist practices recognize that learning is an individualized process, as students need time to reflect, discuss, and negotiate their understanding of new concepts. This process is facilitated by creating opportunities for students to compare their ideas with their peers and resolve any discrepancies. The role of the teacher, therefore, shifts from being a transmitter of knowledge to a facilitator of learning, guiding students as they construct their own understanding.

Summary: Constructivism as a Referent for Science Education Reform. When Lorsbach and Tobin (1992) describe constructivism as a "referent," they mean that constructivism serves as a guiding framework or reference point for making sense of the teaching and learning process. In this context, a referent is a theoretical lens through which teachers can observe, interpret, and guide their practices. Instead of viewing teaching as simply transmitting information to students, constructivism, as a referent, allows teachers to understand that learning is an active, personalized process where students construct knowledge based on their prior experiences.

By using constructivism as a referent, teachers shift their focus from delivering content to facilitating environments where students can engage with ideas, test their understanding, and build knowledge collaboratively. It helps teachers rethink classroom strategies, move away from traditional objectivist practices (where knowledge is seen as static and external), and embrace methods that recognize the dynamic, subjective nature of learning. In short, constructivism as a referent changes the way teachers view their role, emphasizing the importance of student-centered, inquiry-based learning that aligns with how students naturally come to understand the world.

The Question of How Students Learn

In "Constructivism as a Referent for Science Teaching" (1992), Lorsbach and Tobin began by questioning why educators seldom focus on *how* students learn. They suggest that the dominance of objectivist epistemology in traditional education is a significant reason educators do not often focus on the learning process. The objectivist model prioritizes content coverage and efficiency, which can lead teachers to focus more on what they are teaching and less on how students are learning. They also highlight that many teachers are unaware of the constructivist perspective. Since traditional educational practices have long been centered on teacher-directed instruction and control of the classroom, teachers often prioritize managing behavior and delivering information over facilitating deep, reflective, and individualized learning processes. Thus, the reason educators rarely focus on *how* students learn is rooted in entrenched teaching practices and epistemologies that undervalue or overlook the complex, active nature of learning from the student's perspective.

Learning Theories and the Learning Process

In his book, The New Brain, Dr. Richard Restak defines cognition as "the ability of the brain and nervous system to attend, identify, and act on complex stimuli," (Restak, 2003). His definition refers to the various ways the brain functions in order for an individual to adapt to his or her surroundings and learn about the world. Cognition, thus, results in learning. The cognitive brain functions include mental activities such as alertness, concentration, memory, reasoning, creativity, and emotional experience (Restak, 2003; Pritchard, 2017). Educators expect these same mental activities from their students in their classrooms daily, but do educators really understand what cognition is and how it results in learning? This will be addressed momentarily.

Learning starts well before formal schooling, continues for an even longer period after it, occurs at a very fast pace in parallel with school in a variety of settings, assumes many forms, has been studied and explained by numerous researchers and thinkers over a span of many years (Pritchard, 2017), and oftentimes addresses the role of motivation (Bandura, 1977). Theories of learning are frameworks or models that explain how individuals acquire, process, and retain knowledge, skills, and behaviors (Pritchard, 2017; Kropf, 2024). Theories used in education provide insight into the mechanisms behind learning and guide educators in understanding and improving the learning process (Pritchard, 2017; Kropf, 2024). Educational learning theories are designed with the goal of eliciting appropriate cognitive processes to achieve effective learning outcomes (Kropf, 2024), and educators rely heavily on them in some way, shape, or form, oftentimes without realizing it (Pritchard, 2017). For example, Khalil and Elkhider (2016) report that almost all faculty members who teach in higher education lack formal training in learning theory awareness and instructional design. Faculty members, thus, tend to be solely responsible for the instructional design of their course(s) and instructional materials. They identify their program and session objectives, create learning activities to achieve those objectives, and evaluate learners' ability to successfully achieve those objectives. Higher education faculty members, therefore, utilize an objectives-based curriculum to achieve the desired student learning outcomes despite lacking the scientific theoretical underpinnings of educational theories when designing their instructional activities (Issa et al., 2011; Khalil & Elkhider, 2016).

When considering the practical value of educational theory, Anthony Artino and Abigail Konopasky (2018) describe two key contributions of educational theory that go beyond content knowledge, frequent practice, and talent: 1) educational theory provides crucial frameworks from which any educator can create effective instruction, and 2) theory-based instruction can be systematically tested and gradually improved, which refines educators' understanding of the thinking and learning processes and their execution of specific teaching methods.

Learning theories provide the landscape for the selection of the most appealing instructional strategies and act as means to predict their effectiveness (Ertmer & Newby, 1993; Gravells & Simpson, 2014). In classrooms, educators choose an instructional strategy in hopes of achieving the expected learning outcomes. They assume that if the learning outcomes were achieved, then the instructional strategy was effective. Similarly, if the learning outcomes were not achieved, then the instructional strategy was not effective. Thus, to achieve the mental activities that Restak (2003) describes and the effective learning outcomes that educators strive for, the science of instruction and instructional design models and strategies supported by learning theories should be used. Educators, therefore, should be grounded in learning theory frameworks and their actual impact on learners and should be aware of the links between the instructional design and strategies and the learning theories (Pritchard, 2017), otherwise they will have no idea how the quality of their instructional delivery and strategy preferences impact learners and learning outcomes.

Research has shown that the quality of teaching and school leadership are the most important factors affecting student achievement (Miles et al., 2004; Strong et al., 2004). As in any profession, new teachers and principals take years to acquire and develop the necessary skills to be effective. Teaching is highly complex, leading to one-third of teachers leaving the profession within three years and 50% within five years. Even experienced teachers face ongoing challenges, such as changes in subject matter, instructional methods, technology, laws, procedures, and student needs. Without effective professional development, educators struggle to improve their skills, which negatively impacts student learning. Professional development is the only tool that governments around the world use to improve the knowledge base and skill sets of their practicing teachers (Miles et al., 2004; Strong et al., 2004; Popova et al., 2022).

National policy, such as the No Child Left Behind Act of 2001 (NCLB), requires that states ensure the availability of 'high-quality' professional development for all teachers. State laws and local education agencies additionally require all US teachers to attend routine inservice and professional development training on various topics including curriculum development and instructional design, lesson planning, lesson delivery, etc. Such training strategically focuses on increasing instructional efficiency and facilitating student learning. On occasion or as often as can be afforded, primary, middle, and secondary school districts employ formally trained instructional designers to provide professional development to their teachers. It has been my experience that from these trainings, teachers are provided a landscape of instructional materials designed to provide students with more meaningful and impactful learning experiences, but those materials generally do not include a handbook, guide, or brochure that explains the foundational underpinnings of the learning theories upon which the instructional materials were constructed nor how the systemic processes in designing those materials were geared towards increasing instructional efficiency and facilitating student learning. In a study conducted by Andrea Weinberg, Meena Balgopal, and Laura Sample McMeeking (2021), the authors noted that most teacher educators do not receive formal preparation for their roles in education, which results in the distinct need for support to develop pedagogical content knowledge.

Constructivist Learning Theory for 21st Century Science Education. Educational learning theories have been described as abstractions that try to explain what is involved in teaching and learning, although no single theory applies to all learning contexts (Artino and Konopasky, 2018). In constructivism, as has been previously discussed, meaningful learning occurs when the learner tries to make sense of newly presented material by selecting relevant incoming information, organizing it into a schema, and integrating it with the learner's own personal interpretation that incorporates the learner's past experiences and cultural factors (Ertmer & Newby, 1993; Gravells & Simpson, 2014). Similar to cognitivism, constructivism is an active learning process in which learners construct new ideas or concepts based upon their current knowledge, past knowledge, and social interactions (Ertmer & Newby, 1993; Gravells & Simpson, 2014; Goodman, 2014; Lorsbach & Tobin, 1992), and generally falls under the umbrella of cognitive science (Pritchard, 2017). As in cognitivism, constructivism is rooted in the works of Piaget, Vygotsky, and Bruner (Goldman, 2014). Other influential constructivist theorists include Seymour Papert and David Kolb (Packer & Goicoechea, 2000).

Constructivist educators adjust their teaching strategies to student responses, encourage students to analyze, interpret, and predict information according to their personal interpretations, and encourage students to engage in more complex dialogue amongst themselves during open-ended questioning (Ertmer & Newby, 1993). Constructivism promotes learning experiences where the methods and results are not easily measurable or consistent with each learner (Ertmer & Newby, 1993). Examples of constructivist strategies include discovery learning, problem-based learning, experiential learning, inquiry learning, cooperative learning, collaborative learning, hands-on problem solving, learner-centered activities, communication activities, diaries and reflection, and role modeling (Ertmer & Newby, 1993; Gravells & Simpson, 2014; Khalil & Elkhider, 2016).

The Learning Process

A fundamental grasp of cognition and the learning process is crucial for anyone involved in the design of activities that foster effective learning in classrooms, especially for teachers (Restak, 2003). In a review of Ulric Neisser's 1967 book *Cognitive Psychology*, authors Michael Posner and Patrick Bourke (1992) discuss how Neisser, often regarded as a founding figure in cognitive psychology, played a pivotal role in shaping how we understand cognition. Neisser defined cognition as all the mental processes by which sensory input is transformed, reduced, elaborated, stored, recovered, and used, a definition that laid the foundation for the field of cognitive psychology. It encompasses a wide range of functions such as perception, attention, memory, problem-solving, decision-making, reasoning, and language comprehension.

Learning occurs when information is properly received and coded by the brain (Khalil & Elkhider, 2016) . The brain's cognitive system is theoretical rather than anatomical and involves three types of memory - sensory memory, working memory, and long-term memory - that work together to code incoming information (Khalil & Elkhider, 2016). Incoming information is received via the senses and retained by sensory memory (Baddeley, 1999; Khalik & Elkhider, 2016). Information perceived by sensory memory then passes to working memory (WM) where mental activities and learning occur (Baddeley, 1999; Khalil & Elkhider, 2016). Khalil and Elkhider (2016) refer to two types of 'rehearsal' – maintenance rehearsal and elaborative rehearsal - that students use when they process information in WM. Maintenance rehearsal refers to passive rote memorization, which leads to short-term retention, and elaborative rehearsal refers to the active process of organizing information so that it can be transferred into long-term memory. Working memory, however, is limited in its duration and capacity (Baddeley, 1999; Khalil and Elkhider, 2016; Ward et al., 2017), whereas long-term memory is unlimited in capacity and stores information permanently (Khalil and Elkhider, 2016). The goal of instructional delivery is, therefore, to emphasize elaboration (understanding, deep learning) over maintenance (rote memorization) rehearsal of new content to be learned.

The learning process itself is an active process. Constructivist theory emphasizes that learning is an active process where individuals construct knowledge by integrating new information with prior knowledge, experiences, and cultural contexts (Ertmer & Newby, 1993; Gravells & Simpson, 2014; Goodman, 2014). In constructivism, learners do not passively receive information; instead, they actively select relevant information, organize it into meaningful structures, and integrate it into their existing mental frameworks, or schemas. This process allows learners to create personalized understandings, shaped by their unique perspectives and backgrounds (Ertmer & Newby, 1993; Gravells & Simpson, 2014).

Rooted in the works of Piaget, Vygotsky, and Bruner, constructivist theory draws on cognitive psychology principles, as learners actively build new ideas or concepts based on prior experiences and social interactions (Pritchard, 2017; Goldman, 2014). The theory recognizes the importance of social and cultural factors in learning, which aligns with Vygotsky's focus on the role of social interactions and language in cognitive development. For example, constructivist educators engage students in dialogue, encouraging them to analyze and interpret information collaboratively, which fosters a deeper understanding through interaction and exploration (Ertmer & Newby, 1993).

Constructivist learning theory facilitates learning by promoting strategies that enable students to discover knowledge independently, engage in problem-solving, and reflect on their learning experiences. Constructivist methods such as problem-based learning, inquiry learning, and experiential learning encourage students to apply their knowledge in real-world contexts, making learning more relevant and impactful (Ertmer & Newby, 1993; Gravells & Simpson, 2014; Khalil & Elkhider, 2016). These strategies help learners move beyond rote memorization, encouraging them to engage in elaborative rehearsal, a process where they actively organize and connect new information to existing knowledge in a meaningful way (Khalil & Elkhider, 2016). This active engagement helps transfer knowledge from working memory to long-term memory, making it more enduring and accessible for future applications.

Understanding the learning process through a constructivist lens allows educators to create environments that support and enhance cognitive development. Constructivist learning theory provides the framework to design activities that engage the senses, activate working memory, and integrate prior knowledge, facilitating a learning process that leads to a lasting understanding (Kane & Engle, 2002; Wilhelm et al., 2013). By focusing on meaningful engagement, constructivism equips learners with the cognitive tools needed to navigate and make sense of complex information, ultimately fostering lifelong learning and adaptive thinking.

As has been described, the theoretical system of cognition and the processes of thinking and learning are *active* processes (Kane & Engle, 2002; Wilhelm et al., 2013; Khalil & Elkhider, 2016; Ward et al., 2017). For effective and meaningful learning to occur, new information/content should be received by the senses, organized in working memory, and activated with prior knowledge that is stored in long-term memory. The design of effective instructional strategies, therefore, should elicit the appropriate cognitive processes in the learner to yield the best possible learning outcomes.

In sum, constructivism emphasizes elaboration over maintenance rehearsal by encouraging learners to actively engage with new content, linking it to their prior knowledge and experiences. In constructivist learning, students go beyond mere repetition (maintenance rehearsal) by organizing and integrating new information in meaningful ways, creating connections that lead to a deeper understanding (Khalil & Elkhider, 2016). This approach aligns with elaborative rehearsal, where learners structure knowledge within personal frameworks or schemas, making it easier to retrieve and apply in new contexts. By focusing on activities like problem-solving, inquiry, and collaborative discussion, constructivist methods foster comprehension and transfer, promoting lasting knowledge rather than short-term memorization.

Generation Z

It is critical now for a post-pandemic science curriculum re-set and expansion to include a technology re-set (Ladson-Billings, 2021). Why has technology become so vital in education today compared to yesterday? Is the pandemic solely responsible for placing technology at the forefront of teaching and learning? To answer this question, we need to "know" more about the students in our classrooms today – Generation Z - and the impact of community on their learning.

Gen Z's characteristics, behaviors, and engrossment into technology influences their expectations of education. Mahapatra and colleagues (2022) describe Gen Z as 'digital natives' as well as Shrestha and Hansen (2021) because they are the "native language speakers" of the digital language" and teachers as "digital immigrants" who speak "an old-fashioned, non-digital, language" (p. 5). The digital natives (students), thus, do not understand their digital immigrants (teachers) and "as a result, the educational strategies and methods utilized to educate such students have become obsolete" (p. 5). This is a very good reason why the practices, tools, and learning strategies that teachers have relied upon for years no longer seem to be effective.

The factors that shaped Gen Z are diverse and rooted in technology, social dynamics, and cultural diversity (Springer & Newton, 2020). Technology plays a central role, as Gen Z is the first digitally native generation, growing up with social media, connectivity, and instant entertainment and knowledge. Research shows that 95% of teens have access to a smartphone and 45% of teens are online constantly (Orben, 2020). In 2008, 52% of 12th graders reporting visiting social media sites daily, compared to 82% in 2019 (Twenge et al., 2019). This has led to both benefits, such as increased independence in learning and communication (Chicca & Shellenbarger, 2018), and drawbacks, including technology addiction, sleep issues, and mental health struggles (Twenge et al., 2019).

The readily available and accessible technology make Gen Zer's more individualistic in learning, interpersonal interaction, and communication (Chicca & Shellenbarger, 2018), with a preference for digital interactions over in-person socializing (Schlee et al., 2020). They are more likely to spend time alone, shifting socialization to online platforms, which has contributed to difficulties with in-person communication and collaboration. Schlee and colleagues (2020) also note that Gen Zer's are less likely to enjoy group work because they are more likely to be anxious about group member contributions.

Culturally, Gen Z is more racially and ethnically diverse than previous generations (Springer & Newton, 2020). Gen Zer's have a low tolerance for inequality because they have lived through today's era of greater diversity of cultural perspectives. Approximately 62% believe that increasing diversity is good for society. In a comparison between American 9th graders in 2008 and 2019, tolerance for others with different beliefs increased from 73% to 81%, ability to work with diverse people increased from 79% to 87%, and ability to see the world from the lens of more culturally diverse perspectives increased from 65% to 78% (Stolzenberg et al., 2020). This exposure to diverse perspectives has fostered greater tolerance for diversity and inequality, setting them apart from older generations in terms of their progressive views on social issues.

In addition to being digitally savvy, examination of the literature by Chicca and Shellenbarger (2018), revealed ten overall Gen Z characteristics:

1) they are avid consumers of technology and cravers of the digital world
2) because of their high technology use, they have underdeveloped social and relationship skills
3) they are at increased risk for isolation, insecurity, and mental health issues, to include anxiety and depression
4) they have a short attention span and they bore easily
5) require convenience and immediacy, such as immediate feedback on their work
6) they are practical and pragmatic
7) they are concerned with emotional, physical, and financial safety

8) they are racially and ethnically diverse and open-minded

9) they prefer to engage in sedentary activism instead of taking active roles in social issues

10 they are individualistic.

Chicca and Shellenbarger also found that socio-political events and contextual factors experienced by Gen Zer's are key reasons why youths of the generation are described as practical, cautious, and skeptical, not certain if they will succeed, not willing to take risks, and more likely to have a back-up plan in case things do not work out. These characteristics have direct implications for their learning.

Gen Z prefers a virtual means of communication and immediate feedback, they have poor social skills, and they prefer to be involved in decision-making over taking orders (Mahapatra et al., 2022). In addition to being digitally savvy, Gen Z are open to accepting and understanding diverse perspectives, and are truth-seekers, 'expressing individual truths, connecting through different truths, understanding different truths and unveiling the truth behind all things' (p. 250). In other research, Gen Z are described as: 1) being accustomed to the quick access of information, 2) being consumers and producers of knowledge, 3) trusting in themselves, 4) being open-minded, pragmatic, creative, entrepreneurial, skill, and goal oriented, 5) having high expectations, 6) preferring communication with social media outlets, 7) being able to easily multitask, 8) preferring personalized micro experiences and hands-on exercises, 9) preferring graphics over texts, 10) preferring interactive and video-based learning, and 11) preferring to associate what they have learned with real-world problems (Yalcin-Incik & Incik, 2022). These characteristics have direct implications for their learning.

Results of Yalcin-Incik and Incik's (2022) research showed that technology use increases students' interest in lessons, facilitates learning, increases digital literacy and skills, and provides easier and faster access to more information. Researchers Carstens and colleagues (2021) note that "in today's classroom, technology is becoming a more prominent form of learning" (p. 105), causing teachers to be in constant search of the technological tools that work with and enhance student learning. They cite a referent stating:

> Today's educators are under great pressure to provide 21st century students with a quality education based on 21st century standards. Those standards include providing students with the technological and informational skills needed to compete in an ever-changing, technology-driven world (p. 105).

For these reasons, Ladson-Billings (2021) emphasizes that a hard re-set around technology must occur for post COVID-19 pandemic learning and psychosocial recovery.

Underrepresentation in STEM

The history of the underrepresentation in STEM (Science, Technology, Engineering, and Mathematics) education is rooted in various social, cultural, and historical factors that have limited access and opportunities for females, racial and ethnic minorities, and individuals from low socioeconomic backgrounds. The role that educators are asked to play to ensure that all students are academically successful is becoming more urgent and complex because of the growing diversity of today's US student population and widening achievement gaps among the underrepresented minority (URM) and female subgroups (Estrada et al., 2016). STEM persistence is more concerning for these subgroups, despite the more than 40 years of interventions supported by the National Institute of General Medical Sciences, the Howard

Hughes Medical Institute, the National Science Foundation, and other funders, that address this disparity in STEM fields.

Claims of female inferiority in science and math pervade STEM research, but the results are contradictory. According to Upadhayay and Guragain (2014), there exists an extensive research database which suggests that females show advantages in verbal fluency, perceptual speed, accuracy, and fine motor skills, and males show advantages in spatial, working memory, and mathematical abilities. Researcher Janet Hyde, a representative of the National Academy of Sciences (US), National Academy of Engineering (US), and Institute of Medicine (US) Committee on Maximizing the Potential of Women in Academic Science and Engineering (National Academies Press (US), 2006), conducted a meta-analysis to identify gender differences in mathematical, verbal, and visuospatial abilities and found that: 1) girls outperform boys at computation by only a small amount in elementary and middle school, 2) no gender difference at any age level existed for the deeper understanding of mathematical concepts, 3) no gender difference in elementary or middle school students and only a small difference among high school and college students existed for complex problem-solving, which is the highest cognitive level, 4) females only slightly outperformed males in verbal ability, and 5) females only marginally underperformed in the performance of three dimensional mental rotation. Spence, Yu, Feng, and Marshman (2009) found that males and females seem to differ only where visuospatial skills are concerned but stated that these types of skills can be trained.

Despite conflicting claims of female inferiority in math and science in the quantitative research database, the fact remains that females continue to be underrepresented in STEM, and the achievement gaps continue to persist. Females tend to be excluded often because they continue to be subjected to stereotype threats about their presumed inferior cognitive ability and mathematical ability (Eddy et al., 2014; Meador, 2018; Riegle-Crumb et al., 2019). Research conducted by Teo (2014) suggests that women exit the STEM pipeline because there are not enough female educators, scientists, and engineers that serve as role models. In addition to instructor gender and stereotype threat, research evidence by Eddy et al. (2014) also shows that the achievement gaps between males and females in STEM result from: 1) a gap in preparedness, with females entering science courses less prepared than males, and 2) classroom participation, with females reporting lower participation than males, which prevents them from acquiring the confidence to participate in more high-stakes science environments. Stereotype threats, numerous achievement gaps, and a leaky STEM pipeline contribute to the under-representation of women in STEM and STEM careers.

Studies have shown that students in poverty do not develop the same cognitively, socially, emotionally, and behaviorally as students not in poverty and subsequently do not achieve at the same levels of engagement or academic success (Levin, 2007; Jensen, 2013; Banerjee, 2016). It has been said that “low-income students face both an actual curriculum and hidden curriculum that is less rigorous and challenging" (Levin, 2007, pg. 1399). Research evidence also suggests that socio-economic hardships alone (Banerjee, 2016) and being born into a family that qualifies for one or more deprivation measures cause children to face challenges throughout their life, thus making it more difficult for them to be competitive (Hair et al., 2015; Banerjee, 2016).

Education has long been the natural established process that democratic societies use to mitigate disparities and propagate opportunities for those born into stratified social circumstances, yet educators continue to pine with the marginalization and underachievement of the historically disadvantaged and oppressed. The Civil Rights Act of 1964 prohibited discrimination on the basis of race, color, or national origin, which meant that any school district receiving federal funds were required to ensure that minority students received the same access to programs as non-minority students (Kuelzer & Houser, 2019). From desegregation, anti-immigration laws, and quotas in the late 19th and early 20th centuries, to the ideology of tracking and the creation of homogenous groups in the classroom that began in the 1920's (Culpepper, 2011), to the No Child Left Behind (NCLB) framework of 2001, federal legislation has consistently shaped educational policies. Despite these efforts, minorities and underrepresented groups continue to be targets of oppressive legislation in the US (Kuelzer & Houser, 2019). In December 2015, NCLB was replaced by the Every Student Succeeds Act (ESSA), which is still very much like NCLB except that it returns the responsibility of education back to the states and eliminates the NCLB's more prescriptive 'highly qualified' teacher requirements (Klein, 2024). Studies continue to show that students in poverty *consistently* underperform and remain a contributing factor in the achievement gap (Ladson-Billings, 2006; Levin, 2007; Jensen, 2013; Hair et al., 2015; Banerjee, 2016). This is but a mere fraction of the many educational reforms in America that have occurred since the 19th century.

The 1983 *A Nation at Risk* report revealed that American students' academic achievement lagged far behind that of students from other industrialized nations, particularly in STEM (Kuelzer & Houser, 2019). The report called for reform in school curricula by increasing graduation requirements, raising standards for teacher training and professional growth, and introducing high stakes, standardized testing. High stakes testing only perpetuates what Paulo Freire referred to as "banking education " - students are the banks into which teachers deposit information, and the more students work at storing the deposits, the less apt they are to develop critical thinking and critical consciousness (Alam, 2013). Despite government efforts to ensure academic success and provisions for opportunities of disadvantaged students, the 2015 Nation's Report Card shows that females, impoverished students, and students who attend the highest-poverty schools are still least likely to have access to STEM resources, experiences, and classes than their peers in wealthier schools, and thus face dim prospects for rewarding STEM careers (Change the Equation, 2015).

There has been progress, but underrepresentation in STEM and postsecondary science and engineering persists among females and the underrepresented minorities - Blacks or African Americans, Hispanics or Latinos, and Native Americans or Alaska natives. Multiple factors contribute to the underrepresentation. Psychological factors and external environmental variables, such as students' mentorship experiences and preferences, their academic mindsets, STEM attitudes, and family background characteristics stereotyping are key contributors (Kricorian et al., 2020). Additionally, lack of access to quality education in underserved communities, scarcity of role models from underrepresented groups, implicit bias in admissions and hiring processes (Burt et al., 2023), and a lack of inclusive curriculum that reflects diverse perspectives (Palid et al., 2023) perpetuate the marginalization.

Teacher Self-efficacy and STEM Integration

For schools to include quality STEM education into their curricula, it is important to understand teachers' beliefs, attitudes, and self-efficacy related to STEM talent development. Self-efficacy, according to social psychologist Albert Bandura (1997) , "refers to beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments," a core belief that Bandura suggests is the foundation of human inspiration, motivation, cognition, and emotional well-being. Simply stated, this theory contends that people who have the power to affect changes by their actions are, therefore, more inclined to be successful if they have confidence in their abilities and skills. Teachers, therefore, who have more confidence in their skills levels and ability to teach are more inclined to successfully and confidently implement an educational program (Shahzad and Naureen, 2017), more specifically a STEM curriculum.

