2024

# The Decline of Science in the Early Years: A Diagnosis and a Plan of Action

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A Dissertation Submitted

In Partial Fulfillment of the

Requirements for the Degree of

DOCTOR OF EDUCATION

Benerd College
Educational Leadership

University of the Pacific
Stockton, California
2024

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# Dedication

To my parents, both of whom were, and always will be, my biggest cheerleaders.

To The Nine of Cohort 4, Willie, Lupe, Mercedes, Jerry, Brian, Anthony, and Tobi, I would never have been able to make it through this process without your kindness, support, and humor.

And especially to Robynne Rose-Hamer, my writing partner extraordinaire. You have been a coach, a therapist, a teacher, but most of all, a fantastic friend. Thank you.

# The Decline of Science in the Early Years: A Diagnosis and a Plan of Action

## Abstract

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2023

Science instruction in the early years of a student's education career is essential to a student successfully continuing science in their secondary and postsecondary careers. However, the amount of high-quality science instruction students receive at the elementary level has been steadily declining for two decades, resulting in an inequitable imbalance in those who pursue STEM careers, a lack of critical science literacy in the U.S. populace, and a shortage of qualified employees entering the U.S. economy. Much of the lack of science instruction can be traced to decreased training of teachers to teach science during elementary credentialing programs or the complete absence of said training. This qualitative study sought to understand, through multiple-case study analysis, what makes one university "successful" at teaching science methods to their pre-service teachers and what makes another "unsuccessful." Through interviews, observations, and an online document review, the author found that pre-service teachers entering the elementary school classroom need to feel they have the content knowledge necessary to teach science, feel they can overcome and work within barriers to high-quality science instruction in the K-12 system, and feel ready and prepared to teach science by their chosen Teacher Preparation Program.

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# CHAPTER 1: INTRODUCTION

Science instruction in the early years of a student's life can signal the opening of new and fascinating worlds. From an obsession with all things dinosaurs to discovering the natural world surrounding them, science in the elementary classroom is a classic example of engaging instruction. Unfortunately, this essential engagement is being systematically pushed out of elementary classrooms across the state of California and the rest of the United States as a whole. The effects of this are just now showing as the 90s babies are beginning to enter the workforce and take positions of power in government. This study sought to understand the barriers elementary teachers face in implementing high-quality science instruction in their classrooms, as well as understand the ways teacher preparation programs are preparing new teachers to start once again helping our young students capture the wonders of science. In this chapter, I will explain the background of this pressing problem, then describe the current deficiencies in the research and outline the significance of solving this issue with the utmost haste. Finally, I will outline the theoretical framework this study is based upon and give a brief overview of its methodology.

## Background

Hippocrates once said, "There are, in fact, two things, science and opinion; the former begets knowledge, the latter ignorance." (Hippocrates et al., 1983). It is a lofty statement, to be sure, but its loftiness does not detract from its truthfulness. Science is the way humans create knowledge. If the events of the COVID-19 Pandemic have taught us anything, it is the importance of a solid scientific foundation of knowledge. Lives have been lost and saved based on the populace's adherence to science, scientists' advice, and the ability to discern fact from fiction. In the United States, science is a core content for K-12 education. Still, many students are not exposed to this core content until 5th grade or later, and this is having dire consequences for their pursuit of knowledge, the upward mobility a career in science can provide, and their simple ability to understand the world events unfolding around them (Kohlhaas et al., 2010; Blank, 2013; Gerde et al., 2017).

World War II began a new era of science instruction in public education. Before this, education was not seen as a way to prepare the citizenry for the workforce or improve the economy (Bianchini et al., 2013). The entrance of the United States into the Second World War was the impetus for this to change (DeBoer, 1991). We suddenly needed a population that could help to stem the tide of fascism, later, Communism, and public education was seen to be the way to make this happen. Science and engineering were suddenly the new hot areas of schooling, at least for white male students (National Academies of Science, Engineering, and Medicine, 2019). The Space Race of the ’50s and ’60s kept up the momentum and importance of science in the classroom, feeding the growing need for qualified students entering science-related fields in University and the Armed Forces (DeBoer, 1991). Unfortunately, the heyday of science was not to continue forever, and the cultural changes taking place in the United States during the 1980s would soon signal an impending change in the educational arena as well.

Since the early 1990s, federal initiatives around increasing school accountability have changed how content is delivered at the classroom level (Judson, 2012). The testing being done around mathematics and English Language Arts (