In a 2019 systematic literature review of 25 retained articles published between 2010 and 2017, Kelly Margot and Todd Kettler utilized thematic analysis to show that STEM teachers' prior attitudes, views, and experiences influence their STEM instruction (Margot and Kettler, 2019). Their review also showed that while teachers' value STEM education, certain barriers, such as pedagogical challenges, curriculum challenges, structural challenges, concerns about students, concerns about assessments, and lack of teacher support impact their ability to implement STEM education. A total of 17 findings that characterize teachers' perceptions, efficacy, and beliefs about STEM education and pedagogy emerged, but the findings that are relevant to the current study are as follows:

- Finding 4: Teachers believe that the cross-curricular nature of STEM education is significantly important to student learning and success but perceive barriers that block cross-curricular programs.
- Finding 6: Teachers believe that struggle and failure are inevitable but valuable components of the engineering design process within STEM education.
- Finding 7: Teachers' efficacy beliefs and value they place on a STEM education seem to influence their willingness to engage and implement a STEM curriculum. Interestingly, it was also revealed that the field of engineering is the content area that teachers are least confident in teaching.

- Finding 8: Teachers believe that STEM pedagogy requires them to make changes in how they establish classroom environments and teach, and for them the changes are not always positive, i.e. shifting away from teacher-led instruction to student-led instruction. In fact, teachers regarded some of the pedagogical challenges as inhibiting factors to STEM implementation.
- Finding 9: Some teachers, particularly high school teachers, were apprehensive about integrating a STEM curriculum into their existing curricula.
- Finding 10: Teachers believe that certain school structures are barriers to STEM education implementation, e.g. teacher and student scheduling issues, concerns with curriculum pacing and being able to follow the scope and sequences of instruction for numerous disciplines, and lack of financial supports and technology resources.
- Finding 13: Teachers believe that a culture of collaboration would increase their willingness to implement a STEM curriculum. A significant finding of this review that directly ties to the current research is the teacher's belief that "collaborating with other STEM teachers and university professionals in order to not only create an atmosphere that enhances preparation for STEM lessons, but also to model a team approach to students" (pp. 13-14). In other studies, Kleinschmit and colleagues (2023) and Lehman and colleagues (2014) leverage CoPs to develop and improve university faculty and teacher scholarship and to develop effective and vetted educational resources for the purpose of accelerating STEM education reform.

- Finding 14: Teachers believe that a quality engineering-based curriculum that is flexible enough to be used with stratified ability levels and educational environments while still being focused on the engineering design process increased their self-efficacy to teach STEM.
- Finding 17: Teachers believe that well-organized and frequently available professional learning opportunities would increase their ability to effectively integrate STEM content into their curriculum. Teachers at all levels in their careers reported substantial increases in their knowledge and self-efficacy to teach STEM after attending effective professional development programs.

According to a study conducted by Hu, Jiang, and Bi (2022), the value of STEM education has increased over the last 20 years in many countries, but students' enthusiasm for STEM and their participation and enrollment in a STEM career path has significantly decreased. Their final results showed students' lack of science self-efficacy was a number one reason for the lack of willingness to participate in and enroll in a STEM program or career. Their study also revealed that high school is the period when students' science self-efficacy is the lowest. It is well known in the literature that teacher self-efficacy directly impacts student self-efficacy and their academic achievement (Bandura, 1999; Shahzad and Naureen, 2017; Hajovsky et al., 2020; Hu et al., 2022; Unfried et al., 2022).

The article "Self-efficacy Theory and Learning Environment Research" by Anthony W. Lorsbach and Jerry L. Jinks (1999) explores the relationship between self-efficacy and student perceptions of their learning environments. The authors highlight that student beliefs about the classroom roles of themselves and others influence their interactions and perceptions of the learning environments. Perceptions such as these, in turn, affect student outcomes, making the relationship between learning environments and self-efficacy dynamic and reciprocal (Sokmen, 2021; Schweder & Raufelder, 2022). For instance, students who have higher levels of self-efficacy are likely to view their learning environments more positively, which in turn fosters better academic outcomes. Conversely, students with low self-efficacy may view the learning environment negatively, leading to a potential downward spiral of performance. Lorsbach and Jinks (1999) also note that since student self-efficacy is developed through mastery experiences, social comparisons, and feedback from teachers and peers, teachers must be aware of their pivotal role in shaping students' self-efficacy by providing clear expectations, structured learning activities, and positive feedback.

In order to support teachers, students, and STEM programs, teacher and student self-efficacy must improve and the necessary provisions must be set in place before they can even begin to develop STEM talent, and the broken system can begin the process of repair. As part of this research, a vetted and reliable T-STEM science scale survey, the Teacher Efficacy and Beliefs toward STEM Survey, will be used to acquire information from teachers about: 1) their self-efficacy for teaching, 2) their belief that they affect student learning, 3) how often students use technology, 4) how often they use certain STEM instructional practices, 5) their attitudes toward 21st century learning, 6) their attitudes toward teacher leadership, and 7) their awareness of STEM careers (Unfried et al., 2022).

Theoretical Framework

Community of Practice

According to Jean Lave and Etienne Wenger's concept of a "Community of Practice" (CoP), which was introduced in their 1991 book "Situated Learning: Legitimate Peripheral Participation," a community of practice is a group of people who share a common interest, engage in joint activities, and interact regularly to learn from one another through the process of collaborative learning. This community is not solely based on formal instruction, but rather on informal shared learning and mutual collaboration, knowledge, and practices that emerge through ongoing interactions among its members to develop distinctive practices that foster a group identity (Lave and Wenger, 1991; Denscombe, 2008). Lave and Wenger (1991) emphasize that learning is an integral part of participation in a community of practice, and that newcomers learn from more experienced members through observation, participation, and interaction. The underpinning of this concept emphasizes Lorsbach and Tobin's description of the social nature of learning (1992) and the importance of context in shaping how knowledge is acquired and applied (Denscombe, 2008). Members of a community of practice develop a sense of belonging, engage in active mutual learning, and build a collective identity around their common area of focus (Lave and Wenger, 1991; Farnsworth et al., 2016).

The CoP framework describes three key elements: domain (shared interest or focus), community (interactions and relationships among members), and practice (shared resources, activities, and experiences) (Farnsworth et al., 2016). These elements separate a community of practice from just a regular group of friends or acquaintances. The key characteristics of these elements include:

1. Domain: Members share a common area of interest or expertise. This essential component is what brings the CoP members together.
2. Community: There's a sense of belonging and identity among members around their chosen domain. They interact regularly, either in person or through virtual platforms, fostering relationships and a supportive learning environment.

3. Practice: Members engage in shared activities, discussions, and projects that contribute to their collective learning. This might involve workshops, seminars, online forums, collaborative projects, and more.

Communities of practice in STEM education can focus on tackling real-world challenges, which encourages students to apply theoretical concepts to practical situations, and can involve specific scientific fields, technological applications, engineering principles, or mathematical concepts (Feldman et al., 2013). Allan Feldman and his co-authors, Kent Divoll and Allyson Rogan-Klyve, build on the work of Lave and Wenger (1991) but describe the community of practice through the lens of a *scientific research group*, where undergraduate and graduate students develop their scientific abilities through informal, yet structured, learning environments and participation in authentic research activities (Feldman et al., 2013). In the context of STEM education, Feldman and his colleagues highlight that research groups exemplify communities of practice where students learn science through *apprenticeship*, often entering research groups with limited practical experience. However, through legitimate peripheral participation, students start by observing and engaging in smaller, manageable tasks under the guidance of more experienced members. Over time, they take on more responsibility, progressing toward independent research.

This reflects the apprenticeship model of learning, where students traverse various learning trajectories, starting as novices and progressing to becoming proficient technicians, researchers, or even knowledge producers, depending on their individual experiences and contributions to the group. Feldman and colleagues point out that research education relies on this model, where learning by doing is essential. Students acquire research skills, such as using scientific instruments or designing experiments, by working alongside others. Importantly, this learning is often tacit, meaning that students may not even realize they are being taught in a formal sense. Instead, learning is embedded in the research practice itself.

Feldman and colleagues additionally point out that mentoring in research groups is not just the responsibility of the faculty members but is often distributed among the other members of the group as well. For example, advanced graduate students mentor less experienced undergraduates or newer graduate students, offering advice on both technical skills and navigating the scientific process. Such peer mentoring is a crucial aspect of the community of practice and facilitates knowledge transfer within the group. This idea of *distributed mentorship,* as described by Feldman and colleagues, aligns with the CoP model because it emphasizes the communal nature of learning, where all members in the group, regardless of their status, play a role in teaching and learning. As students move through their educational careers, they acquire technical skills (referred to by Feldman and colleagues as methodological proficiency), such as operating lab equipment or analyzing data, which are necessary for conducting research. However, they also develop what Feldman and colleagues refer to as intellectual proficiency, which includes the ability to formulate research questions, engage in scientific reasoning, and contribute original knowledge to the field.

The work of Feldman and his colleagues has shown that learning in a CoP is not linear but distributed and collaborative, which is particularly useful in the interdisciplinary nature of STEM education. Their study reinforces the idea that scientific research groups serve as effective communities of practice where students learn by participating in the social, cognitive, and practical activities of science. Their CoP model emphasizes the importance of mentorship, collaboration, and hands-on experience, making it highly relevant for STEM education, and aligns with Lave and Wenger's (1991) original concept of community of practice and problem-centered learning strategies. The community of practice, thus, can help explain how informal learning as a social endeavor unites participants, students, and experts to improve knowledge, understanding, and skills.

Research Philosophy

As research philosophies are not mutually exclusive, elements from the interpretivism and pragmatism paradigms guide the approach for conducting this research. Interpretivism is the theoretical assumption that concentrates its efforts on understanding and explaining human behavior and social phenomena while respecting the subjective meanings of social actions (Saraswati et al., 2021). Interpretivists recognize the importance of individual experiences, values, and interpretations and seek to better understand them through qualitative research. Pragmatism is not committed to any one particular philosophical stance and argues that what is essential in research is determining pluralistically if the research has helped the researcher find out what s/he wants to know. Pragmatists, therefore, gather numerous forms of data to answer their research questions. Because pragmatism values both objective (quantitative) and subjective (qualitative) knowledge to meet research objectives, it emphasizes a mixed methods approach to answer research questions.

From an epistemological perspective, the interpretivist research philosophy is chosen because it recognizes that: 1) knowledge is subjective and shaped by the researcher's own experiences and biases, and 2) knowledge focuses on social life interactions and the meaning of these interactions as perceived by individuals rather than objective reality (Capper, 2019). Similar to interpretivist epistemology, a major underpinning of pragmatist epistemology is that knowledge and reality are always based on individuals' experiences that are socially constructed (Kaushik and Walsh, 2019; Saraswati et al., 2021). For the pragmatist, "reality is true as far as it helps us to get into satisfactory relations with other parts of our experiences" (Kaushik and Walsh, 2019, p. 4).

The ontological position of interpretivism is relativism (Scotland, 2012). Relativism is the view that reality is subjective and differs from person to person (Guba & Lincoln, 1994). It assumes that reality as we know it is constructed intersubjectively through the meanings and understandings developed socially and experientially. For pragmatism, reality is viewed as a normative concept and maintains that reality is simply what works (Kaushik and Walsh, 2019).

The axiology of both interpretivism and pragmatism philosophies is value-bound because of subjective epistemological components in each (Capper, 2019; Saraswati et al., 2021). In interpretivism, the researcher is part of what is being researched and cannot be separated; interpretations are, therefore, subjective (Capper, 2019). Pragmatism values both objective and subjective knowledge to meet research objectives (Saraswati et al., 2021); the researcher, therefore, adopts both objective and subjective points of view.

Recognizing Contextual Mitigating Factors as a Basis for the STEM CoP

The research by Alejandro Gallard Martinez, Wesley Pitts, Katie Brkich, and Lizette Ramos de Robles (2020), describes factors that shape, define, and position individuals within contextual landscapes and how to promote equitable research practices. Gallard Martinez and colleagues refer to these factors as the previously discussed contextual mitigating factors (CMFs) and define them as constantly changing socio-historical-political constructs that position and bind individuals in time and within socially constructed spaces. In descriptive terms, I use the analogy of brick and mortar: the individuals in a space are the bricks and the dynamic CMFs that they share comprise the mortar that holds them (the bricks) together. If the bricks are too porous, precipitation makes its way into the holes, degrades the bricks, and the walls come tumbling down. The precipitation takes on the many forms of hegemony, status quo, broken socio-historical-political-emotional-financial-educational systems, abuse and neglect, gender, race, ethnicity, to name a few. It is the precipitation that breaks the bricks, which break the walls. If education is the wall, then it is the many forms of precipitation that contribute to students' lack of success, and when students' lack of success breaks them, their education and the education system come crashing down.

To understand the complexities that contribute to students' lack of success and begin the repair process of a broken education system, it is important to identify and unpack the CMFs in the contextual landscapes of research designs (Gallard et al., 2020), specifically our STEM research CoP design. This approach will help us gather deeper understandings of the complexities, difficulties, and intricacies of our work with students and teachers and the integration of engineering practices in STEM curricula.

The CREST-MECIS Community of Practice: Can it Repair the Broken System?

In an effort to repair the broken system and promote STEM education reform, a research CoP was created as part of an NSF funded Centers of Research Excellence in Science and Technology (CREST) program at the University of Texas Rio Grande Valley (UTRGV) in Edinburg, Texas. In conjunction with its Center for Multidisciplinary Research Excellence in Cyber-Physical Infrastructure Systems (MECIS), the CREST-MECIS program united K-12 (kindergarten through 12th grade) teachers from school districts across the Rio Grande Valley (RGV) in South Texas with UTRGV undergraduate students, graduate students, and higher education engineering and education faculty. Feldman and colleagues (2013) describe participants as learners engaged in an apprenticeship model, primarily characterized by legitimate peripheral participation. The participants are seen as apprentices who learn by doing within the research group, gaining skills and knowledge through practice and interaction with peers and mentors. Students take on roles that develop along trajectories, from novices to skilled contributors, benefiting from mentoring distributed among group members. Such a research group act as communities of practice, fostering methodological and intellectual proficiency among participants. The participants in the CREST-MECIS CoP, thus, enacted specific roles: 1) the students were the apprentices, 2) the faculty were the mentors/instructors, and 3) the teachers were the participants who joined as part of professional development or research collaborations.

The goals of this CoP were to address: 1) the integration of engineering activities and practices in primary and secondary STEM curricula, 2) the challenges, perhaps even contextual mitigating factors (CMFs), that arise from discussions within the CoP landscape and identify more equitable practices to promote the presence and expansion of historically underrepresented students in STEM and STEM careers, 3) teacher self-efficacy and its impact on both teacher and student performance, and 4) undergraduate and graduate student self-efficacy in STEM education and career attainment (Tarawneh, 2021). The community collaboration included, but was not limited to, synchronous and asynchronous forms of communication via the CREST-MECIS Google Classroom and Zoom where members unpacked CMFs and shared their experiences, questions, concerns, fears, attitudes, beliefs, content knowledge, self-efficacy, and skills. It was anticipated that this supportive learning environment would entice members to come for the content but stay for the community and transfer of knowledge.

Summary

The literature review examines the significant educational, social, and psychological impacts of the COVID-19 pandemic, emphasizing the urgent need for systemic reform in education. The pandemic disrupted traditional learning environments, highlighting disparities in access to mental health support and exposing the limitations of outdated educational structures. As COVID-19 recovery continues, educational theorist Gloria Ladson-Billings advocates for a "hard re-set" in pedagogy to address deep-rooted issues that inhibit student success.

In Texas, recovery measures like HB 4545 mandate accelerated instruction but fail to address underlying systemic issues, such as socio-economic barriers and limited student engagement. The challenges extend to Generation Z students, who exhibit unique characteristics shaped by technology, digital culture, and socio-political experiences, requiring innovative, student-centered instructional strategies that incorporate technology and reflect their learning preferences.

The literature also underscores persistent inequities in STEM education, particularly among underrepresented groups, as well as the critical role of teacher self-efficacy in student outcomes. The Community of Practice (CoP) framework, introduced by Lave and Wenger, is applied here to STEM education as a potential avenue for reform. Allan Feldman expands on CoP within scientific research settings, highlighting the benefits of distributed mentorship and hands-on learning, which develop students' methodological and intellectual proficiencies that are vital for addressing the interdisciplinary challenges in STEM.

The CREST-MECIS CoP model brings together educators, undergraduate and graduate students, and experts to address CMFs, enhance STEM integration, and improve self-efficacy among teachers and students. By fostering a supportive environment through both synchronous and asynchronous collaboration, the CREST-MECIS CoP seeks to influence STEM education reform and increase opportunities for underrepresented students. The literature advocates for mixed-methods research to capture the depth and breadth of these educational challenges, using both qualitative and quantitative data to support credible and comprehensive analyses. It is expected that the analyses will shed light on how STEM educators, students, and professionals collaborate, share expertise, and develop a sense of belonging within a STEM research CoP to both recognize the CMFs that inhibit student learning and achievement and to accelerate STEM education reform as part of the process to repair *the broken system*.

CHAPTER III

METHODS

Introduction

This study was in response to Ladson-Billings' (2021) call for a hard re-set to influence 21st century STEM education reform. Its purpose was to advance scholarship in STEM education that replaces antiquated practices, which have created an education system in need of repair, with strategies that promote learning for all students, particularly the historically underrepresented groups. Specifically, the researcher investigated how a research CoP supported K-12 STEM teachers, undergraduate and graduate students, and faculty/experts to improve STEM education practices.

The research CoP was created as part of an NSF funded Centers of Research Excellence in Science and Technology (CREST) program at the University of Texas Rio Grande Valley (UTRGV) in Edinburg, Texas, and its Center for Multidisciplinary Research Excellence in Cyber-Physical Infrastructure Systems (MECIS). The CoP united K-12 (kindergarten through 12th grade) teachers from school districts across the Rio Grande Valley (RGV) in South Texas with UTRGV undergraduate students, graduate students, and faculty/experts. The goals of this CoP were: 1) to address the integration of engineering activities and practices in primary and secondary STEM curricula, 2) to unpack any contextual mitigating factors (CMFs) that arose from discussions within the CoP landscape and identify more equitable practices to promote the presence and expansion of historically underrepresented students in STEM and STEM careers, 3) to identify improvements in teacher self-efficacy and its impact on both teacher and student performance, 4) to identify improvements in undergraduate and graduate student self-efficacy in STEM education and career attainment, and 5) to identify STEM education best practices for Gen Z students.

The community collaboration included, but was not limited to, synchronous and asynchronous forms of communication via the CREST-MECIS Google Classroom and the Zoom platform where members could unpack CMFs and share their experiences, questions, concerns, fears, attitudes, beliefs, content knowledge, self-efficacy, and skills. It was anticipated that this supportive learning environment would entice members to come for the content but stay for the community and transfer of knowledge.

Research Design

This research employed a triangulation mixed methods design with concurrent timing (Creswell et al., 2003; Saraswati et al., 2021) to analyze how STEM educators, students, and professionals collaborate, share expertise, and develop a sense of belonging within a STEM research CoP to both recognize potential CMFs that inhibit student learning and achievement and to advance understandings of STEM education reform. Data weighting and mixing decisions were equal and merged during the interpretation phase. The purpose of this type of convergent design is "to obtain different but complementary data on the same topic" (Creswell et al., p. 63) to best understand the research problem by comparing and contrasting quantitative statistical results with qualitative findings for corroboration and validation purposes.

A mixed-methods design offers numerous benefits to approaching complex research problems because it combines the post-positivism and interpretivism paradigms in ways that integrate both quantitative and qualitative data to arrive at meaningful interpretations (Creswell & Plano Clark, 2018; Saraswati et al., 2021). One benefit to this design is that it enables researchers to answer their research questions with sufficient depth and breadth (Saraswati et al., 2021). Quantitative data can provide breadth to a study, and qualitative data can provide the depth. Moreover, qualitative results can be triangulated with quantitative results, and vice versa. Data triangulation, as a qualitative research method, is the use of various sources of data to develop an understanding of the research problem or to test validity through convergence of the different pieces of information. In this regard, the mixed-methods design is the best option for answering the research questions because it combines two sets of strengths all the while compensating for the weaknesses of each method individually.

Since both quantitative and qualitative data were given equal emphasis and the two sets of results were merged into the overall interpretation to draw valid conclusions about the research problem, a triangulation design convergence model, inspired by Creswell and Plano Clark's model (2018), was used (Figure 1). This model enabled discussion of areas of convergence or divergence between the quantitative and qualitative results.

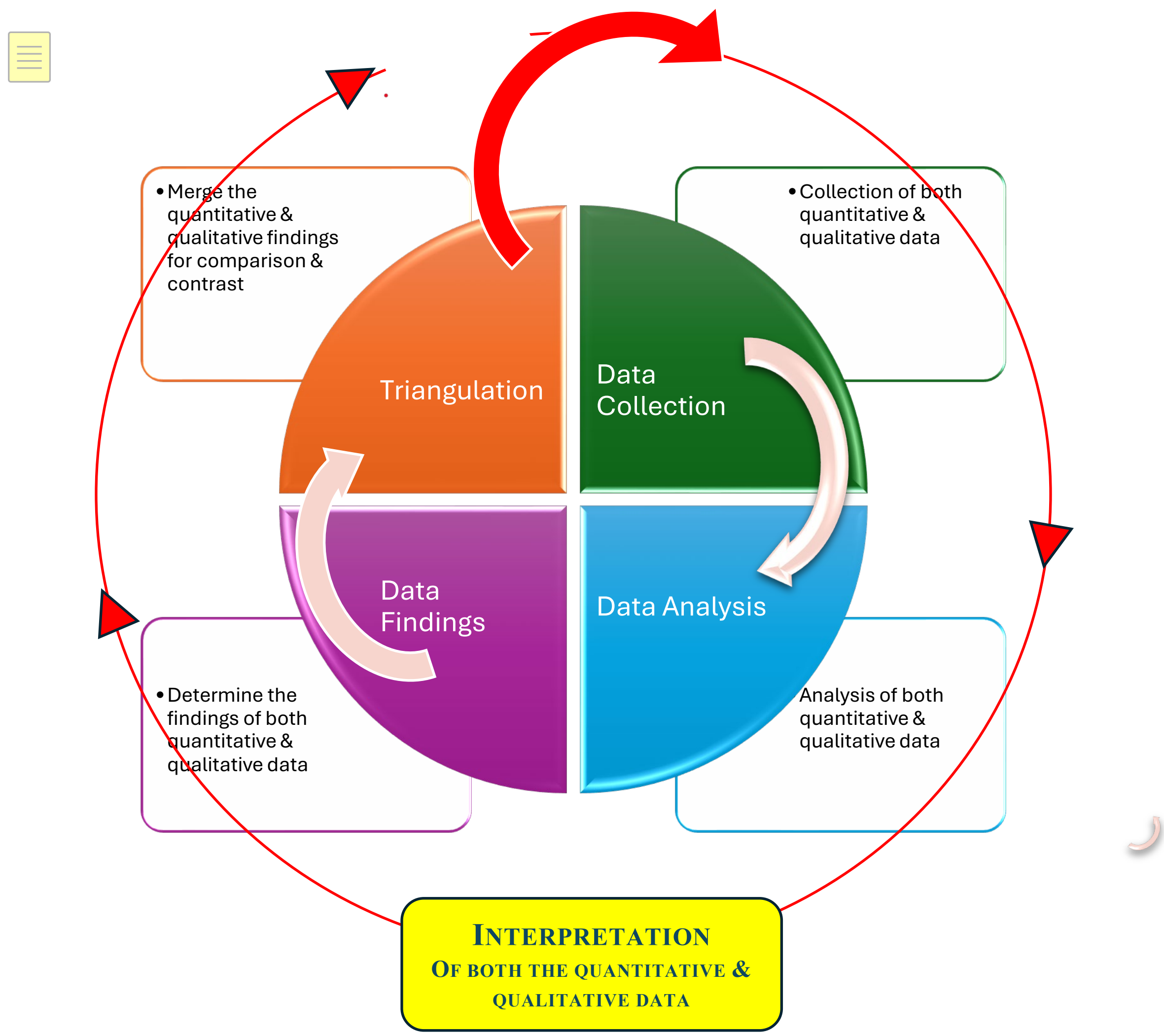

Figure 1: Triangulation Design Convergence Model for this Study inspired by Creswell and Plano Clark's Model (2018)

Research Questions

Guiding the direction of this study is the overarching question "How does the CREST program affect its participants?" The research sub questions are:

1. How do undergraduate and graduate students' perceptions of, participation in, and completion of the CREST program influence their preparation for, interest in, and pursuit of a STEM career?
2. How does the CREST community of practice influence K-12 STEM teachers' efficacy, attitudes, and beliefs toward teaching CREST developed curriculum?

Research Approach

The mixed methods research (MMR) approach strategically integrates or combines rigorous quantitative and qualitative research methods to draw on the strengths of each in order to answer the research questions (Creswell & Plano Clark, 2018; Kaushik and Walsh, 2019; Saraswati et al., 2021). This approach enables researchers to use diverse methods, combining inductive and deductive thinking and offsetting limitations of exclusively quantitative and qualitative research. Additionally, it maximizes the strengths of each data type and facilitates a more comprehensive understanding of the problem and potential resolutions. This approach will be employed, as it combines both qualitative and quantitative research methods in a way that enables the researcher to produce a robust description and interpretation of the research data, make quantitative results more understandable, and facilitate the understanding of the broader applicability of small-sample qualitative findings.

The proposed community of practice research approach was grounded in the work of Martyn Denscombe (Denscombe, 2008). In his publication, Communities of Practice: A Research Paradigm for the Mixed Methods Approach, Denscombe describes the mixed methods approach as a third paradigm for community of practice social research and suggests that:

> …the use of ``communities of practice'' as the basis for such a research paradigm is (a) consistent with the pragmatist underpinnings of the mixed

> methods approach, (b) accommodates a level of diversity, and (c) has good potential for understanding the methodological choices made by those conducting mixed methods research (p. 270).

Central to the notion of communities of practice lies a key issue: *the acquisition of knowledge* (Denscombe, 2008). Denscombe reminds us that for Lave and Wenger, learning has a social and communal aspect to it that exists very differently from learning on an individual and personal level. The type of learning acquired from a community of practice, thus, results as a collective activity, and the knowledge that is communally and collectively acquired from this activity is considered shared knowledge. Shared knowledge is underpinned by the social exchange theory, a theory that plays an important role underlying individuals' knowledge-sharing behavior and their subjective perception of the benefits and gains that could result from such behavior (Liang et al., 2008). What knowledge is and the ways that knowledge is discovered are subjective (Scotland, 2012), which is a reminder of the epistemological foundation of this research.

Triangulation and Interpretation of Findings

Data triangulation is a central methodology in mixed methods research, valued for its ability to enhance credibility and validity by combining both qualitative and quantitative data sources to examine the same phenomenon (Creswell et al., 2003). Creswell defines credibility as the trustworthiness or believability of the findings. It refers to the extent to which the research accurately captures the experiences or phenomena being studied from the perspective of participants. In mixed methods research, credibility can be enhanced by using multiple methods, sources, or perspectives, which allows researchers to cross-verify findings and add depth to their interpretations (Abramovich, 2022). Credibility involves data convergence, which describes how well the data agree with each other; the more the data converge, the more credible the results will be (Creswell et al., 2003). Validity pertains to and is strengthened by the accuracy and rigor of the research design, data collection, and analysis processes (Creswell et al., 2003; Abramovich, 2022). Validity in mixed methods design ensures that the methods effectively capture the intended phenomenon, providing reliable results that can be generalized or applied meaningfully. With respect to credibility and validity, triangulation is used to address the limitations of relying on a single data type by cross-verifying findings, thereby strengthening the study's validity and credibility (Creswell et al., 2003).

Credibility and validity are essential outcomes of data triangulation, as integrating multiple perspectives provides a more thorough and corroborated view of research findings. Saraswati et al. (2021) highlight that triangulation enhances both the *breadth* and *depth* of insights, ensuring that findings are meaningful and applicable across various contexts. By combining quantitative data, known for its breadth and generalizability, with qualitative data, which offers depth and contextual understanding, researchers construct a robust framework that validates results through convergence. This approach facilitates an in-depth examination of complex issues, synthesizing diverse data sources to develop a comprehensive perspective that meets the quantitative need for generalization while capturing the qualitative richness of in-depth description.

The term triangulation derives from its foundation in geometry, where the convergence of multiple lines or angles provides a more accurate location (Abramovich, 2022). Similarly, as a qualitative research method, triangulation involves the convergence of evidence from various sources to corroborate findings and strengthen the overall research design (Saraswati et al., 2021). However, divergence in triangulation, when quantitative and qualitative data do not align, can unveil complex facets of the research problem, prompting deeper analysis requiring careful interpretation or additional data collection to resolve discrepancies (Creswell et al., 2003; Saraswati et al., 2021). Additionally, Abramovich (2022) explains that divergence highlights the necessity of exploring alternative methods or perspectives, which can enhance the rigor and validity of the study by encouraging researchers to examine inconsistencies critically.

On their own, each data source or method has unique strengths and weaknesses, but when combined, each complement the other and accounts for each other's limitations. This study utilized data triangulation to enhance the validity and credibility of the findings by integrating quantitative data from surveys and qualitative data from semi-structured one-to-one recorded interviews (Appendix B). Each data source provided unique insights about how STEM educators, students, and professionals collaborated, shared expertise, and developed a sense of belonging within a STEM research community of practice to both recognize potential contextual mitigating factors (CMFs) that inhibit student learning and achievement and to provide insight on STEM education reform. The qualitative and quantitative results were independently analyzed, merged, and compared to identify and interpret patterns of convergence and divergence.

Data Collection and Sources

Both quantitative and qualitative data were collected from a total of 16 undergraduate and graduate student participants and 6 teacher participants over the course of one year. The collection of each set of data were concurrent but separate, as one set of data were not dependent on the results of the other (Creswell et al., 2003). Quantitative data were collected from a pre- and post-research competencies survey completed by each of the undergraduate and graduate CREST students (Kardash, 2000). This survey measured changes in students' perceptions of their research skills, interest in, and attitudes toward STEM and STEM careers (Kardash, 2000). Students received a personal link to complete their survey via UTRGV's Qualtrics survey platform. The 16 CREST students completed the survey before and after their participation in the CREST-MECIS program.

Similarly, quantitative data were collected from a pre- and post-Mathematics or Science T-STEM survey (Unfried et al., 2022) completed by each of the 6 educators from various elementary, middle, and high schools in the RGV. Math teachers completed the Mathematics T-STEM survey and science teachers completed the Science T-STEM survey. The T-STEM surveys measured changes in teachers' self-efficacy toward teaching science, math, technology, and engineering (Unfried et al., 2022). Teachers received a personal link to complete their survey via the CREST-MECIS Google Classroom. The 6 teachers completed the T-STEM survey before and after their participation in the CREST-MECIS CoP.

Qualitative data were collected from semi-structured online interviews with each of the 16 CREST-MECIS students and each of the 6 teachers. All participants were emailed by the researcher and offered a time and date to be interviewed. Following their reply, appointments were made and confirmed with each participant. Zoom links were emailed on the dates and at the times of each scheduled interview. Each interview was conducted using a set of pre-defined interview questions as well as information that emerged from participants' responses (Appendix B). The average student interview lasted approximately 15 minutes. The average teacher interview lasted about 30 minutes. Eight of the 16 students were participants in the CoP; their interview sessions extended beyond the average 15 minutes to about 30 minutes. Participants were encouraged to genuinely consider their comments and to reflect on the reasons for their responses. Each interview was recorded. The speech from each audio file was converted to a text transcript using Microsoft Word for later analysis.

Quantitative Data Analysis

Student quantitative data were collected from a 5-point pre- and post-Likert scale survey, which was administered at the beginning and the end of their participation in the CREST-MECIS program respectively. The student surveys measured changes in their perceptions of their research skills, interest in, and attitudes toward STEM and STEM careers. Teacher quantitative data were collected from multi-point T-STEM Likert science and mathematics scale surveys at the beginning and end of their participation in the CREST-MECIS Community of Practice and summer 2024 Research Experience for Teachers (RET). The CREST-MECIS RET program is an initiative for teachers that enhances their scientific disciplinary knowledge in engineering or computer science and enables them to integrate their research experiences into classroom activities and curricula to foster students' awareness of and participation in engineering and computer science pathways (*Research Experiences for Teachers in Engineering and Computer Science,* 2023). The T-STEM science and mathematics scale surveys measured changes in teachers' self-efficacy toward teaching science, math, technology, and engineering (Unfried et al., 2022).

Because of the small student and teacher sample sizes, the Wilcoxon signed-rank test was performed using the IBM SPSS version 28 statistical software to measure changes from pre- to post survey responses (Salkind et al., 2020). This particular test is the non-parametric equivalent of the parametric paired t-test that is used to determine if two or more related or matched samples are significantly different from one another. The parametric paired t-test and the Wilcoxon signed-rank test both evaluate differences between two groups but differ in assumptions and applications. The parametric t-test assumes normally distributed, continuous data and independent observations, making it ideal for precise measurements where these assumptions hold (Creswell, 2003). In contrast, the non-parametric Wilcoxon signed-rank test requires no normality and is suited for ordinal or non-normally distributed data (Salkind et al., 2020). The Wilcoxon test ranks data rather than using raw values, making it more robust for small, non-normal samples.

Researchers use the parametric paired t-test for normally distributed data and the Wilcoxon test when normality is assumed. The Wilcoxon signed-rank test performs a paired difference test of repeated measurements on a single sample to determine if their mean ranks differ (Salkind et al., 2020). Thus, for this study, the Wilcoxon signed-rank test was performed on repeated measurements of pre- and post-survey question pairs to determine statistically significant or insignificant differences in their mean ranks.

Qualitative Data Analysis

Inductive thematic analysis, an analytic strategy that begins with a provisional topic and progresses its way into an evolving search of codes and common themes, was used to analyze the student and teacher interview data (Creswell et al., 2003; Braun & Clarke, 2006). In Accordance with Braun and Clarke's (2006) principles of thematic analysis, Figure 2 identifies the six steps in inductive thematic analysis that were followed:

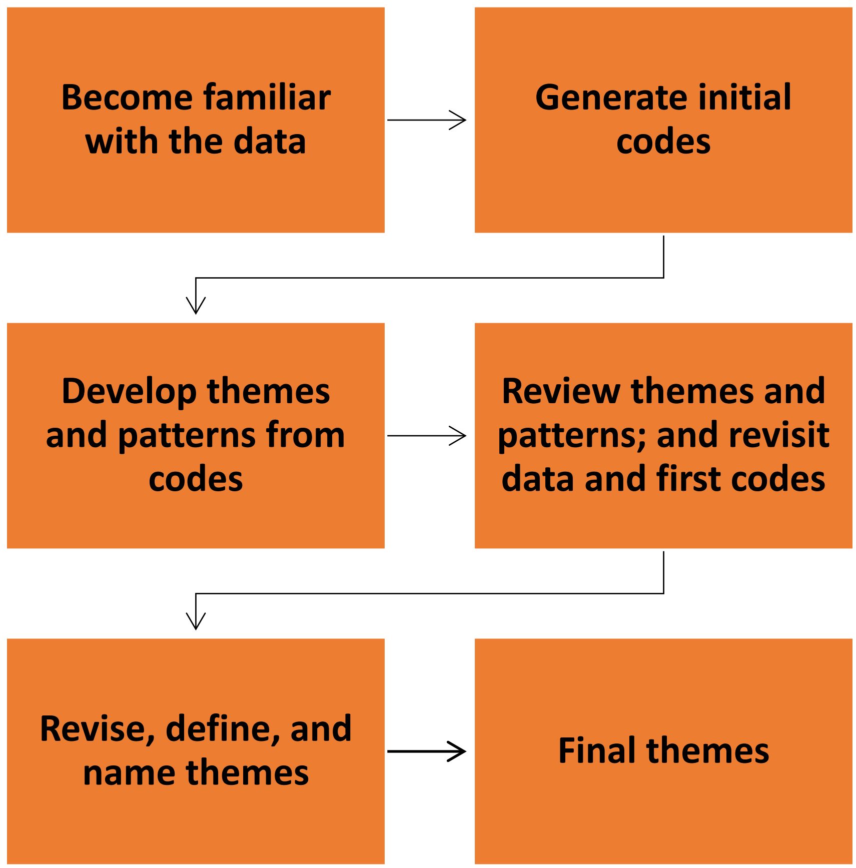

Figure 2: The Steps for Inductive Thematic Analysis

The data familiarization phase involved reading and re-reading of the data to become deeply engaged with it. Once the researcher became familiar with the data, codes were assigned across the entire data set based on interesting features. The researcher then organized codes into potential themes, which were subsequently refined to ensure that each theme accurately represented the data. The researcher clearly and concisely defined and named the themes. Finally, the report was produced, which was a compilation of the analysis into a narrative that demonstrated the story within the data. The ATLAS.ti computer-assisted qualitative data analysis software package was used to facilitate the organization and analysis of the student pre- and post-interview data. However, the AI (artificial intelligence) feature was not used to generate any codes or themes. The teacher pre- and post-interview data were organized and analyzed manually using Excel.

Summary

This dissertation responded to Ladson-Billings' (2021) call for a re-set in STEM education to address systemic inequities and outdated practices, with an emphasis on strategies that enhance learning for all students, especially those from historically underrepresented groups. The study investigated the efficacy of a research Community of Practice (CoP), created within the University of Texas Rio Grande Valley (UTRGV) under the NSF-funded CREST-MECIS program, in promoting STEM education reform. The CoP united various stakeholders - K-12 educators from the Rio Grande Valley, UTRGV undergraduate and graduate students, and faculty/experts - to foster equitable practices that improve the representation of underrepresented groups in STEM fields and enhance self-efficacy among both teachers and students. Goals included integrating engineering principles into STEM curricula, understanding contextual factors that affect educational equity, and identifying best practices for teaching Gen Z students.

A triangulation mixed methods approach was employed to analyze the data, with both quantitative and qualitative data given equal weight. This design aligns with Creswell et al.'s (2003) and Saraswati et al.'s (2021) frameworks for combining complementary data forms to deepen insights into educational reform and community dynamics. By using both qualitative and quantitative data, this study was able to address complex research questions with a holistic perspective, bridging the depth of qualitative analysis with the statistical analysis of quantitative data (Creswell & Plano Clark, 2018; Saraswati et al., 2021).

The study's guiding question, "How does the CREST program affect its participants?" was supported by sub-questions that probed: 1) K-12 teachers' and undergraduate and graduate students’ experiences with the program, 2) the program’s impact on teachers' teaching efficacy and attitudes, and 3) the program’s impact on students’ participation in and completion of the CREST-MECIS program, including interest in and pursuit of a STEM career. Over the course of a year, data were collected via pre- and post-surveys and online one-to-one interviews. Quantitative data analysis used the Wilcoxon signed-rank test to measure changes in student and teacher perceptions of STEM skills and self-efficacy. Qualitative data were analyzed thematically both manually and through the ATLAS.ti software to identify patterns and themes that emerged from participant interactions and reflections.

The study’s use of the triangulation design convergence model (Creswell et al., 2003) allowed for a comprehensive analysis of convergences and divergences between quantitative and qualitative results, providing a robust basis for understanding the CREST-MECIS program’s impact on its participants. This approach underscored the potential of mixed-methods research to inform meaningful STEM education reform that aligns with contemporary educational needs.

CHAPTER IV

RESULTS

In this section, results are organized by the two research questions. Additionally, the data from participant interviews were organized using pseudonyms to ensure confidentiality while allowing for clear and consistent reference throughout the analyses. Table 9 presents the pseudonyms assigned to each participant, along with relevant demographic details that aid in understanding the results. This approach maintains participant anonymity while supporting the interpretive clarity of the findings.

Table 1: Student and Teacher Pseudonyms for Qualitative Analyses

Pseudonym	**Role in CoP**
Finley	4th year Science Teacher
Glen	2nd year Science Teacher
Indigo	7th year Science Teacher
Lee	4th year Science Teacher
Riley	12th year Math Teacher
Murphy	7th year Math Teacher
Avery	Graduate Student
Marley	Graduate Student
Dane	Graduate Student
Aspen	Undergraduate Student
Ash	Graduate Student
Dallas	Undergraduate Student
Dakota	Undergraduate Student
Grey	Undergraduate Student

Research Question 1

How does the CREST-MECIS CoP influence undergraduate and graduate students' participation in and completion of the CREST-MECIS program, including interest in and pursuit of a STEM career? The purpose of the study, based on the research question, was to investigate how the CREST community of practice influenced undergraduate and graduate students' participation in and completion of the CREST program, including interest in and pursuit of a STEM career. Student quantitative data were collected from a 5-point pre- and post-Likert scale survey that captured students' self-reported proficiency across 14 scientific research skill domains before and after their participation in the CREST-MECIS program, the research experience (Kardash, 2000), and the CREST-MECIS community of practice. The student surveys measured changes in their perceptions of their abilities in areas essential to scientific research, including understanding contemporary concepts, utilizing scientific literature, hypothesis formulation, experimental design, data analysis, and communication of results, and were used to evaluate the degree to which those skills were enhanced by participation in the research experience. Student qualitative data were collected from semi-structured pre- and post- interviews.

Undergraduate and Graduate Student Pre- and Post-Survey Data Analyses

Table 1 provides the descriptive statistics, presenting the pre- and post-survey means (M), standard deviations (SD), and minimum (Min) and maximum (Max) Likert scale values for each paired skill domain, as well as the sample size (N = 10 for each pair).

Table 2: Descriptive Statistics of Student Pre- and Post-Survey Responses

	N	M	SD	Min	Max
Pre 1. Understand contemporary concepts in your field	10	4.10	.738	3	5
Post 1. Understand contemporary concepts in your field	10	4.20	.422	4	5
Pre 2. Make use of the primary scientific research literature in your field	10	4.30	.675	3	5
Post 2. Make use of the primary scientific research literature in your field	10	3.70	.675	3	5
Pre 3. Identify a specific question for investigation based on the research in your field	10	4.40	.699	3	5
Post 3. Identify a specific question for investigation based on the research in your field	10	3.80	.789	3	5
Pre 4. Formulate a research hypothesis based on a specific question	10	3.80	.789	2	5
Post 4. Formulate a research hypothesis based on a specific question	10	3.80	.789	3	5
Pre 5. Design an experiment or theoretical test of the hypothesis	10	3.90	1.197	2	5
Post 5. Design an experiment or theoretical test of the hypothesis	10	3.70	.675	2	4
Pre 6. Understand the importance of "controls" in research	10	4.10	.994	2	5
Post 6. Understand the importance of "controls" in research	10	4.20	.632	3	5
Pre 7. Observe and collect data	10	4.40	1.265	1	5
Post 7. Observe and collect data	10	4.40	.516	4	5
Pre 8. Statistically analyze data	10	4.30	1.252	1	5
Post 8. Statistically analyze data	10	4.30	.823	3	5
Pre 9. Interpret data by relating results to the original hypothesis	10	4.30	.823	3	5
Post 9. Interpret data by relating results to the original hypothesis	10	4.30	.483	4	5
Pre 10. Reformulate your original research hypothesis (as appropriate)	10	3.70	1.252	1	5
Post 10. Reformulate your original research hypothesis (as appropriate)	10	4.00	.816	3	5
Pre 11. Relate results to the "bigger picture" in your field	10	4.30	1.337	1	5

(Table 2: continued)

Post 11. Relate results to the "bigger picture" in your field	10	4.10	.316	4	5
Pre 12. Orally communicate the results of research projects	10	4.20	1.135	2	5
Post 12. Orally communicate the results of research projects	10	4.00	.816	3	5
Pre 13. Write a research paper for publication	10	3.60	1.506	1	5
Post 13. Write a research paper for publication	10	3.80	.919	3	5
Pre 14. Think independently	10	4.00	.943	3	5
Post 14. Think independently	10	4.30	.675	3	5

Note: *N* = Sample Size, *M* = mean, *SD* = Standard Deviation, *Min* = Minimum Value, *Max* = Maximum Value.

The descriptive statistics reveal the preliminary direction of the mean scores following the intervention. Scale score options were: 1) 1 - Not at All, 2) 2 - Slightly, 3) 3 – Moderately, 4) 4 – A Lot, and 5) 5 – A Great Deal. If the intervention was successful, then we would expect to see higher post-survey mean scores than pre-survey mean scores. For each skill, the mean score and standard deviation are examined to interpret shifts in student perceptions. The results are presented by the specific areas of research competency measured on the survey:

- *Pre- and post- pair 1, "Understand contemporary concepts in your field":* The mean scores increased from 4.10 (SD = .738) to 4.20 (SD = .422), suggesting marginal improvement in students' understanding of contemporary concepts. The reduction in standard deviation indicates greater consistency in post-survey responses.
- *Pre- and post-pair 2, "Make use of the primary scientific research literature in your field":* Notably, there is a decline in the mean scores, from 4.30 (SD =.675) to 3.70 (SD = .675), showing students' decreased perception in their ability to engage with primary literature after the intervention. This shift may indicate that increased exposure to scientific literature revealed the complexity of the material, tempering initial perception.

- *Pre- and post-pair 3, "Identify a specific question for investigation based on the research in your field"*: Similar to the previous skill, students' self-assessed means in their perceptions of identifying research questions decreased from 4.40 to 3.80, with a slight increase in variability from .699 to .789. This trend may reflect a greater awareness of the rigor involved in identifying viable research questions.
- *Pre- and post-pair 4, "Formulate a research hypothesis based on a specific question"*: Both pre- and post-survey mean scores remained stable at 3.80, with SD = .789, suggesting that students may have maintained consistent perception in this area throughout the intervention.
- *Pre- and post-pair 5, "Design an experiment or theoretical test of the hypothesis":* For this domain, a slight decrease in mean scores, from 3.90 to 3.70, and variability, from 1.197 to.675, indicates a possible alignment in students' understanding of experimental design, though with a marginal decline in perception.
- *Pre- and post-pair 6, "Understand the importance of "controls" in research":* The mean scores increased from 4.10 to 4.20, and variability decreased from .994 to .632. This minor increase in mean score with decreased variability reflects a positive shift, possibly highlighting an enhanced grasp of controls in research.
- *Pre- and post-pair 7, "Observe and collect data":* The mean scores remained stable at 4.40 pre- and post-survey, with a decrease in SD from 1.265 to .516, showing consistent improvement in students' perceived ability to collect data.
- *Pre- and post-pair 8, "Statistically analyze data":* Both pre- and post-survey scores were 4.30 with a reduction in SD, from 1.252 to .823, suggesting greater uniformity in students' self-perception of their ability to statistically analyze data.

- *Pre- and post-pair 9, "Interpret data by relating results to the original hypothesis":* Mean scores remained unchanged (M = 4.30), while the slight decrease in SD, from .823 to .483, indicates a more uniform perception among students on the post-survey.
- *Pre- and post-pair 10, "Reformulate your original research hypothesis (as appropriate)":* Regarding hypothesis reformulation, the mean scores increased from 3.70 to 4.00 and variability decreased from 1.252 to .816, suggesting an enhanced perception in revising hypothesis based on results, potentially attributed to applied experience.
- *Pre- and post-pair 11, "Relate results to the "bigger picture" in your field":* A decrease in both mean scores and variability (M = 4.30, SD = 1.337; M = 4.10, SD = .316) suggests more consistent but slightly tempered perception in connecting research findings to larger scientific frameworks.
- *Pre- and post-pair 12, "Orally communicate the results of research projects":* Mean scores decreased from 4.20 to 4.00, with reduced variability from 1.135 to .816, indicating a more refined self-assurance in their perception of oral communication skills on the post-survey.
- *Pre- and post-pair 13, "Write a research paper for publication":* The mean score for writing a research paper increased slightly from 3.60 to 3.80 and SD decreased from 1.506 to .919, suggesting a minor boost in their perception in writing for publication.
- *Pre- and post-pair 14, "Think independently":* An increase in mean scores from 4.00 to 4.30 with reduced variability (SD declined from .943 to .675) reflects a positive gain in students' self-perceived ability to think independently.

To better understand the pre- and post-survey mean scores, a Wilcoxon signed-rank test was conducted to evaluate the impact of the CREST-MECIS program and community of practice on students' scientific process skills and perceptions in research competencies. The pre- and post-survey responses were analyzed across the same 14 skill domains, assessing students' self-reported proficiency before and after the intervention. The Wilcoxon signed-rank test provides insight into the statistical significance of changes in students' perceptions of their abilities in core research skills. The analysis includes a comparison of ranks between pre- and post-responses, with a focus on identifying positive, negative, and tied ranks to assess shifts in perceived competencies. The test descriptives are summarized in Table 2.

Table 3: Wilcoxon Signed-Ranks of Student Pre- and Post-Survey Responses

		N	Mean Rank	Sum of Ranks
Post 1. Understand contemporary concepts in your field Pre 1. Understand contemporary concepts in your field	Negative Ranks	3[a]	4.00	12.00
	Positive Ranks	4[b]	4.00	16.00
	Ties	3[c]		
	Total	10		
Post 2. Make use of the primary scientific research literature in your field Pre 2. Make use of the primary scientific research literature in your field	Negative Ranks	4[d]	2.50	10.00
	Positive Ranks	0[e]	.00	.00
	Ties	6[f]		
	Total	10		
Post 3. Identify a specific question for investigation based on the research in your field Pre 3. Identify a specific question for investigation based on the research in your field	Negative Ranks	5[g]	3.00	15.00
	Positive Ranks	0[h]	.00	.00
	Ties	5[i]		
	Total	10		
Post 4. Formulate a research hypothesis based on a specific question Pre 4. Formulate a research hypothesis based on a specific question	Negative Ranks	3[j]	3.50	10.50
	Positive Ranks	3[k]	3.50	10.50
	Ties	4[l]		
	Total	10		
Post 5. Design an experiment or theoretical test of the hypothesis Pre 5. Design an experiment or theoretical test of the hypothesis	Negative Ranks	5[m]	4.00	20.00
	Positive Ranks	3[n]	5.33	16.00
	Ties	2[o]		
	Total	10		

(Table 3: continued)

Post 6. Understand the importance of "controls" in research Pre 6. Understand the importance of "controls" in research	Negative Ranks	2[p]	2.25	4.50
	Positive Ranks	2[q]	2.75	5.50
	Ties	6[r]		
	Total	10		
Post 7. Observe and collect data Pre 7. Observe and collect data	Negative Ranks	3[s]	2.00	6.00
	Positive Ranks	1[t]	4.00	4.00
	Ties	6[u]		
	Total	10		
Post 8. Statistically analyze data Pre 8. Statistically analyze data	Negative Ranks	4[v]	3.50	14.00
	Positive Ranks	3[w]	4.67	14.00
	Ties	3[x]		
	Total	10		
Post 9. Interpret data by relating results to the original hypothesis Pre 9. Interpret data by relating results to the original hypothesis	Negative Ranks	3[y]	3.50	10.50
	Positive Ranks	3[z]	3.50	10.50
	Ties	4[aa]		
	Total	10		
Post 10. Reformulate your original research hypothesis (as appropriate) Pre 10. Reformulate your original research hypothesis (as	Negative Ranks	3[ab]	3.50	10.50
	Positive Ranks	4[ac]	4.38	17.50
	Ties	3[ad]		
	Total	10		
Post 11. Relate results to the "bigger picture" in your field Pre 11. Relate results to the "bigger picture" in your field	Negative Ranks	6[ae]	4.00	24.00
	Positive Ranks	2[af]	6.00	12.00
	Ties	2[ag]		
	Total	10		
Post 12. Orally communicate the results of research projects Pre 12. Orally communicate the results of research projects	Negative Ranks	3[ah]	4.50	13.50
	Positive Ranks	3[ai]	2.50	7.50
	Ties	4[aj]		
	Total	10		
Post 13. Write a research paper for publication Pre 13. Write a research paper for publication	Negative Ranks	4[ak]	3.25	13.00
	Positive Ranks	3[al]	5.00	15.00
	Ties	3[am]		
	Total	10		
Post 14. Think independently Pre 14. Think independently	Negative Ranks	2[an]	2.00	4.00
	Positive Ranks	3[ao]	3.67	11.00
	Ties	5[ap]		
	Total	10		

Results of the analysis for paired item 1, Understanding Contemporary Concepts, revealed three negative ranks, four positive ranks, and three ties. Students demonstrated a moderate increase in the perceptions of their understanding of contemporary concepts, with slightly more positive ranks (mean rank = 4.00, sum of ranks = 16.00) than negative ranks (mean rank = 4.00, sum of ranks = 12.00). With three tied ranks, these results suggest that the intervention provided some students with a deeper grasp of current concepts in their field, while others maintained stable confidence.

For paired item 2, Making Use of the Primary Scientific Research Literature, there was a notable decline in students' perceived ability to use primary scientific literature. Four students reported lower perception (mean rank = 2.50, sum of ranks = 10.00), while none reported an increase, and six responses were tied. In Identifying a Specific Question for Investigation Based on the Research, paired item 3, five students reported decreased perception (mean rank = 3.00, sum of ranks = 15.00), while none reported increased perception, and five maintained stable self-assessments. Paired item 4, Formulating a Research Hypothesis Based on a Specific Question, yielded a balanced distribution of positive and negative ranks, with three students reporting improved perception (mean rank = 3.50, sum of ranks = 10.50) and three reporting decreased perception (mean rank = 3.50, sum of ranks = 10.50). Four students' responses remained the same, suggesting overall stability in students' perception to formulate hypotheses. When asked about Designing and Experiment or Theoretical Test of the Hypothesis, paired item 5, five students reported a decrease in perceived ability (mean rank = 4.00, sum of ranks = 20.00), while three reported an increase (mean rank = 5.33, sum of ranks = 16.00), and two responses were tied. The higher number of negative ranks indicates that students may have encountered challenges in understanding experimental design principles in depth.

For paired items 6 and 7, more ties were reported than negative or positive ranks. Paired item 6, Understanding the Importance of Controls in Research, remained relatively stable, with two students reporting increased perception (mean rank = 2.75, sum of ranks = 5.50), two reporting decreased perception (mean rank = 2.25, sum of ranks = 4.50), and six maintaining the same level of perception. This balance suggests that students overall retained a consistent understanding of the role of controls in research. For skills related to Observing and Collecting Data, paired item 7, the majority of responses were tied (n = 6), with three students reporting decreased perception (mean rank = 2.00, sum of ranks = 6.00) and one reporting increased perception (mean rank = 4.00, sum of ranks = 4.00). The prevalence of tied responses suggests minimal change, with only a slight indication of reduced perception in data collection skills.

For Statistical Data Analysis, paired item 8, four students reported decreased perception (mean rank = 3.50, sum of ranks = 14.00), three reported an increase (mean rank = 4.67, sum of ranks = 14.00), and three were tied. The nearly equal balance of positive and negative ranks points to mixed impacts, reflecting that some students found statistical analysis challenging while others gained confidence. Students' perception of their ability to Interpret Data by Relating Results to the Original Hypothesis, paired item 9, showed equal numbers of positive and negative ranks (mean rank = 3.50, sum of ranks = 10.50 for both), with four tied responses. This balance indicates a consistent level of students' perception of their ability to relate their findings back to their original hypotheses.

The ability to Reformulate [the] Original Research Hypothesis, paired item 10, saw slight gains, with four students reporting increased perception (mean rank = 4.38, sum of ranks = 17.50) and three reporting decreased perception (mean rank = 3.50, sum of ranks = 10.50), while three responses were tied. These results suggest that students experienced some improvement in adapting and refining hypotheses based on new findings. In Relating Results to the "Bigger Picture" in [the] Field, paired item 11, a notable decline in perception was observed, with six students reporting decreased perception (mean rank = 4.00, sum of ranks = 24.00) and only two reporting an increase (mean rank = 6.00, sum of ranks = 12.00), with two tied responses. The post-survey results suggest that students found connecting specific results to broader frameworks more challenging.

Results for the final three competency areas emphasize both the statistical findings and their implications for student learning and skill development. Orally Communicating the Results of Research Projects, paired item 12, revealed three students who reported both increased and decreased perception (mean ranks of 2.50 and 4.50, sum of ranks = 7.50 and 13.50, respectively) and four students who reported ties. This balance suggests a stable overall perception of their oral communication abilities. Writing a Research Paper for Publication, paired item 13, showed a near balance, with four students reporting lower perception (mean rank = 3.25, sum of ranks = 13.00) and three reporting increased perception (mean rank = 5.00, sum of ranks = 15.00), with three ties. These findings indicate some gains in their perception in writing for a scholarly audience, although challenges in this skill area remain. Finally, Independent Thinking, paired item 14, saw a modest increase, with three students reporting increased perception (mean rank = 3.67, sum of ranks = 11.00), two reporting decreased perception (mean rank = 2.00, sum of ranks = 4.00), and five reporting ties. This positive trend suggests that the intervention supported slight growth in students' ability to approach research tasks independently.

Overall, the Wilcoxon Signed-Ranks Test results reveal a mixed impact of the intervention on students' self-assessed research competencies. Certain areas, such as hypothesis reformulation and independent thinking, showed positive shifts. However, decreases in competencies related to scientific literature use and relating results to broader contexts suggest areas where students may need additional guidance and practice. This nuanced understanding of changes in students' self-perceptions highlights the strengths of the CREST-MECIS program and community of practice. To further support the claim that the CREST-MECIS program and community of practice were effective in shaping students' perceptions of their self-assessed research competencies, Table 3 provides a summary of the aggregate totals of the Wilcoxon signed-rank results, focusing on the aggregated shifts in student perceptions across the 14 scientific process skill domains.

Table 4: Aggregated Summary of Wilcoxon Signed-Ranks Results on Student Pre- and Post-Survey Responses Across 14 Scientific Process Skill Domains

Pre- and Post-Pairs	NC	PC	No Change	N
Pair 1: Understand contemporary concepts in your field	3	4	3	10
Pair 2: Make use of the primary scientific research literature in your field	4	0	6	10
Pair 3: Identify a specific question for investigation based on the research in your field	5	0	5	10
Pair 4: Formulate a research hypothesis based on a specific question	3	3	4	10
Pair 5: Design an experiment or theoretical test of the hypothesis	5	3	2	10
Pair 6: Understand the importance of "controls" in research	2	2	6	10
Pair 7: Observe and collect data	3	1	6	10
Pair 8: Statistically analyze data	4	3	3	10
Pair 9: Interpret data by relating results to the original hypothesis	3	3	4	10
Pair 10: Reformulate your original research hypothesis (as appropriate)	3	4	3	10
Pair 11: Relate results to the "bigger picture" in your field	6	2	2	10
Pair 12: Orally communicate the results of research projects	3	3	4	10
Pair 13: Write a research paper for publication	4	3	3	10
Pair 14: Think independently	2	3	5	10
Totals:	50	34	56	

Note: *NC* = Negative Change, *PC* = Positive Change, *No Change* = Tie, *N* = Sample Size.

The aggregated Wilcoxon Ranks results, showing 50 negative changes, 34 positive changes, and 56 no changes, indicate a complex impact of the CREST-MECIS program on students' perceived competencies. The higher rate of negative changes suggests that, for many areas, students' perceptions in certain skills decreased from pre- to post-survey. The 34 positive changes indicate that for some areas, students experienced an increase in perception, suggesting that the intervention effectively enhanced their perceived abilities in these specific skills. Meanwhile, the 56 ties reflect stable perceptions for a substantial portion of the competencies assessed, meaning many students maintained their initial perception levels despite the intervention. Figure 3 shows the mix of outcomes, which underscore the nuanced effect of the CREST-MECIS program and community of practice, revealing both areas of growth and areas where students' self-assessment became more tempered or cautious. While the negative changes suggest a decline in the research competencies measures, triangulation of this data with the qualitative results refute this finding and provide a more in-depth understanding how the CREST MECIS program affected the students.

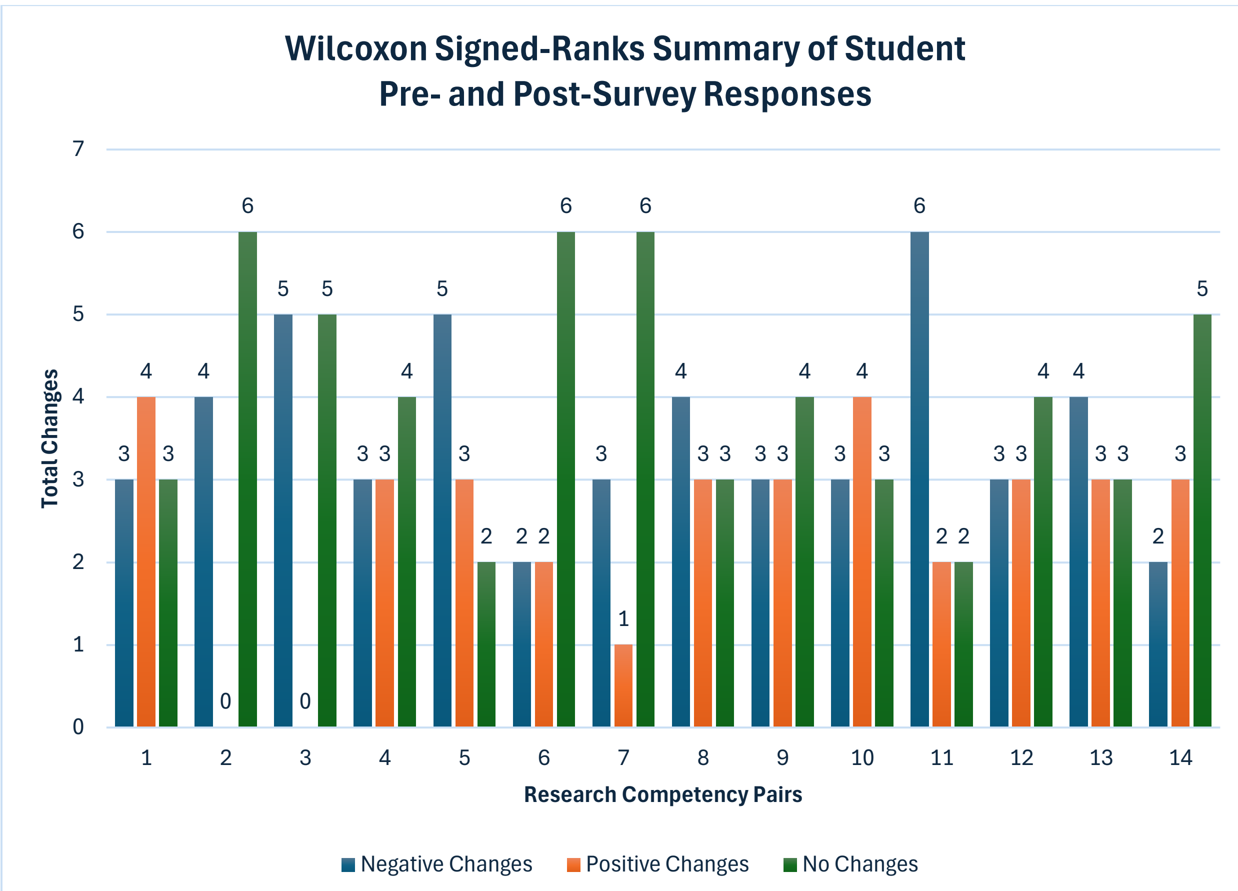

Figure 3: Bar Chart of Wilcoxon Signed-Ranks Summary of Results on Student Pre- and Post-Survey Responses Across 14 Scientific Process Skill Domains

The final analysis of the student pre- and post-survey responses was the Wilcoxon signed-rank test for statistical significance (Table 4). This data offers insights into how students were affected by the CREST-MECIS community of practice.

Table 5: Wilcoxon Signed-Rank Test Statisticsa of Student Pre- and Post-Survey Responses Across 14 Process Skill Competencies

Statements	Z	Asymp. Sig. (2-tailed)
Understand contemporary concepts in your field	-.378[b]	0.705
Make use of the primary scientific research literature in your field	-1.857[c]	0.063
Identify a specific question for investigation based on the research in your field	-2.121[c]	0.034
Formulate a research hypothesis based on a specific question	.000[d]	1
Design an experiment or theoretical test of the hypothesis	-.288[c]	0.774
Understand the importance of "controls" in research	-.184[b]	0.854
Observe and collect data	-.378[c]	0.705
Statistically analyze data	.000[d]	1
Interpret data by relating results to the original hypothesis	.000[d]	1
Reformulate your original research hypothesis	-.604[b]	0.546
Relate results to the "bigger picture" in your field	-.905[c]	0.366
Orally communicate the results of research projects	-.649[c]	0.516
Write a research paper for publication	-.172[b]	0.863
Think independently	-.966[b]	0.334

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

c. Based on positive ranks.

d. The sum of negative ranks equals the sum of positive ranks.

The Wilcoxon signed-rank test statistics (Table 4) highlight a significant decrease in student perception in one specific competency: Identifying Research Questions ($Z = -2.121$, $p = .034$, $r = .474$). This finding suggests that the CREST-MECIS program and community of practice led students to reassess their abilities in formulating researchable questions, potentially revealing the complexity of this skill. This may reflect a more critical understanding of the nuanced demands of identifying effective research questions. A separate analysis of the survey data comparing undergraduate and graduate responses for this research competency revealed a statistically significant difference within the Undergraduate group ($Z = -1.890$, $p = .059$, $r = .42$). This indicates a variation in performance on this skill among undergraduate students, while no statistically significant differences were observed within the Graduate group. These findings suggest that the variability in identifying research questions may be specific to the undergraduate population in this sample.

Using Primary Scientific Literature approached statistical significance ($Z = -1.857$, $p = .063$, $r = .415$), indicating a trend toward reduced perception. Although this result was not statistically significant at the .05 level, it approached significance, indicating that the intervention may have introduced students to the complexities of engaging with scientific literature, thereby affecting their self-assessment. These results underscore that while most competencies showed stable perception levels, the intervention had a discernible impact in prompting students to reevaluate and perhaps adopt a more cautious view of their abilities in specific, complex aspects of the research process.

The remaining 12 domains, although showing changes in mean scores from the pre- to post-survey, did not demonstrate statistically significant differences. These domains included understanding contemporary concepts in the field, formulating research hypotheses based on a specific question, designing experiments or theoretical tests of the hypothesis, understanding research controls, observing and collecting data, statistically analyzing data, interpreting data by relating results to the original hypothesis, reformulating the original research hypothesis, relating the results to the bigger picture, orally communicating the results, writing research papers for publication, and thinking independently.

The analysis of pre- and post-survey data shows that the CREST-MECIS program had a selective impact on students' research competencies, leading to significant or near-significant decreases in perceptions for only a few specific areas. The most notable takeaway is the significant decrease in perception in *identifying research questions*, suggesting that participation in the program or its activities prompted students to recognize the complexity of this skill, resulting in a more realistic self-assessment. Similarly, a near-significant decrease in perception in *using primary scientific literature* indicates that students may have encountered challenges engaging with complex research sources.

Overall, the majority of competencies, such as hypothesis formulation, experimental design, and data analysis, remained unchanged, showing that students retained a consistent level of perception in these areas throughout the program. This stability suggests that while the program and the program activities reinforced existing competencies, it did not dramatically alter students' self-perceptions in the remaining foundational, research skills. At this point, the quantitative data would lead one to believe that the CREST-MECIS program failed to deliver its promises. However, this is a mere limitation of reliance upon the findings of just one data set. Since this study employed a triangulation mixed methods design, both the quantitative and qualitative findings were merged into the overall interpretation to draw valid conclusions about the research question. This interpretation will soon demonstrate a most spectacular finding in this study.

Exploring the Students' Participation in CREST-MECIS and a Community of Practice

The CREST-MECIS community of practice transformed students' academic journeys and career aspirations, guiding them through challenges and building their confidence as they navigated the rigorous demands of STEM. As a collective, students described CREST as a vital influence that provided support, encouragement, and a deeper connection to their chosen fields. The NSF CREST community of practice emerged not just as a program but as a transformative space where students evolved academically, professionally, and personally. Through a dynamic network of mentors, peers, and research experiences, the CREST-MECIS program provided students with a foundation that went beyond the classroom, fostering resilience, confidence, and a clear path forward in STEM. The following themes reveal how the program and the CoP influenced each student's journey, capturing the essence of this unique community's impact on learning, motivation, and career aspirations.

Theme 1: Student Self-Efficacy and Building STEM Confidence. For many students, CREST was an introduction to the realization of their potential in STEM. The program's supportive structure allowed them to build technical confidence and cultivate a strong sense of self-efficacy as they took on new responsibilities in research and academic projects. One student, describing their experience in CREST, shared, "…I was afraid to touch the breadboard. I was afraid to wire stuff. I was afraid to touch electronic devices, and now, I'm over here designing, calculating, getting passive components, active components, and wiring them up" (Chris). This empowerment, this belief in their newfound technical confidence, was echoed by countless others who found that CREST strengthened their confidence: "So, it has allowed me to develop more for my skills such as CAD modeling, 3D printing, manufacturing, additive manufacturing, learning how to use the machines, repair them, that sort of things" (Angel), and "… I wasn't sure if I was ready to be an engineer, but I think if I was to go into the field right now, I would feel like 100% confident that I'll do really good" (Dorian). One student shared confidence in technical ability stating:

> I was never capable of reading, you know, diagrams or data sheets or stuff like that. And through the [CREST] program that I just went through, I definitely feel more comfortable about that. I can get a data sheet and, you know, read through it and understand what's going on; maybe read an amplifier data sheet; read a motor data sheet…It says V for volts; A for

> amps. Now, it's like it has this certain reading for voltage. It has this certain reading for Average…So, now I can actually go in there and be like oh it has this much power, it has this much noise…so yeah definitely I feel way more improved about that. (Chris)

Another student reflected on how the program reshaped their sense of progress: "…but most of my progress, educational, professional, and mental progress, is because of CREST" (Marley). For students who were already self-motivated to participate in and complete the CREST program, they still credited the program for providing the needed guidance and direction:

> I feel like that motivation was always in me, but [CREST] helped guide my spark in the sense, right. It helped the spark grow in the sense that I was able to have access to [materials] and be able to develop my own skills… (Angel)

For another student, the program opened the door to new professional experiences: "CREST has given me confidence to present at conferences" (Marley). CREST's influence became evident as students began to view themselves as capable professionals in their fields, with one student summing it up by saying, "I feel equipped to handle anything now, even though some things are daunting" (Ash).

Theme 2: Students' Increased Career and Academic Motivation. While CREST instilled a sense of confidence, it also ignited students' drive to excel academically and professionally. Surrounded by high-achieving peers and passionate faculty, students reported feeling inspired to aim higher in their goals. "The opportunities to present all the data that I tested, seeing others' success in CREST, and being paid to the research encouraged me to aim higher" (Bailey), one student reflected. Through the CREST experience, students also developed confidence to advance their studies, feeling better prepared for the challenges of graduate school. One student affirmed, “I feel more prepared for graduate school solely because of the CREST program” (Aspen). The supportive environment provided a valuable push for many to think about their long-term goals and to envision new possibilities within STEM. One student explained,

> I started working in the field as a mechanical engineer because that was something that I found interesting, right? I think a lot of what we were doing [in CREST] might be more related to computer science or electrical engineering. But at the end of the day, I have a good understanding of the field now, and I feel more confident, in terms of being able to apply that research or some of the more basic concepts to everyday problems [in other fields of engineering] that I think would benefit from it. (Andy)

Faculty engagement further bolstered students’ motivation. The enthusiasm and commitment from professors were deeply motivating, as noted by one student who summed it up nicely for nearly all of the students, “It was the professor in charge [who] definitely motivated us to want to pursue our education” (Auden). For many, this encouragement left a lasting impact, as another student recalled, “The CREST professors were the true motivators in my interest to pursue engineering. I just wanted to learn more and more from them. Now here I am…I’m an engineer [stated with emphasis]” (Dallas). CREST’s supportive faculty also fostered a sense of ambition, with a participant describing how “The CREST faculty’s high expectations inspired me to improve” (Marley). This community, where motivation was encouraged and celebrated, had a profound effect on students’ academic pursuits and career trajectories.

Theme 3: Mentorship and Peer Support. A foundational component of CREST's impact was its mentorship and peer support network, which created a vital safety net for students as they navigated STEM. Graduate students, professors, and peers offered guidance and support, helping undergraduates to overcome academic insecurities and find direction in their studies.

> So, with CREST, meeting these upper classmen, meeting these graduate students, not having to just work alone. When we struggled, they were the ones that would help us. They [gave] us ideas. They [were] the ones that would tell us…if you do this or in order to accomplish this you have to do this and this first. So, I guess you could say they helped me a lot in my final year when I was going through my most difficult part of undergrad" (Aspen)

Another student shared, describing the value of peer mentorship, "…he's [student referring to Avery] constructed videos that have really been constructive to my learning experience. He's really helped me with that" (Dorian), and professor mentorship,

> So, I think he's been amazing. Like, he's not just an advisor to me. He's been an amazing friend and someone who's helped me with personal issues, too. I think honestly if I had to have someone as an advisor on any project or as a boss, it would for sure be him. I've never met someone that's so helpful. I'll struggle on a problem and then he'll try to help me out, like on his own. (Dorian)

This peer support also helped combat isolation, with another student explaining,

> Interacting with CREST students helped me feel less isolated because I am a very structured, independent person. I've definitely gotten out of that bubble. When I first started working at CREST, I was like very introverted. I wouldn't really communicate with anyone. I wouldn't share my progress with anyone except for my professor, right? But then I think just talking with the students has actually helped me grow a lot, at least personality-wise and getting to know people. So, it's nice. It's been helping me make a lot of connections. This has definitely helped me out a lot with my professional growth. (Dane)

Professors and mentors within the program shared their experiences and professional knowledge, often providing insights that students might not have otherwise encountered. One student noted, "My mentor helped me with insights on the field that I wouldn't have had otherwise" (Bailey). CREST mentors and faculty guided students with advice and shared their own paths in STEM, helping students understand what a future career in engineering or science might look like. As one student put it, "The professors and advisors really showed us well what a career in engineering industry would be like" (Dallas). Through mentorship and peer support, CREST established a foundation that reassured students and helped them find clarity in their academic and career goals.

Theme 4: Connecting Classroom Knowledge to Real-World Scenarios Through Original Research Experiences. One of CREST's most impactful features was its emphasis on hands-on learning, or research experience, which allowed students to directly apply classroom knowledge to real-world scenarios. This experiential approach made theoretical concepts more accessible and instilled a sense of curiosity about STEM's practical applications. One student reflected, "[CREST] really helped me learn how to apply the things that I was learning in classes" (Auden). Research experience and hands-on activities gave students the opportunity to engage with material beyond textbooks, cultivating a sense of enthusiasm for their studies. Another student appreciated how labs within CREST made a difference in their understanding, saying, "But I feel like the department has these labs structured to help the students. Those labs are like…stepping stones for students and [they] really, really improve your skills" (Chris). Observing more advanced researchers offered invaluable insights, as one student shared: "…the CREST program itself shows you opportunities and you can see different projects or see different things that other students are doing" (Auden). CREST's workshops and labs brought the theoretical into the tangible, helping students connect with their studies in ways that extended beyond traditional learning. This opportunity to engage with projects and research added an important dimension to their education, as highlighted by one student: "The CREST workshops and conferences helped me better understand the applications of my studies" (Avery).

Theme 5: Community and Sense of Belonging. The sense of community that CREST fostered was essential in helping students feel connected to their studies and career paths. Many described the program as a place where they felt supported and encouraged, a place where they could see themselves as part of a larger mission. As one student explained, "The CREST community helped me feel part of something larger" (Ash). For another student, the sense of community was at the forefront of his pursuit of excellence:

> For me, being able to lead and know that I have a voice and not be scared…will make me a great engineer. If you can't communicate with others and share your ideas, you're basically not an engineer. You're just

> someone who has a very smart brain but cannot communicate [with] me. [The CoP] showed me that it takes more than one person and communication to be able to make things work and make things happen. The [CREST] Research Center that I'm in also showed me that. So, like with the community of practice, they showed me that as an engineer, or along any path in any career, it is very important to communicate with others. (Dakota)

This environment was integral to building their commitment to STEM and reinforcing their dedication to learning.

For some, the CREST experience was pivotal in strengthening their desire to pursue a STEM career. "Being part of CREST reaffirmed my interest in a STEM career" (Avery), noted one student, expressing how the CREST program and faculty inspired them to envision a future in STEM. Collaborative projects within CREST were not only motivating but also brought students together in pursuit of shared goals. One student reflected, "Having group projects not only motivated me to get my work done, but they were the best ways for me to learn the material" (Aspen). Many students developed a sense of belonging that came from being part of the CREST-MECIS program:

> I feel like it just made me feel like I was a part of something, you know. It's nice because I really don't have extracurriculars. Like [I'm] really [not involved] with other things. So, being able to, like, communicate with my community actually makes me feel, you know, better, like a better person. [It] makes me happier because I'm actually making an impact. (Dakota)

Theme 6: An Emerging Epistemological Stance on Conducting STEM Research. In addition to providing a sense of community, CREST helped students navigate uncertainty and build resilience, as they realized that original research can be complex, nonlinear, iterative, and sometimes just plain messy. In doing so, they developed confidence and resilience. For example, to questions about decreased scores on the scientific process skills survey that students completed, one student stated, “It was just kind of like what I thought I knew. And so when I actually got into research and started applying the concepts I learned, I realized it's not quite as easy as I thought” (Grey). Another student explained:

> So, I guess to explain it, back then when I had first taken [the process skills survey], I was fairly new to the CREST center, and I guess I was pretty confident in everything. I wasn't like being realistic. Throughout the year, I learned that there's still definitely a lot more room to grow…It’s pretty humbling. (Ash)

Many students credited the program with teaching them that failure was a natural part of the learning process, which in turn helped them face challenges with less self-doubt. As one student described,

> [CREST] did, for sure, help me with failure…It like changed the way that I saw or how I rationalized things not working. Rather than being a failure, it is just another way that doesn’t work, and it propels you find a new way. (Rae)

Through original research projects and collaborative learning, students found the tools to manage academic challenges more effectively. “Well, at first it's kind of difficult to really get a grasp of what it is you're learning, but once you get to the labs where you're actually doing hands-on…it definitely helps to kind of connect the dots…” (Auden), one participant said. The program’s support network enabled students to feel equipped to tackle difficulties with a constructive approach, as one explained, “The CREST program showed me how to handle uncertainties." (Lane). This resilience extended beyond academic success, preparing students to adapt to setbacks in a way that will serve them in their future careers.

Summary of the Findings

The quantitative analyses demonstrate that the CREST-MECIS program led to significant or near-significant changes in only a few targeted areas, while the majority of research experience competencies remained unchanged. The most notable change was observed in students' perceived ability to *identify specific research questions*, which showed a statistically significant decrease. This result suggests that as students engaged more deeply in the research process, they developed a more cautious and perhaps critical view of their skills in question formulation. This shift may indicate that the program effectively exposed the inherent complexities of defining precise, researchable questions, prompting students to reassess and refine their understanding of this fundamental research task. Additionally, further analysis of research competency #3 - *Identifying Research Questions* - revealed a statistically significant difference within the Undergraduate group ($Z = -1.890$, $p = .059$, $r = .422$). This indicates a variation in performance on this skill among undergraduate students, while no statistically significant differences were observed within the Graduate group. These findings suggest that the variability in identifying research questions may be specific to the undergraduate population in this sample.

A near-significant decrease in perception was also identified in *using primary scientific literature*, reflecting a similar trend of recalibrated self-assessment. While students likely gained exposure to a variety of primary sources, this experience may have illuminated the challenges involved in critically analyzing and synthesizing original research findings. The tendency toward decreased perception suggests that students are developing a more realistic appreciation for the interpretive skills required to engage meaningfully with scientific literature.

The aggregated Wilcoxon signed-rank results further emphasize this nuanced impact, with a total of 50 negative ranks, 34 positive ranks, and 56 ties across all competencies. This distribution highlights a pattern of tempered perception, as more students reported slight decreases rather than increases in their perceived abilities. The high number of ties also suggests that, for many skills, students maintained a consistent level of perceptions throughout the program. These findings imply that while the program may have reinforced existing understanding, it did not substantially alter students' self-perceptions in these areas.

Overall, the findings from the combined analyses of the students' pre- and post-survey data suggest that the CREST-MECIS program and community of practice encouraged students to adopt a more refined, cautious view of their research skills, particularly in complex areas like question development and literature engagement. The selective impact, with significant or near-significant changes in only a couple competencies, underscores the importance of tailored instructional support provided through the CREST-MECIS program. This comprehensive assessment provides clear insights into the influence of the CREST community of practice on both undergraduate and graduate students' participation in and completion of the CREST-MECIS program.

Research Question 2

How does the CREST-MECIS CoP influence K-12 STEM teachers' efficacy, attitudes, and beliefs toward teaching a CREST-developed curriculum? The purpose of the study, based on the research question, was to investigate how the CREST-MECIS community of practice (CoP) influenced K-12 STEM teachers' efficacy, attitudes, and beliefs toward teaching a CREST-developed curriculum. Teacher quantitative data were collected from multi-point Mathematics and Science Teacher Efficacy and Attitudes Toward STEM (T-STEM) Surveys (Unfried et al., 2022). The T-STEM science and mathematics scale surveys measured changes in teachers' confidence and self-efficacy toward teaching science, math, technology, and engineering (STEM). Science teachers completed the Science T-STEM Survey and math teachers completed the Mathematics T-STEM Survey. Each T-STEM survey was a multi-point Likert scale survey that captured teachers' self-reported responses across eight separate domains: Domain 1) Science/Math Teaching Efficacy and Beliefs, Domain 2) Science/Math Teaching Outcome Expectancy, Domain 3) Student Technology Use, Domain 4) Science/Math Instruction, Domain 5) 21st Century Learning Attitudes, Domain 6) Teacher Leadership Attitudes, Domain 7) STEM Career Awareness, and Domain 8) Engineering Teaching Efficacy and Beliefs. The T-STEM surveys captured teachers' self-reported proficiencies before and after their participation in the CREST-MECIS community of practice (the intervention). Teacher qualitative data were collected from semi-structured pre- and post- interviews.

Teacher Attitudes and Beliefs towards STEM

Table 5 provides descriptive statistics of teacher responses to survey questions before and after the intervention aimed at measuring changes in teachers' attitudes and beliefs towards science, technology, engineering, and math teaching, along with leadership attitudes, 21st-century learning perspectives, and STEM career awareness. The math and science surveys consisted of sets of statements across 8 separate domains, with responses rated on a Likert scale of 1, Strongly Disagree, to 5, Strongly Agree, or 1, Never, to 5, Every Time. The data from the surveys for 6 teachers (N = 6) were averaged across each domain and analyzed through the mean (M), standard deviation (SD), minimum (Min) values, and maximum (Max) values.

Table 6: Descriptive Statistics of Averaged Teacher Pre- and Post-Survey Responses Across All Domains

	N	M	SD	Min	Max
Section 1 PRE Avg: Science/Math Teaching Efficacy and Beliefs	6	4.0606	.29129	3.73	4.45
Section 1 POST Avg: Science/Math Teaching Efficacy and Beliefs	6	4.0152	.31184	3.45	4.36
Section 2 PRE Avg: Science/Math Teaching Outcome Expectancy	6	3.6481	.24762	3.33	4.00
Section 2 POST Avg: Science/Math Teaching Outcome Expectancy	6	3.5370	.45225	3.00	4.11
Section 3 PRE Avg: Student Technology Use	6	3.0625	1.06580	1.75	4.25
Section 3 POST Avg: Student Technology Use	6	2.7917	1.59622	.00	4.38
Section 4 PRE Avg: Science/Math Instruction	6	2.9048	.42538	2.43	3.50
Section 4 POST Avg: Science/Math Instruction	6	3.7143	1.00204	2.29	5.00
Section 5 PRE Avg: 21st Century Learning Attitudes	6	4.5152	.57973	3.82	5.00
Section 5 POST Avg: 21st Century Learning Attitudes	6	4.7121	.54672	3.64	5.00
Section 6 PRE Avg: Teacher Leadership Attitudes	6	4.6389	.48781	3.67	5.00
Section 6 POST Avg: Teacher Leadership Attitudes	6	4.5833	.39087	4.00	5.00
Section 7 PRE Avg: STEM Career Awareness	6	3.2083	.71443	2.00	4.00
Section 7 POST Avg: STEM Career Awareness	6	4.1250	.51841	3.50	5.00
Section 8 PRE Avg: Engineering Teaching Efficacy and Beliefs	6	2.8939	.59312	2.00	3.45
Section 8 POST Avg: Engineering Teaching Efficacy and Beliefs	6	3.9242	.25335	3.55	4.27

Note: *N* = Sample Size, *M* = mean, *SD* = Standard Deviation, *Min* = Minimum Value, *Max* = Maximum Value.

The descriptive statistics reveal the preliminary direction of the mean scores following the intervention. The results of the findings are as follows:

- *Pre- and post- pair 1, Science/Math Teaching Efficacy and Beliefs (Domain 1):* The pre-intervention mean was 4.06 (SD = .26), indicating a relatively high initial level of efficacy and beliefs, with minor variation among responses. The post-survey mean decreased slightly to 4.02 (SD = .31), suggesting minimal change in perception in science and math teaching efficacy.
- *Pre- and post-pair 2, Science/Math Teaching Outcome Expectancy (Domain 2):* The initial mean score of 3.65 (SD = .25) suggests moderate expectations about students' success in science and math, with relatively low variance. The post-survey mean decreased slightly to 3.54 (SD = .45), indicating a greater spread in teachers' expectations about student outcomes.
- *Pre- and post-pair 3, Student Technology Use (Domain 3)*: With a pre-intervention mean score of 3.06 (SD = 1.07), teachers initially reported moderate levels of student technology use, though responses varied widely. The post-survey mean score dropped to 2.79, with a much larger SD of 1.60, suggesting variability in technology use and perhaps reduced reliance on technology.
- *Pre- and post-pair 4, Science/Math Instruction (Domain 4)*: The pre-survey mean was 2.90 (SD = .43), indicating limited engagement in science/math instructional practices. The post-survey mean, however, rose significantly to 3.71, with increased variability (SD = 1.00), suggesting that the intervention may have positively influenced instructional practices, though individual responses varied widely.
- *Pre- and post-pair 5, 21st Century Learning Attitudes (Domain 5):* Teachers showed positive attitudes with a high mean of 4.52 (SD = .58), reflecting strong alignment with

21st-century learning approaches. Attitudes further improved to a post-survey mean of 4.71 (SD = .55), showing enhanced support for modern learning frameworks.

- *Pre- and post-pair 6, Teacher Leadership Attitudes (Domain 6):* With a pre-survey mean of 4.64 (SD = .49), teachers expressed positive leadership. The mean score was 4.58 (SD = .39) following the intervention, indicating consistent leadership attitudes with minimal variation.
- *Pre- and post-pair 7, STEM Career Awareness (Domain 7):* The initial mean score of 3.21 (SD = .71) reflects moderate awareness of STEM careers. Following the intervention, however, the mean increased notably to 4.13 (SD = .52), suggesting a clearer understanding of STEM career pathways.
- *Pre- and post-pair 8, Engineering Teaching Efficacy and Beliefs (Domain 8):* The mean score prior to the intervention was 2.89 (SD = .25), showing initial low confidence in engineering teaching. The mean score increased notably to 3.92 (SD = .25), indicating a significant boost in self-efficacy for engineering education.

The overall analysis reveals notable improvements in science/math instruction, STEM career awareness, and engineering teaching efficacy. These improvements suggest that the NSF community of practice may have positively impacted teachers' practical teaching approaches and awareness of STEM career relevance.

Following the descriptive analysis, a non-parametric Wilcoxon signed-rank test was conducted to evaluate the impact of the CREST-MECIS community of practice on six teachers' (N = 6) science and math teaching efficacy and beliefs. This analysis employed Wilcoxon ranks to compare paired teacher responses across the same 8 domains, examining the differences in pre- and post- intervention responses. The test's components included negative ranks, indicating cases where post-survey responses were lower than pre-survey responses; positive ranks, where post-survey responses were higher than pre-survey responses; and ties, where responses remained the same. The test descriptives are summarized in Table 6.

Table 7: Wilcoxon Signed-Ranks of Averaged Teacher Pre- and Post-Survey Responses Across All Domains

		N	Mean Rank	Sum of Ranks
Section 1 POST Avg: Science/Math Teaching Efficacy and Beliefs Section 1 PRE Avg: Science/Math Teaching Efficacy and Beliefs	Negative Ranks	3[a]	4.17	12.50
	Positive Ranks	3[b]	2.83	8.50
	Ties	0[c]		
	Total	6		
Section 2 POST Avg: Science/Math Teaching Outcome Expectancy Section 2 PRE Avg: Science/Math Teaching Outcome Expectancy	Negative Ranks	3[d]	4.17	12.50
	Positive Ranks	3[e]	2.83	8.50
	Ties	0[f]		
	Total	6		
Section 3 POST Avg: Student Technology Use Section 3 PRE Avg: Student Technology Use	Negative Ranks	1[g]	5.00	5.00
	Positive Ranks	4[h]	2.50	10.00
	Ties	1[i]		
	Total	6		
Section 4 POST Avg: Science/Math Instruction Section 4 PRE Avg: Science/Math Instruction	Negative Ranks	2[j]	1.50	3.00
	Positive Ranks	4[k]	4.50	18.00
	Ties	0[l]		
	Total	6		
Section 5 POST Avg: 21st Century Learning Attitudes Section 5 PRE Avg: 21st Century Learning Attitudes	Negative Ranks	1[m]	1.50	1.50
	Positive Ranks	2[n]	2.25	4.50
	Ties	3[o]		
	Total	6		
Section 6 POST Avg: Teacher Leadership Attitudes Section 6 PRE Avg: Teacher Leadership Attitudes	Negative Ranks	3[p]	3.17	9.50
	Positive Ranks	2[q]	2.75	5.50
	Ties	1[r]		
	Total	6		

(Table 7: continued)

Section 7 POST Avg: STEM Career Awareness	Negative Ranks	0[s]	.00	.00
Section 7 PRE Avg: STEM Career Awareness	Positive Ranks	6[t]	3.50	21.00
	Ties	0[u]		
	Total	6		
Section 8 POST Avg: Engineering Teaching Efficacy and Beliefs	Negative Ranks	0[v]	.00	.00
Section 8 PRE Avg: Engineering Teaching Efficacy and Beliefs	Positive Ranks	6[w]	3.50	21.00
	Ties	0[x]		
	Total	6		

Results of the analysis for Domain 1, Science/Math Teaching Efficacy and Beliefs, revealed three negative ranks and three positive ranks, indicating that three participants had lower post-survey scores, with a mean rank of 4.17 and a sum of ranks of 12.5, and three participants had higher post-survey scores, with a mean rank of 2.83 and a sum of ranks of 8.5.

For Domain 2, Science/Math Teaching Outcome Expectancy, there were three negative and three positive ranks. Similar to Domain 1, three participants exhibited lower post-survey scores, with a mean rank of 4.17 and a sum of ranks of 12.5, and three participants had improved scores, with a mean rank of 2.83 and a sum of ranks of 8.5. This equal distribution of ranks across the negative and positive categories reflects varied shifts in teaching outcome expectations, potentially indicating differentiated impacts of the community of practice on individual teacher expectations.

Domain 3, Student Technology Use, revealed one negative rank, indicating that one teacher showed a decline in student technology use. Four positive ranks were identified, pointing to a general increase in student technology use, and one teacher showed no change. The predominance of positive changes points to a general increase in technology integration in the classroom following participation in the CRESTS-MECIS community of practice and research experience for teachers, although one teacher felt less reliance on technology, possibly reflecting a nuanced approach to technology use in education.

The negative and positive ranks for the fourth Domain, Science/Math Instruction, were two and four respectively. Two teachers reported a decrease in science/math instructional practices, and four teachers reported improvement in their instructional practices. The increased positive changes in this area suggest the community of practice had a constructive impact on teachers' science/math instructional methods, with most teachers adopting enhanced practices.

More ties, or no changes, were seen in Domain 5, 21^{st} -Century Learning Attitudes. One teacher reported a decline in attitudes (negative rank), two teachers showed improvements (positive ranks), and three reported no changes. The presence of several unchanged responses and few positive changes indicates that teachers generally held steady in their attitudes toward 21^{st}-century learning, with only slight increase.

Domain 6, Teacher Leadership Attitudes, revealed three negative changes, two positive changes, and one no change, possibly suggesting that three teachers experienced a decrease in leadership attitudes, two teachers experienced improvements, and one teacher experienced no change after their participation in the CRESTS-MECIS CoP and RET. This area showed a slight decline in leadership attitudes, potentially highlighting challenges in translating professional development into perceived leadership growth.

For both Domain 7, STEM Career Awareness, and Domain 8, Engineering Teaching Efficacy and Beliefs, only positive changes were reported by all six teachers. All six teachers demonstrated increased STEM awareness and growth in their efficacy and beliefs about engineering teaching. The unanimous positive change in STEM career awareness underscores the community of practice's strong impact on increasing teachers' understanding of STEM career pathways, a crucial outcome for fostering students' interest in STEM fields. The consentient positive responses in engineering teaching and beliefs indicate that the community of practice was highly effective in boosting confidence and beliefs in this area, reflecting a successful focus on practical engineering applications.

Overall, the Wilcoxon signed-ranks highlight the effectiveness of the NSF community of practice in all eight T-STEM Domains. The most notable areas of improvement were seen in promoting STEM career awareness and engineering teaching efficacy and beliefs, aligning with the broader goal of enhancing STEM education. To further support the claim that the NSF community of practice was effective in shaping teachers' perceptions in the eight outlined areas of teaching practice, Table 7 provides a summary of the aggregate totals of the Wilcoxon signed-rank results, focusing on the aggregated shifts in teacher attitudes across each Domain.

Table 8: Aggregated Summary of Wilcoxon Signed-Ranks Results on Teacher Averaged Pre- and Post-Survey Responses Across All Domains

Averaged Pre- and Post-Pairs	NC	PC	No Change	N
Pair 1 Avg: Science/Math Teaching Efficacy and Beliefs	3	3	0	6
Pair 2 Avg: Science/Math Teaching Outcome Expectancy	3	3	0	6
Pair 3 Avg: Student Technology Use	1	4	1	6
Pair 4 Avg: Science/Math Instruction	2	4	0	6
Pair 5 Avg: 21st Century Learning Attitudes	1	2	3	6
Pair 6 Avg: Teacher Leadership Attitudes	3	2	1	6
Pair 7 Avg : STEM Career Awareness	0	6	0	6
Pair 8 Avg: Engineering Teaching Efficacy and Beliefs	0	6	0	6
Totals:	13	30	5	

Note: *NC* = Negative Change, *PC* = Positive Change, *No Change* = Tie, *N* = Sample Size.

These aggregated results captured the paired differences in pre- and post-responses, detailing Negative Changes (NC), Positive Changes (PC), and No Changes across the 8 Domains. Thirteen negative changes, 30 positive changes, and 5 no changes were identified. The 30 positive changes reveal the shifts in a positive direction where all participants showed improvements, suggesting that the CREST-MECIS community of practice was particularly effective in enhancing teacher self-efficacy, attitudes, and beliefs in all eight teaching Domains.

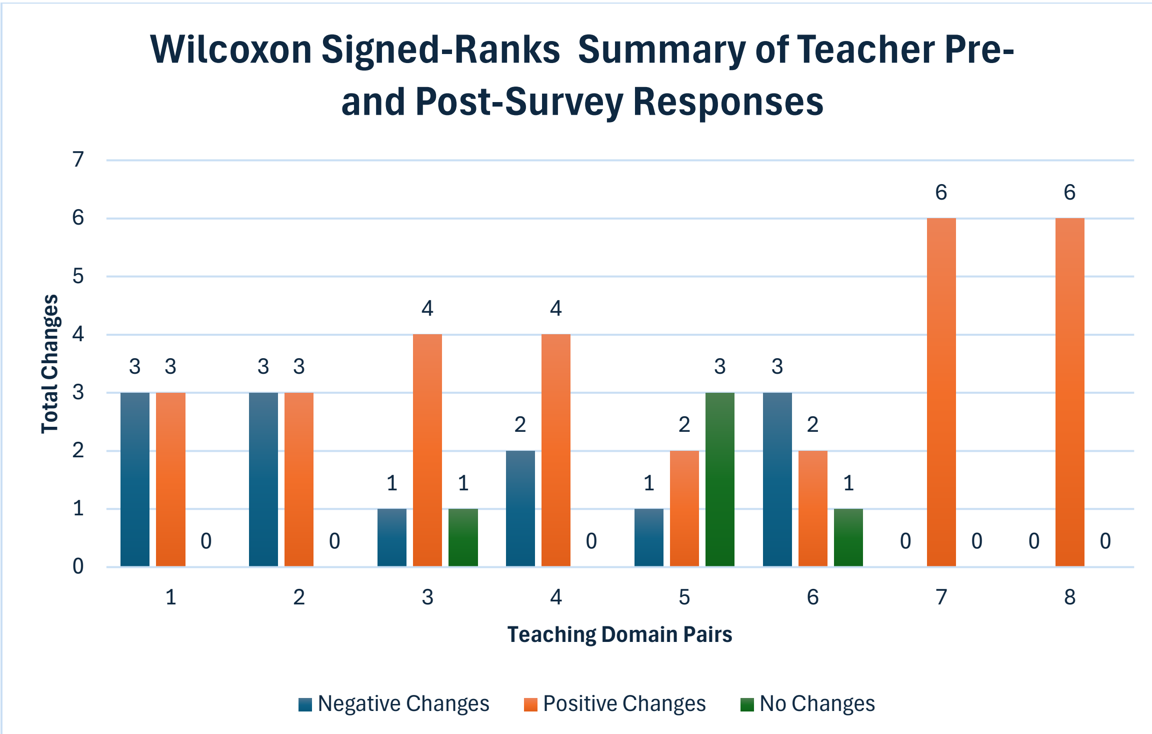

Figure 4: Bar Chart of Wilcoxon Signed-Ranks Summary of Results on Teachers' Pre- and Post-Survey Responses Across 8 Teaching Domains

The final analysis of the teacher pre- and post-survey responses was the Wilcoxon signed-rank test for statistical significance (Table 8) in the positive and negative shifts, measured by the Z-scores and asymptotic significance (Asymp. Sig.) values. This data offers insights into the Domains most impacted by the CREST-MECIS community of practice.

Table 9: Wilcoxon Signed-Rank Test Statistics a of Teacher Pre- and Post-Survey Responses Across All Domains

Domain/Item	Z	Asymp. Sig. (2-tailed)
Science/Math Teaching Efficacy and Beliefs	-.422[b]	0.673
Science/Math Teaching Outcome Expectancy	-.425[b]	0.671
Student Technology Use	-.677[c]	0.498
Science/Math Instruction	-1.572[c]	0.116
21st Century Learning Attitudes	-.816[c]	0.414
Teacher Leadership Attitudes	-.552[b]	0.581
STEM Career Awareness	-2.207[c]	0.027*
Engineering Teaching Efficacy and Beliefs	-2.201[c]	0.028*

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

c. Based on positive ranks.

d. The sum of negative ranks equals the sum of positive ranks.
* significantly different ($p < .05$)

The Wilcoxon signed-rank test statistical analysis (Table 8) provided a non-parametric method to measure changes in teacher responses across the eight Domains, determining whether observed shifts in teachers' responses were statistically significant. The analysis revealed that the CREST-MECIS community of practice had a statistically significant effect in two areas: 1) STEM Career Awareness ($Z = -2.207$, $p = .027$, $r = .637$), and 2) Engineering Teaching Efficacy and Beliefs ($Z = -2.201$, $p = .028$, $r = .635$). These findings indicate the CoP's success in strengthening teacher competencies and awareness in areas critical to STEM education. No statistically significant changes were observed in the remaining Domains, suggesting that the CoP's impact, though effective, was less pronounced in these areas.

This comprehensive analysis of teacher survey data across multiple professional development domains reveals a nuanced picture of the CoP's impact on various educational beliefs, attitudes, and practices. By examining both descriptive statistics and Wilcoxon signed-rank tests, insight was gained into where the CoP initiative successfully influenced teachers and where it fell short of achieving significant changes. The descriptive statistics demonstrated that while teachers generally maintained positive attitudes in many areas, there were notable areas of change, especially in STEM-related beliefs. Specifically, the averages for *Science/Math Instruction* and *Engineering Teaching Efficacy* showed meaningful increases, suggesting that the CoP and RET helped strengthen teaching practices and confidence in delivering STEM content. Additionally, *STEM Career Awareness* exhibited a marked increase, highlighting an enhanced focus on guiding students toward STEM fields, which aligns with national educational priorities. However, the data showed a decrease in *Student Technology Use*, suggesting that teachers' reliance on or attitudes toward technology integration might need further support or clarification.

The Wilcoxon ranks analyses and test statistics provided statistical backing to these observations. The Wilcoxon signed-rank test results revealed statistically significant improvements in *STEM Career Awareness* and *Engineering Teaching Efficacy*, affirming the positive impact of CoP and RET on teachers' preparedness to address and promote STEM pathways. The absence of significant changes in areas like *Science/Math Teaching Efficacy and Beliefs, Teacher Leadership Attitudes,* and *21st Century Learning Attitudes* indicates that these areas may require additional or alternative forms of professional support to foster more impactful growth. Furthermore, the variability in *Science/Math Teaching Outcome Expectancy* suggests differentiated impacts of the training on teacher expectations for student success, a complexity that might reflect varying initial confidence levels or contextual factors influencing outcome beliefs.

Exploring the Teacher' Participation in a Community of Practice

In the early stages of the CREST-MECIS CoP, K-12 STEM teachers began with a mixture of excitement and apprehension. They were seasoned in traditional teaching practices but new to the dynamic demands of a curriculum rich in engineering, coding, and inquiry-based learning. Their journey began with a round of pre-interviews, where teachers shared their hopes and hesitations, revealing a common thread: they were eager to bring STEM to life but uncertain about their ability to integrate hand-on, real-world applications into their classrooms.

As the teachers immersed themselves in the CREST-MECIS CoP, they began to transform, both individually and collectively. Through collaboration, expert guidance, and the development of adaptable teaching strategies, they discovered new methods to inspire students and overcome their initial reservations. By the end of the program, the post-interviews painted a picture of growth and newfound confidence, showing how each teacher's journey in the CREST-MECIS CoP shaped not only their teaching practices but also their beliefs about what STEM education could be.

The following results section traces this evolution, examining six major themes that emerged from the teacher pre- and post-interview data. Each theme reflects a significant shift, from teachers' initial uncertainties to the skills, strategies, and confidence they developed in response to the CREST-MECIS CoP's supportive and innovative framework. These results tell the story of how a community of practice empowered teachers to transform their classrooms, not only by enhancing their own efficacy and adaptability but also by fostering environments where students could thrive through hands-on, inquiry-based, and real-world STEM experiences.

Theme 1: STEM Teachers Develop Confidence in Teaching Engineering Through a Community of Practice. At the start of the CREST-MECIS CoP, the teachers found themselves treading cautiously around new STEM concepts, particularly those related to engineering and coding. Their uncertainty was clear as they faced the challenge of bringing an unfamiliar curriculum into their classrooms. Once teacher candidly admitted, "I don't feel that confident because I've never done engineering independently. I've never done robotics, [and] I've never done coding" (Lee). Another shared a similar sentiment, noting that "the actual meat and potatoes of the content concerns me, but I feel like watching the professionals will help me understand" (Indigo).

Through the CREST-MECIS CoP, teachers gradually gained the confidence to make these concepts accessible. By the end of the program, they spoke with a sense of accomplishment and readiness. One teacher shared, "My confidence level is pretty high. It's easier to implement a STEM lesson…I can create a lesson from scratch" (Glen). Another echoed this newfound self-assurance, stating, "I feel like I already have a good three activities with engineering concepts that I could do with the students because I understand the engineering process" (Murphy). This demonstrates a journey from apprehension to confidence and highlights how the CREST-MECIS CoP positively impacted STEM teachers.

Theme 2: Reaffirming Hands-On, Student-Centered Learning. The CREST curriculum encouraged teachers to adopt more hands-on, exploratory learning activities, contrasting with their previous reliance on textbook-driven approaches. Teachers found this shift engaging and effective, both for themselves and their students. As one participant explained, "Implementing hands-on activities really helped the students engage with the lesson" (Glen). Another described their transition from traditional teaching, noting, "We used to do textbook-based science; now I see the value in hands-on engineering projects" (Lee). This transition allowed students to apply their leaning to real-life contexts, which one teacher observed as particularly impactful: “My students could apply what they learned in real-life contexts, like robotics and programming” (Riley). Teachers described these new instructional approaches as refreshing and enlightening, expressing enjoyment in learning a “different way of thinking” through the engineering design process (Murphy).

As teachers immersed in CREST’s curriculum, they embraced student-led learning. One teacher reflected, “The shift to student independence was eye-opening; they became more engaged and learned by doing” (Glen). Another explained, “Letting students explore and figure things out without my constant input improved their understanding and engagement” (Indigo). This transformation shows how CREST enabled teachers to create environments where students explore concepts independently, deepening engagement and understanding.

Theme 3: Integration of Engineering Design Process into Traditional Science and Math Curricula. Teachers who previously had limited exposure to engineering reported that CREST broadened their understanding and appreciation of engineering as a critical aspect of STEM education. For example, one teacher shared, “Before CREST, I didn't think much about engineering, but now I see its importance in problem-solving” (Finley). This shift was further reflected in their commitment to integrate engineering principles in their teaching, as one stated, “I now incorporate the engineering design process, which I hadn’t done before” (Lee). Teachers discussed how this approach also provided interdisciplinary opportunities, such as connecting biology with engineering concepts. One participant noted, “I have new ideas to tie biology concepts to engineering design” (Glen). The CREST training encouraged teachers to extend engineering applications even to math, with one explaining, “CREST encouraged me to bring engineering applications into my math lessons” (Murphy). As they adopted this broader perspective, teachers found engineering integration to be a “core part of science education” (Riley), highlighting its growing importance in their classrooms.

By the post-interviews, teachers had developed ways to tie engineering concepts with real-world experiences. “Connecting lessons to real-life situations kept students engaged and gave them purpose in learning,” explained one teacher (Glen). Another shared, “Now, I integrate engineering concepts to real-world math scenarios, showing students how they can apply STEM skills beyond the classroom” (Indigo). These insights highlight CREST’s role in helping teachers transform abstract concepts into practical, engaging lessons that connect to students' lives. This also takes us to the next major theme, Real-World Application Emphasis.

Theme 4: An Emphasis on Real-World Application. The CREST curriculum’s emphasis on real-world applications was instrumental in changing teachers' beliefs about STEM education. Through the CoP, teachers were introduced to strategies for linking classroom lessons to real-world situations, which they found motivating and beneficial for student engagement. As one teacher explained, “The CREST training showed me the importance of real-world applications of STEM concepts in my class” (Finley). This approach extended to math, where one teacher noted, “CREST encouraged me to bring more practical applications into my math lessons” (Riley). Teachers observed the impact on students’ problem-solving skills, describing the importance of letting students “work through a problem without expecting immediate answers” (Lee). Teachers also began to see their role as preparing students with practical skills for life, as one stated, “Now, I’m not only teaching facts but skills students can use in life, like in STEM careers” (Indigo). Through CREST, teachers gained an “interdisciplinary lens” (Glen), helping them appreciate the broader impact of STEM education.

Theme 5: Nurturing Professional Growth Through a Community of Practice. A distinctive aspect of the CREST-MECIS CoP was the emphasis on collaborative learning, both among K-12 teachers and with undergraduate and graduate students. Teachers valued the opportunity to learn from each other, share diverse approaches, and engage in collaborative lesson planning. As one teacher noted, "Working with other teachers helped me understand different approaches to the same topic" (Lee). Another appreciated the impact of collaborative lesson planning: "CREST's collaborative setup improved my lesson planning through feedback from peers" (Glen). Additionally, working alongside undergraduate and graduate students offered teachers insights into how students approach complex problems, with one participant remarking, "Collaborating with [undergraduate and graduate] students introduced new perspectives on how students approach problems" (Finley). The experience encouraged teachers to become lifelong learners, as one reflected, "Collaborating on projects during CREST reminded me of the importance of lifelong learning" (Indigo). Observing and adopting flexible methods from other educators also reinforced the benefits of this collaborative approach, with one teacher concluding, "Seeing other teachers' methods helped me adopt a more flexible approach to my lessons" (Murphy).

When teaching a STEM subject, a few teachers commented that a lack of support made them feel isolated. One teacher explained, "Without a support network, teaching STEM can feel overwhelming" (Riley). Another teacher stated, "If I could work with other teachers or at least get expert feedback, I'd feel less isolated" (Lee). The CREST-MECIS CoP provided that support and fostered a collaborative community. "The community of practice provided critical support, allowing us to share strategies that we could apply to our lessons and in our classrooms immediately," shared one teacher (Indigo). Another described how collaboration with peers and experts enhanced their confidence: “Collaboration with the other teachers and our experts has given me new ideas and more confidence” (Glen). This shift shows CREST’s impact in creating a supportive network for sustained professional growth.

Theme 6: A Pathway for a Hard Re-set in STEM Education. Prior to their participation in the CREST-MECIS CoP, teachers expressed feeling restricted by standardized testing and traditional teaching structures. “We’re so boxed in by standardized testing requirements that I can’t adapt my lessons the way I want,” one teacher remarked (Lee). Another expressed frustration, saying that “…traditional teaching methods make it challenging to let students explore on their own. Students need to dive into the science and explore. We need to let [students] be creative, but standardized testing doesn’t allow for that” (Indigo).

After participating in the CREST-MECIS CoP, teachers felt more resourceful and adaptable with the curriculum. “The CREST curriculum is adaptable; I feel more resourceful and confident in changing it up at school to meet my students’ needs,” said one teacher (Indigo). Another teacher noted, “I feel like I am able to adjust lessons and still stick to the district curriculum, which I think will make a huge difference in student understanding” (Riley). This flexibility illustrates how CREST supported teachers in creating responsive, inclusive learning environments.

Participation in the CREST-MECIS CoP enabled teachers to transition from teacher-centered to more student-centered instructional strategies, fostering exploration and active learning. One teacher pointed out, “The [CREST] curriculum showed me the importance of moving past instruction the way we’ve been doing it to instruction that is more creative and active for students” (Murphy). Another shared the satisfaction of seeing students’ enthusiasm increase, noting, “Seeing my students’ curiosity and excitement grow and watching them really get into the lesson made me feel more confident as a teacher” (Riley).

The CREST curriculum also encouraged teachers to reevaluate their assessment strategies, focusing more on students' learning processes than merely testing for correct answers. One participant shared this reflection after the CREST summer camps ended: “As I watched the kids….I realized that [the] short experience with the CREST curriculum made me rethink how I assess student learning beyond just multiple choice tests,” adding that “the real test of learning is seen in [students’] their ability to apply critical thinking to real-world applications” (Indigo). Motivated by CREST, teachers became more intentional in encouraging student participation and engagement, with one teacher stating, “I feel more motivated to help students pursue STEM after seeing the CREST curriculum’s impact” (Lee).

Through these six themes, the narrative of the CREST-MECIS community of practice’s influence on teachers’ attitudes, beliefs, and efficacy unfolded, depicting a journey from initial uncertainty to confidence and adaptability. Each theme underscored the CoP’s role in transforming teaching practices, empowering educators to create meaningful, engaging, and real-world learning experiences in STEM classrooms. However, teachers also expressed barriers that would potentially hinder or prevent them from incorporating a CREST or engineering type curriculum in their classrooms.

Barriers and Challenges

The CREST-MECIS community of practice empowered teachers to take on a new curriculum with confidence, collaborative support, and innovative strategies. However, as they navigated the practicalities of implementing a hands-on, engineering-focused curriculum, they reflected on barriers and challenges that could disrupt this momentum and underscore the complexity of integrating such a curriculum within the K-12 context. This journey revealed that transforming STEM education is as much about overcoming constraints that are oftentimes out of teachers' control as it is about inspiring innovation and resilience in teaching.

Although the themes of Confidence in STEM Teaching, Shift Towards Hands-On, Student-Centered Learning, Integration of Engineering Concepts, and Collaborative Professional Growth stood out, teachers expressed difficulties that would test these gains. For instance, while the CREST-MECIS CoP emphasized enhanced teacher confidence, teachers worried that their newfound confidence would dwindle if they were not met with the resources and support needed to integrate a CREST or engineering type curriculum. One teacher remarked,

> At first, I wasn't confident with Python coding, but the CREST training really helped me learn it. The thing is, though, I learn it for the summer camps, but at school I just forget it because we don't have the technology and probably not even the money to buy the technology. (Finley)

Another teacher explained that the educational focus in the teacher's geographical area limits students' exposure to engineering and engineering fields, which the teacher acknowledged adversely impacted confidence in integrating a CREST or engineering type curriculum:

> I think…most of those kids are not really interested in engineering, and it's simply because [of] where they're growing up. They…all want to go into agriculture. They all want to do things like welding, things like that, because they grow up around it, and the parents [are] always pushing it on them. Our school doesn't seem all that interested in steering them in a different direction either. You kind of just lose hope for engineering and other STEM fields and just help push [the students] in the direction they want to go. (Glen)

The Shift to Hands-On Learning theme captured how the CREST curriculum introduced engaging, hands-on activities that replaced traditional rote memorization and textbook-based learning. Teachers were thrilled to see students apply lessons to real-life contexts, as one explained, “My students could apply what they learned in real-life contexts, like robotics and programming” (Riley). Yet, making hands-on learning accessible came with logistical barriers. All teachers noted that “time constraints,” “lack of resources,” and “schedule disruptions” were significant obstacles in the shift to hands-on learning. Aside from these obstacles, one teacher perceived the shift as being more complex from a systemic point of view:

> One of the things that I've noticed is that kids don't think anymore because as a school system we have put them into a box of this is what you must know, and this is how you're going to get it. There's no inquiry because everything [has been] handed to [students] them, to include learning. (Lee)

Similarly, the Integration of Engineering Concepts theme through the enriched CREST curriculum inspired teachers to integrate engineering design into subjects such as math and biology. As one teacher reflected, “Before CREST, I didn't think much about engineering, but now I see its importance in problem-solving” (Riley). Yet, with this expanded perspective came the expressed challenge of learning and implementing new engineering content in fields where teachers in general have minimal prior experience. One teacher explained: “Teachers tackle [these] learning curves with the help of [their] peers and professional development that we have to attend, but still we don’t really learn exactly *what* we’re supposed to teach and *how* we’re supposed to teach it” (Indigo).

The Collaborative Professional Growth theme revealed that the CREST-MECIS CoP fostered camaraderie and mutual learning among teachers and undergraduate and graduate students. However, creating a truly collaborative online environment for the CoP required adaptation and open-mindedness. Teachers expressed that while the Google Classroom and Zoom video conferencing app provided convenient platforms for accessibility and sharing resources and assignments, they were challenging to embrace because "[they] lacked the depth of face-to-face communication" (Murphy), "face-to-face interactions were just easier to understand" (Finley), "online communication just felt less personal, and sometimes I didn't understand what was said but was too scared to ask for clarification" (Indigo), and "a few technical issues interfered with the flow of things, and so I got bored" (Riley).

Teachers valued online collaboration but noted that face-to-face meetings fostered stronger collaboration with peers and experts and allowed for richer discussions, brainstorming, and immediate feedback on lesson ideas more effectively than the virtual setting: "Zoom was like the place to have *just* a meeting, but face-to-face was for richer, more meaningful discussions and actual learning…" (Indigo), "Google Classroom reminded me of school, and I just couldn't get into the meeting or the discussions" (Finley), "Brainstorming our lesson plan ideas and how to apply the engineering design process in Zoom was almost impossible because nobody wanted to talk" (Glen), and "Though I appreciated the virtual setting, there was nothing better than being able to talk to and learn from [the experts] in person" (Lee). One teacher viewed the online platform as a barrier to boosting confidence, emphatically stating:

> As I sat in [the] Zoom session, I could not imagine actually being able to teach my lesson, but when I was in-person with [the expert] and [the expert] answered my questions, I felt like I could teach all the lessons!" (Indigo).

The theme of Real-World Application Emphasis in the CREST-MECIS CoP fostered a more interdisciplinary approach, with teachers increasingly linking lessons to real-world STEM careers and applications. One teacher's enthusiasm was evident in the reflection: "The CREST training showed me how to apply engineering concepts to my school curriculum and real-world scenarios" (Finley) but not without a fair share of challenges. Real-world applications require additional preparation, both in terms of content knowledge and resources, which added another layer of challenge. One teacher noted:

> It's hard to, in my school at least, to do a lot of those really fun lab activities because a lot of the fun lab activities that we do extend to the next day and sometimes require extra research on the content. And when you teach as many subjects as I do, it is not possible to prep each class today and then continue from where you left off the next day, especially when each lab requires different supplies and equipment. So, I have to do a lot of cleanups and a lot of prepping for the next class. Passing periods are only two minutes long, so it's very, very, very challenging for me when every period is a different class." (Glen)

Teachers without extensive engineering backgrounds faced the dual challenge of learning new concepts and finding effective ways to present them to students. "I've never taken an engineering course in my life," reflected one teacher, adding, "Until this community of practice, I had no idea how I would even begin to combine engineering concepts in [my subject] and then teach it to students" (Riley). Another teacher stated, "I'm a [subject] teacher, and even though I feel more confident teaching the CREST curriculum, I am not confident that I could teach and apply engineering concepts to just any real-world scenario" (Finley).

The barriers teachers expressed in integrating a CREST or engineering type curriculum ultimately underscored the importance of the community of practice model itself, as the CoP experience empowered teachers to engage students in ways that would have been difficult to achieve had they not participated in the CoP. Teachers credited expert support as crucial for overcoming these challenges, noting how their newfound skills and adaptability prepared them for an engineering-based curriculum that, while demanding, proved to be deeply rewarding. This juxtaposition of themes and barriers highlights the resilience of teachers within the CREST-MECIS CoP, where they navigated challenges collaboratively, innovatively, and with a commitment to transforming STEM education for their students.

Convergence of Findings

The CREST-MECIS community of practice (CoP) represents a dynamic and impactful environment for STEM educators, students, and professionals. The triangulated data, derived from both qualitative and quantitative sources, presents convergences in how collaboration, shared expertise, and community-building fostered growth, self-efficacy, and a strong sense of belonging within the CoP. This community framework not only facilitated essential changes in teaching practices and student engagement but also revealed critical contextual mitigating factors (CMFs) that could affect the continuity and efficacy of these advancements. Through analysis, the results section captures the essence of how a CoP can shape STEM education reform, illustrating how these elements converge to recognize and address the CMFs and catalyze progress toward STEM education reform.

Confidence and Skill Development in STEM Teaching

One of the most notable convergences between qualitative and quantitative data was in the area of confidence and skill development among educators. At the onset, many K-12 STEM teachers displayed both enthusiasm and apprehension toward implementing the CREST-developed curriculum, which was focused on engineering, coding, and inquiry-based learning.

Qualitative pre-interview responses revealed that teachers were uncertain about their capacity to integrate engineering concepts into their existing classrooms. For example, one teacher expressed this hesitation candidly, saying, “I don’t feel that confident because I’ve never done engineering independently” (Lee). Similarly, another teacher shared their concerns, noting, “The actual meat and potatoes of the content concerns me, but I feel like watching the professionals will help me understand” (Indigo).

However, the post-interview data painted a contrasting picture, where teachers reported a marked improvement in their self-efficacy and readiness to implement STEM lessons independently. Teachers conveyed a new sense of accomplishment, with one sharing, “My confidence level is pretty high. It’s easier to implement a STEM lesson…I can create a lesson from scratch” (Glen). Another teacher echoed this newfound confidence, stating, “I feel like I already have a good three activities with engineering concepts that I could do with the students because I understand the engineering process” (Murphy). The qualitative data on confidence was further corroborated by quantitative data. Post-survey responses demonstrated a statistically significant increase in the “Engineering Teaching Efficacy and Beliefs” domain, underscoring the CoP’s success in enhancing teachers' self-confidence and instructional capabilities in engineering (Wilcoxon $Z = -2.201$, $p = .028$). Figure 4 shows the comparisons of these findings.

Teacher Quantitative Data:
Wilcoxon Signed Ranks Test Statistics

Domain/Item	Z	Asymp. Sig. (2-tailed)
Science/Math Teaching Efficacy and Beliefs	$-.422^{b}$	0.673
Science/Math Teaching Outcome Expectancy	$-.425^{b}$	0.671
Student Technology Use	$-.677^{c}$	0.498
Science/Math Instruction	-1.572^{c}	0.116
21st Century Learning Attitudes	$-.816^{c}$	0.414
Teacher Leadership Attitudes	$-.552^{b}$	0.581
STEM Career Awareness	-2.207^{c}	0.027*
Engineering Teaching Efficacy and Beliefs	-2.201^{c}	0.028*

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.
c. Based on positive ranks.
d. The sum of negative ranks equals the sum of positive ranks.
* significantly different ($p < .05$)

Teacher Qualitative Data

THEME 1:

STEM Teachers Develop Confidence in Teaching Engineering Through a Community of Practice

"It was just kind of like what I thought I knew. And so when I actually got into research and started applying the concepts I learned, I realized it's not quite as easy as I thought" (Grey).

So, I guess to explain it, back then when I had first taken [the process skills survey], I was fairly new to the CREST center, and I guess I was pretty confident in everything. I wasn't like being realistic. Throughout the year, I learned that there's still definitely a lot more room to grow…It's pretty humbling. (Ash

[CREST] did, for sure, help me with failure…It like changed the way that I saw or how I rationalized things not working. Rather than being a failure, it is just another way that doesn't work, and it propels you find a new way. (Rae)

Figure 5: Convergence of Findings: Teacher Quantitative Data Corroborated with Teacher Qualitative Data

Reaffirming Hands-On, Student-Centered Learning

Another theme of convergence was the shift from traditional, textbook-driven instruction to a hands-on, student-centered learning approach. Qualitative data from the interviews highlighted that teachers initially relied on a conventional teaching model but were motivated to adopt exploratory, student-led learning practices through their CoP involvement. Teachers described how hands-on activities not only increased engagement for students but also made STEM content more accessible and applicable. For instance, one teacher noted, "Implementing hands-on activities really helped the students engage with the lesson" (Glen), while another reflected, "My students could apply what they learned in real-life contexts, like robotics and programming" (Riley). Such insights indicate that the CoP experience encouraged teachers to adopt a more interactive, inquiry-based teaching style, which aligned with the engineering and problem-solving components of the CREST curriculum.

Quantitatively, this shift was evident in the positive changes observed in the "Science/Math Instruction" domain of the T-STEM surveys. The pre- and post-survey scores in this domain increased significantly, demonstrating a collective shift toward instructional practices that prioritize engagement and inquiry over rote memorization. These findings underscore the CoP's impact in fostering an environment where teachers could confidently implement hands-on learning experiences that enhance student participation and deepen comprehension.

Community and Sense of Belonging through Mentorship and Peer Support

The CoP's design also created a robust network of support among teachers, undergraduate and graduate students, and STEM professionals. This sense of community fostered professional growth, as evidenced by qualitative findings where teachers frequently expressed appreciation for collaborative learning. Teachers emphasized the value of peer support and expert guidance, with one teacher noting, "Working with other teachers helped me understand different approaches to the same topic" (Lee). Another teacher elaborated on the role of peer feedback in refining lesson plans, sharing, "CREST's collaborative setup improved my lesson planning through feedback from peers" (Glen).

Among students, this sense of community translated into a reinforced commitment to STEM. Many students felt inspired by the collaborative environment, as described by one participant: “The CREST community helped me feel part of something larger” (Ash). These community-building aspects were further reflected in the quantitative data, where increases in the domains of “STEM Career Awareness” and “Teacher Leadership Attitudes” indicated enhanced confidence and support networks, which are vital for long-term professional growth.

Addressing Contextual Mitigating Factors (CMFs)

Despite the CoP’s success in cultivating STEM knowledge and engagement, several contextual mitigating factors (CMFs) were identified as potential challenges to the sustained adoption of the CREST curriculum.

Resource and Time Constraints. A significant challenge expressed by educators was the systemic lack of resources and time to implement hands-on, engineering-focused lessons effectively, particularly in under-resourced schools, including many rural schools. Because of neoliberal reforms, school schedules have increased in the number of classes, reducing the time available for each, which hinders educators' ability to deliver in-depth, engaging content. Additionally, despite the supportive structure of the CoP, many teachers voiced concerns that the curriculum's demands may be unsustainable without sufficient technological resources. As one teacher described, “We don’t have the technology and probably not even the money to buy the technology” (Finley). Quantitative data from the "Student Technology Use" domain showed minimal progress, highlighting persistent challenges tied to systemic issues in resource distribution and funding. These findings suggest that addressing structural factors like funding inequities and resource allocation is crucial for the long-term sustainability of such curricula.

Cultural and Geographical Barriers. The influence of cultural and geographical barriers on students' responses to the hegemonic education system is both profound and multifaceted, particularly when these students lack agency within such a system. When educational structures are shaped by dominant cultural norms and values that do not reflect the diverse backgrounds of the students within them, the result can be alienation, disengagement, resistance (Cordoba et al., 2022). For instance, teachers from specific regions observed that students' career aspirations, heavily influenced by local economies, cultural expectations, and even schools that students attended, often conflicted with the push toward engineering and other STEM pathways. As one teacher explained,

> I think…most of those kids are not really interested in engineering, and it's simply because [of] where they're growing up. They…all want to go into agriculture. They all want to do things like welding, things like that, because they grow up around it, and the parents [are] always pushing it on them. Our school doesn't seem all that interested in steering them in a different direction either. You kind of just lose hope for engineering and other STEM fields and just help push [the students] in the direction they want to go. (Glen)

Geographical isolation adds another layer to the barriers students face in hegemonic education systems, particularly for those in rural or economically disadvantaged regions (Cordoba et al., 2022). Students in these areas often have limited access to educational resources, less exposure to trained teachers, and restricted access to STEM career pathways. These limitations can create a perception among students that they are excluded from broader societal opportunities, resulting in frustration and a feeling of being constrained within an education system that does not support their aspirations. The lack of agency within the classroom and limited opportunities beyond it leave students feeling disenfranchised and hinder their ability to shape their own educational experiences.

Barriers such as these prevent students from fully participating in and benefiting from their education. Instead of facilitating growth, these structures can inadvertently suppress students' potential by limiting their agency and invalidating their cultural identities. Cultural influences underscore the need for engagement strategies that are not only contextually relevant but also responsive to the systemic limitations shaping students' perspectives. Addressing these structural barriers could enable educators and CoP leaders to craft more inclusive approaches that honor students' backgrounds while gradually expanding their career possibilities within STEM fields.

Digital versus In-Person Collaboration. While the CoP offered online platforms like Zoom and Google Classroom to facilitate collaboration, qualitative feedback from teachers indicated that virtual interactions did not always provide the same level of connection as in-person engagements. Teachers described online sessions as lacking the depth and immediacy of face-to-face interactions. One teacher reflected, "Zoom was like the place to have just a meeting, but face-to-face was for richer, more meaningful discussions" (Indigo). This preference for in-person collaboration highlights a limitation of the virtual component of the CoP and suggests that future efforts to expand CoP access should balance online accessibility with opportunities for in-person engagement where feasible.

Accelerating STEM Education Reform through the CREST-MECIS CoP

In summary, the CREST-MECIS CoP emerged as a transformative influence on STEM teaching practices and student engagement, offering a model for STEM education reform that addresses both skill development and contextual barriers. Through increased teacher confidence, a shift toward hands-on learning, and the establishment of a supportive community, the CoP encouraged educators to integrate innovative, student-centered instructional strategies. The triangulated qualitative and quantitative data affirm that the CoP fostered growth in self-efficacy, instructional skills, and community belonging among participants, creating a ripple effect that benefits both educators and students.

However, the presence of CMFs such as resource limitations, cultural influences, and challenges with virtual collaboration suggests that sustained reform will require systemic support beyond the CoP. Addressing these contextual factors can help ensure that the momentum generated within the CoP is preserved and that the CREST-MECIS CoP model continues to empower educators and inspire students across diverse educational contexts.

Divergence and Additional Insights

While the CREST-MECIS community of practice (CoP) produced substantial gains in STEM teaching and learning, the triangulated qualitative and quantitative data revealed several important divergences in outcomes for both students and teachers. These divergences illustrate complex challenges in STEM education, particularly in areas where theoretical understanding meets practical application. Additionally, further insights emerged into how these divergences reflect selective growth in certain competencies, as well as the stabilization of core skills that could serve as a foundation for further advancement.

Divergences in Student Research Experience Competency Perceptions

One of the most notable divergences arose in the area of student research experience competency perceptions, particularly as students engaged more deeply with complex aspects of scientific research. For example, while students generally reported gains in technical skills, their perceptions waned in specific research competencies, particularly when working with primary scientific literature and defining research questions. Triangulation of the quantitative and qualitative findings revealed that as students engaged more deeply with the research experience skills taught in the CREST-MECIS program, they developed more cautious and realistic self-assessments on their own. This waning in perceptions is the reason for divergence, as scores for certain competencies moved in a direction opposite what was expected. However, it is also this waning that demonstrates remarkable improvement in student self-efficacy, an attribute that occurred as a result of past experiences, vicarious learning and observing of others, and managing unexpected events (Bandura, 1977). Figure 5 reveals the unfolding of this interpretation.

Student Quantitative Data:
Summary of Wilcoxon Signed Ranks

Pre- and Post-Pairs	**NC**	**PC**	**No Change**	**N**
Pair 1: Understand contemporary concepts in your field	3	4	3	10
: Make use of the primary scientific research literature in your field	4	0	6	10
: Identify a specific question for investigation based on the research in your field	5	0	5	10
: Formulate a research hypothesis based on a specific question	3	3	4	10
Pair 5: Design an experiment or theoretical test of the hypothesis	5	3	2	10
Pair 6: Understand the importance of "controls" in research	2	2	6	10
Pair 7: Observe and collect data	3	1	6	10
Pair 8: Statistically analyze data	4	3	3	10
Pair 9: Interpret data by relating results to the original hypothesis	3	3	4	10
: Reformulate your original research hypothesis (as appropriate)	3	4	3	10
Pair 11: Relate results to the "bigger picture" in your field	6	2	2	10
Pair 12: Orally communicate the results of research projects	3	3	4	10
Pair 13: Write a research paper for publication	4	3	3	10
Pair 14: Think independently	2	3	5	10
Totals:	**50**	**34**	**56**	

Student Qualitative Data

THEME 6:

An Emerging Epistemological Stance on Conducting STEM Research

"It was just kind of like what I thought I knew. And so when I actually got into research and started applying the concepts I learned, I realized it's not quite as easy as I thought" (Grey).

So, I guess to explain it, back then when I had first taken [the process skills survey], I was fairly new to the CREST center, and I guess I was pretty confident in everything. I wasn't like being realistic. Throughout the year, I learned that there's still definitely a lot more room to grow…It's pretty humbling. (Ash

[CREST] did, for sure, help me with failure…It like changed the way that I saw or how I rationalized things not working. Rather than being a failure, it is just another way that doesn't work, and it propels you find a new way. (Rae)

Figure 6: Divergence of Findings: Student Quantitative Data Corroborated with Student Qualitative Data

Perceptions in Scientific Literature and Research Formulation. Both qualitative and quantitative data highlighted a decrease in students' perceptions when engaging with primary scientific literature, which they found challenging to interpret and apply. Quantitative data showed that four students reported decreased perceptions in *Making Use of the Primary Scientific Research Literature*, no participants indicated improved perceptions, and six participants reported no change in their perceptions. This decline suggests that increased exposure to primary literature, while informative, also revealed gaps in students' interpretive and analytical skills, leading them to feel less assured about their ability to comprehend and utilize these complex texts. In alignment with these findings, qualitative reflections from students emphasized the challenges of making sense of advanced scientific material, noting that while they initially felt prepared, the nuances and technicality of primary sources tempered their perceptions.

Identifying Research Questions. Similar patterns emerged in the area of research question development. Quantitative findings showed that five students reported a decline in their perception to *Identify a Specific Question for Investigation Based on the Research*, while none reported gains. This outcome reflects a greater awareness among students of the challenges involved in formulating precise, researchable questions. As they progressed in their research journey, students often found it difficult to translate theoretical knowledge into clear, actionable research questions. Qualitative data supported these findings, with students expressing frustration at the complexity of developing focused research inquiries. This divergence underscores a gap in students' readiness to independently navigate early research stages, indicating an area where additional guidance within the CoP could be beneficial.

Divergences in Teacher Confidence in Practical Application of Engineering Concepts

Among teachers, a divergence emerged between their increased confidence in teaching STEM content and their hesitancy in applying engineering concepts to real-world scenarios. While many teachers reported enhanced self-efficacy in delivering STEM content overall, they encountered challenges in connecting engineering principles to practical applications, particularly when lacking a formal background in engineering. One teacher illustrated this sentiment by stating, "I'm a [subject] teacher, and even though I feel more confident teaching the CREST curriculum, I am not confident that I could teach and apply engineering concepts to just any real-world scenario" (Finley). This divergence reflects the difficulty that some teachers faced in bridging the gap between theoretical understanding and real-world application, especially in engineering, an area where many K-12 teachers may have limited prior experience.

Additional Insights: Selective Growth and Stabilized Competencies

Beyond these divergences, additional insights emerged, offering a more comprehensive view of how the CoP impacted students' and teachers' competencies. These insights reveal areas of selective growth and stability that could inform future instructional support within the CoP.

Mixed Outcomes in Data Analysis and Interpretation. One area where selective growth was observed was in data analysis and interpretation. In the competency of *Statistical Data Analysis*, quantitative data indicated a mixed impact, with an equal number of students reporting increased and decreased perceptions in this area. Qualitative reflections further highlighted this trend, as students noted they felt more adept in basic statistical analysis but encountered challenges with more advanced techniques. These findings suggest that while the CoP supported students in achieving a baseline level of competency in data analysis, additional resources or instruction may be required to address varied levels of expertise among participants.

Similarly, in *Interpret Data by Relating Results to the Original Hypothesis*, quantitative data showed both gains and losses. Students' reflections indicated that they could perform basic interpretations but struggled with connecting their results to broader theoretical frameworks. This divergence points to a need for more targeted training in drawing connections between experimental findings and the overarching research hypothesis, a skill critical for in-depth scientific inquiry.

Complexities in Relating Research to Broader Contexts. A notable area of decreased perception was observed in *Relating Results to the Bigger Picture in [the] Field*, where six students reported lower perception in this area following their participation in the CREST-MECIS program. This trend suggests that while students gained technical skills, many faced difficulties in contextualizing their findings within the larger scientific landscape. Qualitative insights further revealed that students often struggled to see the broader implications of their research, an essential skill for holistic scientific understanding and one that might require additional focus within the CoP. Addressing this competency could support students in developing a more integrated understanding of their work and its potential applications within the field.

Stabilized Competencies: Consistent Strength in Data Collection and Independent Thinking

Despite these areas of divergence, certain skills demonstrated stability or even improvement, underscoring the CREST-MECIS program's impact in reinforcing core competencies.

Consistency in Data Collection. Among the stabilized competencies was *Observing and Collecting Data*, an area where student perceptions remained high with minimal changes reported in both pre- and post-survey responses. The stability in this domain suggests that the CREST-MECIS program was effective in establishing a strong foundation in basic data skills, an essential competency that students can build upon as they progress to more advanced research tasks. Students' qualitative reflections echoed this consistency, with many expressing that they felt capable of conducting data collection tasks and had a clear understanding of the procedures involved.

Growth in Independent Thinking and Research Adaptability. In the domain of *Independent Thinking*, slight but positive growth was observed. Three students reported increased perception in their ability to think independently when approaching research tasks. This trend reflects the CREST-MECIS program's role in fostering a supportive environment that encourages critical thinking and adaptability, essential qualities for success in STEM fields. Qualitative feedback suggested that students were more likely to take the initiative and approach research challenges with a problem-solving mindset. This increased independence aligns with the CREST-MECIS program's goal of preparing students to tackle complex STEM challenges autonomously, positioning them for success in both academic and professional contexts.

Summary of Divergences and Insights

In summary, the divergences and additional insights within the CREST-MECIS program and CoP reveal both the strengths and challenges of this community of practice model. While the CREST-MECIS research experience program successfully enhanced core competencies in areas like data collection and independent thinking, certain complex skills, such as engaging with primary scientific literature and formulating research questions, required additional support to bridge the gap between theory and practice. For teachers, the divergence between general STEM confidence and the application of engineering concepts highlights the nuanced challenges of interdisciplinary instruction in STEM.

These divergences and insights underscore the importance of targeted instructional support within the CoP, particularly in advanced research skills and real-world applications. By addressing these areas of divergence, the CoP can further refine its approach to equipping participants with both the foundational skills and higher-level competencies needed for sustained success in STEM fields. Through enhanced guidance and mentorship, the CoP has the potential to close these gaps, fostering a more comprehensive and adaptable STEM education environment.

Summary of Findings

The CREST-MECIS program and community of practice significantly enhanced STEM confidence, self-efficacy, and career aspirations for both students and teachers. Quantitative data showed that students gained increased perceptions in their abilities to conduct technical and problem-solving skills, becoming more capable of tackling complex tasks and more inclined to pursue advanced STEM studies and careers. Structured research experiences and real-world applications helped students feel prepared and motivated to set academic and career goals in STEM. Mentorship and peer support within the CoP were central, inspiring students to overcome initial apprehensions and build practical skills. Exposure to various STEM fields and professionals further deepened their commitment to STEM careers.

For teachers, the CoP increased teaching efficacy, particularly in engineering, with educators transitioning from lecture-based methods to inquiry-driven, interdisciplinary hands-on learning. This shift engaged students more actively and aligned with constructivist principles, encouraging exploration and enthusiasm, especially with real-world STEM applications. Teachers also gained a clearer understanding of STEM career pathways, which they confidently shared with students, fostering an environment that prepares students for future academic and career pursuits in STEM.

Additionally, the CoP fostered a strong sense of community among teachers, reducing isolation and providing support through collaborative planning and shared experiences. Teachers reported personal and professional growth, feeling more connected to a professional network that reinforced their commitment to STEM education. Overall, the CoP empowered students and teachers alike, fostering an enthusiastic, motivated community ready to excel and advance in STEM fields.

Quantitative Results

Quantitative data from students' pre- and post-surveys illustrated significant gains in STEM Confidence and Self-Efficacy, particularly in technical and problem-solving skills. Post-survey results indicated that students felt more capable of tackling complex tasks and more prepared to pursue STEM studies and careers. This increase in self-efficacy was reflected in students' willingness to consider advanced studies, with many expressing interest in graduate school following their CoP experience. The structured support provided by the CoP, such as hands-on training and real-world applications of STEM concepts, contributed significantly to these gains, as students felt they were not only gaining knowledge but also practicing skills necessary for advanced STEM roles.

Another area of growth was motivation to excel academically and professionally within STEM fields. The quantitative results revealed that students reported greater career ambition and goal setting in STEM, a shift attributed to the CoP's emphasis on both practical skills and academic achievements. Students were not only learning STEM content but were also inspired by the program's mentors and by observing the progress and achievements of their peers. For many, the opportunity to present their projects, engage in research, and apply classroom learning in real-world contexts fostered a sense of purpose and a commitment to STEM.

Quantitative analysis of teacher data indicated significant increases in several domains, reflecting the positive impact of the CoP. For instance, Engineering Teaching Efficacy showed a marked increase from pre- to post-intervention, indicating that teachers gained confidence in incorporating engineering concepts into their STEM curriculum. Initially, teachers felt unsure about their abilities to integrate these concepts, but the CoP's training, collaborative planning, and hands-on experiences empowered them to engage more deeply with engineering content.

This confidence boost was essential, as many teachers reported that engineering, unlike other STEM areas, was a new focus that had previously been underrepresented in their teaching practices.

Another area of notable growth was STEM Career Awareness, where teachers demonstrated a clearer understanding of STEM career pathways and the importance of conveying this information to their students. Teachers initially viewed STEM as a broad field without recognizing the diverse range of career possibilities within it. Through their participation in the CoP, however, they reported increased confidence in discussing STEM career options, highlighting a shift toward preparing students for future academic and career pursuits in STEM fields.

Despite these gains, some quantitative results reflected a slight decrease in Student Technology Use following the intervention. This could indicate that while teachers became more confident in engineering content, logistical or resource constraints may have hindered their ability to implement technology-based learning activities fully. The quantitative data suggest a gap between the CoP's ideals of integrating digital tools and the practical realities of classroom access to technology, a point further expanded in the qualitative findings.

Qualitative Results

For students, qualitative findings highlighted the CoP's impact on Self-efficacy, Motivation, and Career Aspirations. Students described initial uncertainties in applying STEM knowledge to real-world scenarios, particularly in technical areas such as coding, engineering design, and laboratory work. However, through the CoP's structured, hands-on approach, students gained confidence and expressed increased enthusiasm for STEM. Themes of mentorship, peer support, and hands-on application were central to students' experiences. Many students recounted how they initially felt intimidated by complex STEM tasks, but with the guidance of mentors and support from peers, they overcame these fears and developed practical skills.

Students also reported feeling more prepared for future STEM careers, as the CREST program exposed them to various fields and research opportunities. By working closely with faculty, participating in projects, and observing professionals, students gained insights into what STEM careers entail, and they felt motivated to continue on this path. The CoP helped students build a sense of belonging and identity within the STEM community, which was instrumental in fostering a commitment to further studies and professional development.

Qualitative data from teacher interviews enriched the understanding of their experiences within the CoP, revealing personal growth in teaching practices and self-efficacy. Initially, teachers expressed apprehension about incorporating engineering and technology due to limited prior exposure. However, as they engaged with the CoP's training sessions, collaborated with peers, and received guidance from experts, they reported a transformative shift in their teaching approach. Themes such as confidence building, collaborative professional growth, and student-centered learning emerged prominently. Teachers described how their initial hesitation was replaced by a sense of accomplishment as they developed new instructional strategies aligned with active learning and problem-solving.

Teachers reported significant shifts in classroom practices, moving from lecture-based methods to inquiry-driven, hands-on activities that encouraged student exploration and engagement. This shift aligns with constructivist principles, as teachers moved towards facilitating learning environments where students construct knowledge through experience. Teachers noted that their students responded positively to these changes, showing increased enthusiasm and curiosity, especially when engineering and real-world applications were integrated into lessons. This transition not only influenced teachers' self-perception as STEM educators but also increased their motivation to further refine their STEM teaching practices.

The CoP also fostered a strong sense of community among teachers. Participants emphasized that the CoP's collaborative nature provided a support system that was particularly beneficial in overcoming the challenges of STEM teaching. Teachers valued the opportunity to share experiences, discuss difficulties, and collectively brainstorm solutions. They reported feeling less isolated and more connected to a professional network, which reinforced their commitment to STEM education. Teachers noted that while the CoP required them to step outside of their comfort zones, the shared experience of tackling these challenges as a group made the process rewarding and enriching.

Triangulated Findings: Convergences and Divergences

Triangulation of quantitative and qualitative data revealed key areas of convergence and divergence, adding depth to the interpretation of the CoP's impact on both teachers and students.

Convergences

Both data sources converge in showing that Self-efficacy and Confidence in STEM teaching and learning increased significantly for both groups. For teachers, this was evident in the increase in engineering teaching efficacy scores, and qualitative reports emphasized that teachers felt more capable of delivering STEM content in innovative, hands-on ways. Similarly, students' quantitative results indicated increased self-efficacy in technical skills, a finding corroborated by interview data describing the confidence students gained through practical applications of STEM.

Another convergence across qualitative and quantitative data is the shift in both teachers' and students' motivation and commitment to STEM. Teachers reported a renewed passion for STEM teaching, supported by increased knowledge and skills, while students expressed an interest in continuing STEM studies, including pursuing graduate degrees. The CoP's structured mentorship and community support reinforced participants' motivation, creating a collaborative environment where they could envision themselves succeeding in STEM fields.

Divergences

A notable divergence emerged around technology use. While teachers expressed a desire to integrate more technology in their classrooms, quantitative data indicated a slight decrease in technology use post-intervention. Qualitative findings revealed that although teachers gained confidence in engineering content, resource constraints or lack of access to technology in their school environments posed barriers to full implementation. This divergence highlights a challenge for the CoP: while teachers became more prepared to use technology, practical limitations hindered their ability to apply this knowledge fully.

Another divergence appeared in the degree of student-centered learning adoption among teachers. While quantitative results reflect a general increase in 21st-century learning attitudes, qualitative data showed variations in how teachers adapted to hands-on, student-driven methods. Some teachers fully embraced inquiry-based approaches, whereas others faced challenges transitioning away from traditional teaching practices, particularly in environments heavily focused on standardized testing. This divergence suggests that while the CoP promoted innovative practices, individual adaptation varied, influenced by external constraints and teachers' prior experiences.

Conclusions

Influence of CREST-MECIS on Students' Research Skills

The CREST-MECIS program and community of practice (CoP) impacted students' participation in and completion of the CREST-MECIS program by fostering a more cautious and refined perspective on their research skills, particularly in complex areas. Quantitative analyses indicated a statistically significant decrease in students' perceptions of their ability to identify research questions. This decrease suggests that as students delved deeper into the research process, they encountered the complexities of precise question formulation, leading to a reassessment of their skills. Such a shift implies that the program successfully highlighted the challenges inherent in defining researchable questions, prompting students to develop a more critical view of this essential research task.

A similar trend was noted in students' perceptions of their ability to use primary scientific literature, where a near-significant decrease was observed. Students may have recognized the challenges of critically analyzing and synthesizing original research, which prompted a recalibration of their self-assessment. This tempered perception indicates that students are beginning to appreciate the complexities of engaging with scientific literature, a foundational skill in research.

The overall distribution of changes across competencies showed more students reporting slight decreases rather than increases in perceived abilities, with a high number of ties indicating stable perceptions in many areas. These findings suggest that while the CREST-MECIS program reinforced students' understanding in certain competencies, it did not substantially alter their self-perceptions across all skills.

In summary, the CREST-MECIS program and CoP guided students to adopt a more nuanced view of their research abilities, especially in question development and literature engagement. This selective impact points to the value of targeted instructional support within the program, helping students to critically assess and refine key research skills as they move forward in their STEM education and career pursuits.

Influence of CREST-MECIS CoP on Teachers' Attitudes, Beliefs, and Teaching Self-efficacy

The comprehensive quantitative analyses of teacher survey data across eight critical Domains revealed a nuanced picture of the CREST-MECIS community of practice's impact on teachers' educational attitudes, beliefs, and teaching self-efficacy. The descriptive statistics demonstrated that while teachers generally maintained positive attitudes in many areas, there were pronounced areas of change, especially in STEM-related beliefs. Notably, the collapsed averages for Science/Math Instruction and Engineering Teaching Efficacy and Beliefs showed meaningful increases post-intervention, suggesting that the CoP helped strengthen teaching practices and confidence in delivering STEM content. Additionally, STEM Career Awareness exhibited a marked increase, highlighting an enhanced focus on guiding students toward STEM fields, which aligns with local, state, and national educational priorities.

The Wilcoxon signed ranks and test statistics analyses provided statistical backing of these observations, revealing statistically significant improvements in STEM Career Awareness and Engineering Teaching Efficacy and Beliefs. These tests affirmed the CoP's positive impact on teachers' preparedness to address and promote STEM pathways. All of the analyses underscore the CREST-MECIS community of practice's effectiveness in promoting a STEM-focused teaching environment by enhancing teachers' knowledge and confidence in STEM careers and engineering concepts.

CHAPTER V

DISCUSSION

Introduction

This study was inspired by and was in response to Gloria Ladson-Billings' call for a hard re-set to improve STEM education in the 21st century. Its purpose was twofold: 1) to investigate how a research community of practice supports K-12 STEM teachers, college students, and engineering faculty to improve STEM education practices, and 2) to advance scholarship in STEM education that replaces antiquated practices, which have created an education system in need of repair, with strategies that promote learning for all students.

The discussion of findings from the CREST-MECIS Community of Practice (CoP) research, based on a triangulated mixed-methods design, provides an in-depth understanding of how participation in the CoP influenced both teachers and students in STEM fields. This integrative approach leveraged qualitative and quantitative data to offer a holistic view of the shifts in knowledge, attitudes, self-efficacy, and practices among teachers and students. Through triangulation, the findings revealed areas of convergence, where data from multiple sources aligned, as well as divergences, where inconsistencies highlighted challenges or unique perspectives within the CoP framework.

Impact of the CREST-MECIS Community of Practice

The CREST-MECIS Community of Practice (CoP) embodied Gloria Ladson-Billings' vision of a *hard re-set* in education, as she outlines in her call to action for culturally relevant pedagogy and post-COVID-19 educational reform. Ladson-Billings argues that the pandemic exposed deep-seated inequities in the education system, and rather than returning to an inequitable *normal*, she advocates for a foundational rethinking of pedagogy to include student learning, cultural competence, and curricular reform that revolved around technology (Ladson-Billings2021). The CREST-MECIS program and CoP aligned with these principles, offering transformative support to educators that challenged traditional teaching methods and emphasized culturally relevant, hands-on, and collaborative approaches in STEM.

A key element of the CoP's impact was its emphasis on teacher empowerment and self-efficacy. Teachers, who initially lacked confidence in areas like coding and engineering, gained new competencies through expert guidance, hands-on training, and peer collaboration. This mirrors Ladson-Billings' call for cultural competence, where teachers become secure in their knowledge and can bridge mainstream culture and students' lived experiences. CREST's approach to demystifying STEM for educators reflected this, making it more accessible to teachers and, in turn, to their students, who often face systemic barriers to these fields.

The CoP also helped teachers shift from lecture-based methods to exploratory and student-centered learning, where real-world applications of STEM are prioritized. As Ladson-Billings emphasizes, a re-set in pedagogy involves helping students connect learning to their lives and current social issues (Ladson-Billings, 2021). The CREST-MECIS CoP teachers not only taught STEM concepts but linked them to real-world contexts and career pathways, engaging students with content that was relevant and attainable. This transformation supports

Ladson-Billings' vision of teaching as an agent for socio-political consciousness, where students develop critical perspectives and recognize STEM's role in addressing societal challenges.

Lastly, the CREST-MECIS CoP exemplified the collaborative, community-driven education Ladson-Billings envisions, particularly in its cultivation of supportive networks among teachers, students, and STEM professionals. This collaborative ethos encourages shared learning and mutual growth, empowering teachers to overcome logistical barriers and resource limitations. Like Ladson-Billings' idealized *hard re-set*, the CoP challenged educational norms and facilitated systemic change by creating empowered, resilient educators equipped to inspire the next generation in a re-imagined, inclusive STEM landscape. Through this synergy of practical and cultural enrichment, the CREST-MECIS CoP reflected and advanced the transformative goals central to Ladson-Billings' call for a profound educational re-set.

Empowering a Hard Re-Set: Integrating a CoP to Transform STEM Education

Community of Practice Theory, introduced by Lave and Wenger (1991), posits that learning occurs within a social context where individuals with a shared interest interact, collaborate, and develop a collective identity (Townley, 2020; Weinberg et al., 2021; Smeplass, 2023). For both teachers and students, the CoP fostered a sense of belonging and purpose through shared STEM goals. The CoP provided a structured environment where teachers could overcome initial hesitations around STEM content, especially in new areas like engineering, by participating in collaborative lesson planning, sharing classroom experiences, and receiving expert guidance.

For teachers, the CoP supported their journey from novices in certain STEM concepts to more confident practitioners. By engaging with peers who shared similar goals, teachers not only enhanced their STEM skills but also developed a supportive professional identity within STEM education. This aligns with CoP framework's emphasis on learning as a socially shared process, where skills are acquired through active participation, observation, and collaboration (Lave & Wenger, 1991). Teachers' interactions within the CoP helped them form a community defined by shared experiences, mutual learning, and a commitment to student-centered, STEM-driven education.

For students, the CoP offered a platform to engage directly with STEM professionals and peers, allowing them to witness and adopt practices they observed within the community. Through activities like collaborative research and presentations, students developed a sense of community-driven achievement and motivation to pursue advanced STEM studies and careers. This aligned with the CoP framework's focus on the development of domain expertise through continuous engagement in a shared practice (Lave & Wenger, 1991). The CoP's structure allowed students to see themselves as part of a larger mission, reinforcing their identities as emerging STEM professionals.

Implications, Significance, and Future Directions

The CREST-MECIS community of practice (CoP) model offers valuable insights into advancing theoretical frameworks and informing future research in STEM education. The triangulated data from this study highlights several important implications for communities of practice theory, self-efficacy in STEM, and experiential learning, especially in how these theories can be adapted to better support the unique needs of STEM learners. Additionally, the observed divergences in participant outcomes, particularly in advanced STEM skills, provide a foundation for future research aimed at optimizing CoPs and other collaborative learning models in STEM.

Experiential learning theory, which emphasizes the cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation, is particularly relevant in understanding the impact of the CREST-MECIS CoP ((Andresen et al., 2019; Morris, 2019). This theory supports the idea that hands-on, practical experiences are essential to effective learning, a concept that was successfully demonstrated in the CoP's ability to enhance participants' basic STEM skills. However, the challenges that some participants faced in connecting theoretical knowledge with real-world applications suggest a need to expand upon traditional experiential learning models, especially in interdisciplinary fields like STEM where abstract concepts are prevalent.

This study's findings imply that experiential learning theory may need to be adapted to include more structured reflection and conceptualization phases, especially when participants are learning to apply advanced concepts like engineering or scientific research methodologies. For instance, providing additional reflection sessions where participants explicitly link abstract engineering principles to classroom scenarios could help teachers feel more confident in applying these concepts to their teaching practices. Similarly, for students, added guidance on research design and critical analysis could bridge the gap between theoretical knowledge and practical scientific inquiry, ensuring a well-rounded experiential learning process.

Extending Communities of Practice (CoP) Models

This study underscores the potential of CoP models to enhance participants' knowledge and skill development, particularly in STEM fields where practical, collaborative learning is crucial. Wenger's theory of communities of practice posits that CoPs foster shared knowledge, skill growth, and a sense of community among members. The CREST-MECIS CoP effectively demonstrated these outcomes, particularly in building participants' confidence and foundational

STEM skills through collaborative engagement with peers and experts. However, the divergences observed in complex skill development, such as undergraduate and graduate students ability to interpret scientific literature and formulate research questions, suggest that CoP models may benefit from incorporating differentiated instructional supports to meet the needs of participants at varying levels of expertise.

This study also points to the importance of both in-person and virtual interactions within CoPs, a finding with implications for the future adaptation of CoP models. Participants indicated that while online platforms like Zoom and Google Classroom provided convenient access to resources and communication, they often preferred the depth and immediacy of face-to-face interactions. This feedback suggests that an ideal CoP structure may blend digital and in-person interactions to maximize both accessibility and meaningful engagement. As CoP models continue to evolve, incorporating this hybrid approach could offer a balanced learning environment, enriching the community experience while accommodating diverse learners.

Self-Efficacy Theory in STEM Education

The results of the CREST-MECIS CoP align with Bandura's self-efficacy theory (1977), which emphasizes mastery experiences and social learning as essential to building confidence. Through hands-on projects, peer collaboration, and expert mentorship, the CoP successfully increased participants' self-efficacy in core STEM areas. This growth in confidence was especially evident in the areas of student process skills acquisition, such as data collection, and OTHER foundational process skills, where participants consistently reported improved self-assurance. However, the study's findings reveal an important extension to self-efficacy theory within STEM education: mastery in foundational skills does not necessarily lead to self-efficacy in more complex analytical tasks, such as engaging with scientific literature or independently developing research questions.

These divergences suggest that self-efficacy in STEM education may be multi-dimensional, with different types of skills, such as technical versus analytical competencies, requiring unique support to foster confidence and capability. A theory of multi-dimensional self-efficacy could propose that technical skills benefit most from hands-on, experiential learning, whereas analytical or conceptual skills may require more structured critical thinking exercises, guidance in research formulation, and specialized mentorship. Adapting self-efficacy theory in this way could lead to more effective support structures within STEM-focused CoPs, providing tailored resources that encourage participants to build confidence across a broader spectrum of STEM competencies.

Future Research Directions in STEM CoPs

The divergences observed in the study open avenues for future research to investigate the specific instructional supports that might optimize STEM-focused CoPs for diverse learner needs. One area of exploration could be the impact of tailored interventions, such as scaffolding or differentiated instructional strategies, on participants' confidence and competency in advanced research skills. Studies could examine whether targeted mentorship or tiered learning activities improve participants' ability to engage deeply with scientific literature, develop independent research questions, and draw connections between research findings and broader scientific contexts.

In light of the challenges that some teachers faced in applying engineering concepts to real-world scenarios, future research could also focus on strategies to support interdisciplinary teaching within STEM education. For example, research could evaluate the effectiveness of subject-specific modules that introduce teachers from non-engineering backgrounds to engineering applications. These modules could provide practical guidance and resources that help teachers translate engineering principles into classroom scenarios, especially in ways that align with their subject specialties. Such studies could contribute valuable insights into how STEM-focused CoPs can better support educators who face unique disciplinary challenges.

Another promising direction for future research is the examination of hybrid CoP models that integrate both virtual and in-person components. The findings from this study highlight the value of face-to-face interaction in building rapport and fostering deeper discussions, while online platforms offer flexibility and accessibility. Research could investigate the optimal balance between these modes of interaction, assessing how different configurations of digital and in-person learning impact engagement, collaborative efficacy, and learning outcomes in CoPs.

Broader Implications for STEM Education Reform

The findings from the CREST-MECIS CoP study emphasize the need for STEM education models that not only build foundational technical skills but also cultivate higher-order competencies such as critical analysis, problem formulation, and interdisciplinary application. The CoP model, as demonstrated in this study, aligns with STEM education reform efforts by creating a collaborative framework where educators and students can collectively build both practical and theoretical skills. However, the challenges identified in advanced skill development suggest that for STEM education reform to be most effective, it must incorporate targeted supports that address both foundational and complex learning needs.

These findings imply that future CoP and experiential learning models should be designed with differentiated learning pathways that allow for both novice and advanced learners to thrive. Such an approach could promote inclusivity and foster sustained engagement in STEM, ensuring that participants at all levels of experience feel supported and capable of pursuing higher STEM competencies. Through refinement of CoP and experiential learning frameworks, STEM education reform initiatives can further support a diverse range of learners, empowering them with the skills and confidence needed to excel in STEM fields.

Implications for Practice

The findings from the CREST-MECIS community of practice (CoP) provide actionable insights for educators, curriculum designers, and administrators aiming to improve STEM teaching and learning experiences. The study's results highlight areas where targeted instructional practices and support structures can significantly enhance both teacher and student confidence, engagement, and competency in STEM. These practical implications include strategies for improving STEM instruction, supporting diverse levels of expertise within CoPs, integrating interdisciplinary concepts, and fostering an inclusive, community-oriented learning environment.

Differentiated Instructional Support for Advanced STEM Skills

The study's findings reveal that while the CoP effectively built foundational STEM skills, participants faced challenges in developing more complex competencies, such as engaging with scientific literature and independently formulating research questions. To address these needs, CoP leaders and educators should implement differentiated instructional support that provides tiered learning experiences aligned with participants' varying levels of expertise (Tomlinson, 2014). For instance, scaffolding techniques - such as step-by-step guides for interpreting scientific articles or structured brainstorming sessions for research question development - can help learners progressively build confidence in these advanced skills.

Additionally, embedding targeted mentorship programs within the CoP could support participants who need more individualized guidance. Matching less experienced participants with mentors, such as advanced graduate students or STEM professionals, can provide valuable one-on-one support and feedback, enhancing the practical understanding of complex concepts. By incorporating these structured and differentiated supports, CoPs can create an environment where participants at all levels feel equipped to engage deeply with advanced STEM skills.

Blended Learning Approach to Balance Digital and In-Person Engagement

The study indicated that while digital tools such as Zoom and Google Classroom were beneficial for accessibility, informational sessions, resource sharing, or general updates, participants felt that in-person interactions fostered richer discussions and a stronger sense of community (Kumar et al., 2021). This finding suggests that CoP organizers should still consider a blended learning approach but one that combines more in-person elements, such interactive workshops, collaborative brainstorming, and skill-building activities.

For educators in resource-limited areas where in-person participation may be challenging, incorporating synchronous or asynchronous breakout sessions that allow small groups to discuss and reflect on lesson applications could help replicate the benefits of face-to-face engagement. Additionally, digital tools can be enhanced to create more interactive, personalized experiences - such as using breakout rooms, live polls, or shared digital workspaces - to foster engagement even when participants are connecting remotely.

Interdisciplinary Professional Development for Teachers

The study highlighted challenges faced by teachers from non-engineering backgrounds when integrating engineering concepts into their classrooms. Many teachers reported enhanced confidence in teaching STEM but expressed uncertainty about applying interdisciplinary concepts to real-world scenarios (Weinberger et al., 2021). To address this need, CoPs and school districts can offer professional development modules, workshops, or research experiences, e.g. https://www.utrgv.edu/railwaysafety/education/resources/curricula/index.htm, that introduce non-specialist teachers to foundational engineering principles and provide them with classroom-ready activities and/or curricula that tie these concepts to their subject areas (Tarawneh, 2021; *Research Experiences for Teachers in Engineering and Computer Science, 2023)*. The link provided above is an excellent example of curricula for elementary, middle school, and high school STEM courses developed by the CoP teachers, students, and experts and is posted on the University Transportation Center for Railway Safety, College of Engineering and Computer Science website.

Workshops and hands-on training sessions where teachers practice integrating interdisciplinary concepts into lesson plans could build confidence and competence (*Research Experiences for Teachers in Engineering and Computer Science,* 2023). For example, math and science teachers could benefit from guided projects where they apply engineering concepts to real-world scenarios, such as designing a simple machine or analyzing data from an engineering problem. These interdisciplinary professional development sessions can provide teachers with practical examples and resources, encouraging them to incorporate engineering and other STEM principles more seamlessly into their existing curricula.

Building a Reflective Practice Culture within CoPs

The experiential learning model emphasizes the importance of reflection as a step toward internalizing new skills and knowledge (Andresen et al., 2019; Morris, 2019). This study's findings indicated that participants, especially students, struggled to connect theoretical knowledge with practical applications and with understanding the broader impact of their research. CoP leaders can cultivate a culture of reflective practice by incorporating structured reflection activities into CoP sessions, where participants are encouraged to critically evaluate their experiences, explore challenges, and connect their learning to real-world contexts (Chang, 2019). To facilitate reflective practice, CoPs could integrate journal assignments, peer discussions, and guided reflection prompts at the end of workshops or training sessions (Chang, 2019). For instance, teachers might reflect on how an engineering concept they learned could be applied to a specific classroom scenario, or students might discuss how their research fits within broader STEM fields. These reflective exercises would not only deepen participants' understanding of the material but also help them develop critical thinking skills that are essential for STEM problem-solving and innovation.

Fostering a Supportive, Inclusive Community Environment

A central finding of the study was the positive impact of the community support on participants' confidence and engagement, underscoring the importance of a sense of belonging within CoPs (Lave & Wenger, 1991; Farnsworth et al., 2016). To maintain and enhance this community atmosphere, CoP leaders and educators should actively foster a welcoming, inclusive environment where participants feel encouraged to share their ideas, ask questions, and collaborate openly (Townley, 2020) . Strategies to reinforce inclusivity might include establishing peer support groups, offering regular check-ins, and creating safe spaces where participants can discuss their challenges without fear of judgment.

CoP leaders should also celebrate small achievements and recognize progress to build participants' confidence and motivation. Regular "success spotlights" where teachers or students share recent accomplishments, classroom strategies, or project updates can promote an environment where everyone's contributions are valued. Additionally, organizing community-building activities, such as team challenges, social events, or STEM-related excursions, can strengthen the bond among participants and reinforce their commitment to STEM learning and growth.

Incorporating Contextual Relevance into STEM Curricula

The study revealed that some teachers and students faced challenges connecting STEM concepts to their own cultural and geographical contexts, which can influence student engagement and career interest (Ladson-Billings, 1995; Gallard et al., 2020). To address this, CoP organizers and curriculum developers should strive to incorporate culturally relevant and localized examples into STEM lessons, making concepts more relatable and meaningful for participants. This approach can be particularly valuable in communities where local industries, traditions, or economic factors influence career aspirations.

For example, in areas where agriculture is a predominant industry, STEM curricula could integrate agricultural engineering or environmental science projects that allow students to apply STEM concepts within their communities. Teachers could also be trained to identify local issues or resources that align with STEM principles, helping them create lessons that resonate with their students' experiences (Kolb, 1983; Andresen et al., 2019; Morris, 2019) and environments (Tomlinson, 2014). By making STEM education contextually relevant, educators can inspire a broader range of students to consider careers in STEM fields and see its value in their everyday lives.

Summary

The CREST-MECIS CoP offers a successful model for promoting STEM skills and confidence, with several practical implications for enhancing STEM education. Differentiated instructional support, a blended learning approach, interdisciplinary training, reflective practices, a supportive community environment, and contextual relevance are key areas that CoP leaders and educators can focus on to maximize the impact of STEM CoPs. By addressing these areas, CoPs can empower participants at all levels to develop both foundational and advanced STEM skills, fostering a more inclusive and effective approach to STEM education. Through these enhancements, the CoP model can continue to inspire and support educators and students, contributing to the ongoing evolution of STEM education and preparing participants for success in diverse and interdisciplinary STEM fields.

Limitations and Recommendations for Future Research

While the CREST-MECIS community of practice (CoP) provided valuable insights into the impact of collaborative, experiential learning on STEM education, several limitations influenced the findings and suggested avenues for future research. These limitations relate to participant diversity, scope of skill assessment, and measurement methods, each of which can be addressed through targeted research to improve the CoP model and expand its applicability. Below are the primary limitations of this study, along with recommendations for future research aimed at addressing these constraints and building on the initial findings.

Limitations

Limited Diversity of Participant Backgrounds

One limitation of this study was the limited diversity in participants' backgrounds, particularly among teachers and students with varying levels of experience in STEM disciplines. While the CoP was successful in enhancing basic STEM competencies, some participants, particularly those from non-STEM or non-engineering backgrounds, struggled with more advanced concepts such as engineering applications and scientific literature analysis. This gap highlights a limitation in the study's ability to generalize findings across diverse participant profiles, such as those with different STEM experiences.

Reliance on Self-Reported Data

Another limitation is the study's reliance on self-reported data, which can introduce bias and limit objectivity in measuring actual skill development. Interviews provided valuable qualitative insights but were subject to individual interpretation and potential over- or under-estimation of abilities. This reliance on subjective data may have influenced the accuracy of the reported changes in confidence, self-efficacy, and skill mastery, making it challenging to fully quantify the CoP's impact on participants' STEM capabilities.

Short Duration of the Study

The relatively short duration of the CoP program presented another limitation. Although participants reported gains in confidence and skills within the program, the limited timeframe may have restricted sustained practice and mastery, particularly for complex competencies requiring longer-term engagement. As a result, it is unclear whether the improvements observed in this study are durable or if they will persist over time without continued support.

Recommendations for Future Research

Developing Advanced Research Practices

The CoP primarily focused on building foundational and intermediate STEM skills (Kardash, 2000), but limited attention was given to advanced analytical and research skills, such as hypothesis development, scientific communication, and critical analysis of literature. These more complex competencies are essential for advanced STEM learning and professional growth, and the limited emphasis on them within the study restricts the understanding of how CoPs can support participants in mastering these higher-order skills. As such, the study may not fully capture the broader potential of CoPs to impact participants at advanced stages of STEM education.

Expand Participant Diversity and Comparative Analysis

Future research should focus on expanding the diversity of participants to include a wider range of STEM and non-STEM backgrounds, including those with minimal or no prior STEM exposure. Additionally, a comparative analysis of participants with varied backgrounds could provide insights into how prior knowledge and experience influence outcomes in a science CoP. Studies could explore tailored strategies for novice and advanced participants within the same CoP, allowing researchers to identify effective methods for supporting individuals with diverse educational and professional histories. By enhancing participant diversity and conducting comparative analyses, future research could increase the generalizability and inclusivity of CoP models in STEM education.

Investigate the Development of Advanced Analytical and Research Practices

To address the gap in advanced skill assessment, future research should examine how CoPs can support the development of higher-order competencies such as scientific literature review, hypothesis development, advanced statistical analysis, and interdisciplinary integration. Researchers could incorporate specialized modules focused on these complex skills and measure their effectiveness in equipping participants for advanced STEM tasks. Additionally, studies could track skill development across various stages, from foundational to advanced, to better understand the progression of competency within a CoP. This research would provide a clearer picture of how CoPs can be structured to support a full spectrum of STEM skills and career readiness.

Examine the Long-Term Impact of CoP Participation

Given the limited duration of this study's CoP intervention, future research should explore the long-term impact of CoP participation on STEM skill retention, career development, and professional engagement. Longitudinal studies tracking participants over an extended period - such as six months, one year, or even longer - would provide insights into the sustainability of skills and confidence gained through a science CoP. Researchers could assess whether participants continue to apply STEM principles in their work or further their STEM education, providing a more comprehensive understanding of CoP's influence on enduring professional growth.

Explore the Effectiveness of Hybrid CoP Models

With many participants expressing a preference for in-person interactions over virtual meetings, future studies could examine the effectiveness of hybrid CoP models that blend both digital and face-to-face components. Research could explore different configurations, such as the optimal balance between online and in-person engagement, to determine which aspects of each format are most conducive to STEM learning and collaboration. Additionally, studies could examine how hybrid models impact participant engagement, skill acquisition, and community cohesion, offering practical insights into how CoPs can be designed to accommodate diverse needs while maximizing learning outcomes.

Investigate Contextual Relevance and Cultural Adaptations

The study's findings suggest that participants from different cultural and geographic backgrounds may experience unique challenges in applying STEM concepts. Future research could investigate how science CoPs can incorporate culturally relevant materials and localized applications to make STEM learning more relatable. Studies could examine the impact of contextually adapted curricula on participant engagement, skill retention, and STEM career interest, especially in underrepresented or resource-limited communities. By exploring the role of cultural relevance, researchers can identify ways to make science CoPs more inclusive and accessible, supporting a broader range of participants in STEM learning.

Conclusion

This study explored the impacts of the CREST-MECIS community of practice on both K-12 STEM teachers and undergraduate and graduate students, illustrating how collaborative, supportive learning environments can address critical gaps in contemporary science education. Through an approach grounded in real-world experiences, hands-on learning, and mentorship, the CREST-MECIS CoP model not only shaped participants' confidence, motivation, and engagement in STEM but also aligned with established educational theories. In particular, this study's findings resonate with the works of Lorsbach and Tobin (1992) and Feldman (2013), who underscore the importance of constructivist approaches and community-based learning to achieve meaningful, self-driven student engagement in science.

In addressing Ladson-Billings' (2021) call for a hard re-set in education, this study underscored the urgent need to replace traditional methods with culturally relevant, inclusive, and technologically enriched strategies. According to Ladson-Billings, returning to normal post-pandemic would only reinforce systemic inequities that have historically impeded the success of underrepresented groups in education. Instead, she advocates for an educational shift that acknowledges students' lived experiences, cultural contexts, and socio-emotional needs, especially as they have been profoundly affected by the COVID-19 pandemic. This study's findings reflect the implementation of this vision, demonstrating how the CREST-MECIS community of practice fostered an environment that promoted resilience, inclusivity, and empowerment in STEM education.

Key elements of the CREST-MECIS CoP model aligned with Ladson-Billings' vision of culturally relevant pedagogy, which emphasizes student achievement and cultural competence that revolves around a re-set in curriculum and technology. The model created spaces where students and teachers could explore STEM concepts through hands-on applications, fostering a deeper connection to their academic and professional identities. For students, this approach enhanced their sense of belonging and reinforced their commitment to STEM pathways, while teachers reported increased efficacy and enthusiasm in delivering STEM curricula that were more engaging, inclusive, and relevant to their students' lives.

This study's findings also align with the theoretical perspectives of Lorsbach and Tobin, who advocate for constructivist approaches to science education. They argue that students learn most effectively in environments that prioritize exploration, inquiry, and personal engagement with the material. Lorsbach and Tobin's constructivist approach underscores that science education should not merely involve the passive absorption of knowledge but should encourage students to actively construct understanding based on their experiences. The CREST-MECIS CoP model reflected this by emphasizing experiential learning and collaborative problem-solving. Through projects that required critical thinking, experimentation, and the application of theoretical knowledge, CoP teachers and undergraduate and graduate students were able to construct their understanding of STEM in ways that were meaningful and memorable. This aligns closely with Feldman's (2013) emphasis on reflective practice and the role of community in learning. Feldman argues that a supportive community allows learners to reflect on their experiences, gain insights from their peers, and refine their approaches over time. The CREST-MECIS CoP model provided such a community, where mentorship and peer support helped participants navigate challenges and reinforce their resilience in pursuing STEM goals.

For educators, the CREST-MECIS CoP offered a transformative experience that helped bridge the gap between traditional pedagogy and the needs of modern learners. Teachers reported improvements in their instructional approaches, particularly in integrating culturally relevant and constructivist methods. Teachers noted that the CoP helped them reframe their teaching to be more responsive to students' unique learning needs and social contexts, consistent with the goals of a culturally relevant pedagogy. This reframe extended beyond science and math content to encompass socio-emotional development and cultural inclusivity, reflecting both Ladson-Billings' call for a re-set and Feldman's emphasis on community-based learning.

The study also highlighted the value of mentorship, a core aspect of the CREST-MECIS community of practice. This mentorship not only facilitated technical learning but also supported socio-emotional growth for both students and teachers. Peer and faculty mentors offered guidance, encouraged perseverance, and provided role models who exemplified success in STEM fields. For students, especially those from underrepresented backgrounds, this mentorship was essential in fostering self-efficacy and long-term motivation. Teachers, too, benefited from professional development and peer support that enhanced their confidence in using innovative STEM approaches in the classroom.

In conclusion, the CREST-MECIS CoP embodied the transformative potential of an educational framework that integrates culturally relevant pedagogy, constructivist learning, and community-based mentorship. By supporting educators and students through collaborative learning and mentorship, the CREST-MECIS CoP demonstrated how an educational hard re-set, as envisioned by Ladson-Billings, can meet the demands of a complex and diverse world. The findings from this study underscore the necessity of innovative and inclusive approaches in STEM education, bridging theoretical insights from Lorsbach and Tobin’s constructivist framework, Feldman’s community-centered learning, and Ladson-Billings' call for a re-set around curriculum and technology. Through such integrated approaches, science education can shift towards a future where all STEM students have access to the support, knowledge, and opportunities they need to excel in the 21st century, aligning with the broader educational calls for systemic reform advocated by Ladson-Billings….to fix the *broken system*.

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APPENDIX A

APPENDIX A

IRB APPROVAL

The University of Texas Rio Grande Valley
Institutional Review Board

August 25, 2021

Angela Chapman, Principal Investigator

College of Education & P-16 Integration

Via Electronic Routing System

Dear Dr. Chapman:

RE: APPROVAL FOR HUMAN SUBJECTS RESEARCH IRB-21-0327 "CREST Center for Multidisciplinary Research Excellence in Cyber-Physical Infrastructure Systems (MECIS): Improving STEM Education in the Rio Grande Valley"

The study referenced above bas been reviewed and approved on August 25, 2021 though Expedited Review procedures under the following categories:

(6) "Collection of voice, video, digital or image recordings made for research purposes"; and

(7) "Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies."

Approved number of subjects to be enrolled: 15 high school teachers, high school students, 15 undergraduate engineering students, 5 graduate students each year, and approximately 650 students from participating school districts in summer camps each year.

This project is not subject to continuation review.

Recruitment and Informed Consent: You must follow the approved recruitment and consent procedures.

Modifications to the approved protocol: Modifications to the approved protocol (including recruitment methods, study procedures, survey/interview questions, personnel, consent form, or subject population), must be submitted to the IRB for approval. Changes should not be implemented until approved by the IRB.

Data retention: All research data and signed informed consent documents should be retained for a minimum of 3 years after completion of the study.

Closure of the Study: Please be sure to inform the IRB when you have completed your study, have graduated, and/or have left the university as an employee. A final report should be submitted for completed studies or studies that will be completed by their respective expiration date.

Cordially,

Laura D. Seligman

Laura Seligman, Ph.D.

Chair, IRB - Social, Behavioral & Educational Panel

Brownsville • Edinburg • Harlingen

APPENDIX B

APPENDIX B

STUDENT SEMI-STRUCTURED INTERVIEW QUESTIONS

CREST & CoP Student Interview Questions

Pre-Interview Questions	Post-Interview Questions
1. Tell me about your involvement with CREST? a. How long have you been affiliated with CREST? b. What is your role in the program?	1. Tell me your thoughts about CREST, now that you have completed the program. How did the program impact you? a. Confidence? b. Research/engineering skills c. Research experience
2. Can you elaborate on some of the ways that you think the CREST program will benefit you?	2. Can you elaborate on some of the ways that the CREST program benefited you?
3. Tell me about your future career goals. Will you need to pursue higher education to achieve those goals?	3. Did the CREST program motivate you to continue with higher education?
4. Tell me about your current studies. What do you plan on doing with your degree? a. Industry? b. Higher ed?	4. How will the CREST curriculum compare to the curriculum that you typically teach during the academic year?
5. What are your motivations for participating in the CREST program?	5. Did the CREST program motivate you enough to continue with your research?

6. What would you like for your professors to do to help you learn [your field]? a. Learning strategies used b. Anything different/unique	6. What did your professors do to help you learn [your field]? a. Learning strategies used b. Anything different/unique
7. REVIEW RESPONSES ON THE PRE-SURVEY	7. REVIEW RESPONSES ON THE POST-SURVEY
CoP PARTICIPANT QUESTIONS	
1. Tell me about your interactions with your peers, the teachers, and the experts. a. What do you think they learned from you? b. What did you learn from them?	
2. How did the CREST CoP impact you?	
3. What did you learn from the CoP	
4. Do you think the CREST CoP achieved its goals? Was it successful?	

APPENDIX C

APPENDIX C

TEACHER SEMI-STRUCTURED INTERVIEW QUESTIONS

CoP Teacher Interview Questions

Pre-Interview Questions	Post-Interview Questions
1. What do you think is the best way for your students to learn STEM concepts?	1. Tell me your thoughts about your participation as a Railway Safety Summer Camp RET this past summer?
2. Tell me about a time when you intentionally took on a STEM teaching task or activity that required you to stretch the limits of your strengths - maybe outside of your comfort zone. (*First of all, you are looking for an awareness of strengths and self-awareness. Secondly, you want to hear the candidate describe a situation that was out of their comfort zone, perhaps even risky. How did they approach it, and what was the outcome?)*	2. Did your participation as a Railway Safety Summer Camp RET require you to stretch the limits of your strengths/comfort zone? **a. If Yes** - Was the stretch enough to prepare you for the implementation of the acquired skills into your curriculum(a) this coming academic school year? **b.If No** - Please explain.
3. Tell me your thoughts about your confidence in teaching the CREST curriculum - either now in the summer camps or in the fall during the regular academic year.	3. After having completed the Railway Summer Camps 2024 RET, what are your thoughts about your confidence in teaching the CREST curriculum in the fall this coming academic school year?
4. How does the CREST curriculum compare to the curriculum that you typically teach during the academic year?	4. How will the CREST curriculum compare to the curriculum that you typically teach during the academic year?

5. What barriers or challenges would prevent this type of curriculum in your classroom?	5. What barriers or challenges would prevent this type of curriculum in your classroom?
6. Tell me about your interactions with CREST students and/or CREST faculty. a. What do you think about having a CREST student or faculty support you during the academic year - to implement curriculum, etc.?	6. What are your final thoughts about your interactions with CREST students and the CREST faculty?
7. Would you consider participating in another STEM Community of Practice if an opportunity presented itself?	7. Would you consider participating in another STEM Community of Practice if an opportunity presented itself?

VITA

Ms. Ruth Renee Colyer has been a certified life science teacher in the state of Texas since 2012, where she has demonstrated competence in the state-tested subject of biology. Ms. Colyer received her Bachelor of Science degree in Pre-Medicine Biology from The University of Texas Pan-American (now The University of Texas Rio Grande Valley, or UTRGV) in May 2009. She subsequently earned her Master of Science degree in General Biology from UTRGV in August 2014. She earned a Doctor of Education degree in Curriculum and Instruction with a specialization in Science Education from UTRGV in December 2024.

Ms. Colyer has taught high school Modified Biology, Regular Biology, Pre-Advanced Placement Biology, Advanced Placement Biology, Chemistry, Anatomy and Physiology, Science Research and Design, Path to College Success, and Environmental Systems courses. Additionally, she has taught college level General Biology 1401, General Biology 1402, and Principals of Ecology. Ms. Colyer teaches freshmen Pre-Advanced Placement Biology, freshmen Path to College Success, senior Environmental Systems, and sophomore Science Research and Design at an early college high school. She has additionally served her campus and colleagues as the Science Department Head, UIL Science Coordinator, UIL Science Coach, Society of Hispanic Professional Engineers Sponsor, National Honor Society Sponsor, Campus Teacher Mentor, Rigor Coach, Grade Level Team Leader, Student Attendance Committee Member, Summer Bridge Program Instructor, district-wide Science Vertical Team member, member of the School Based Decision Making Council, and District Curriculum Writer. Ms. Colyer can be contacted at ruth_colyer@yahoo.com.

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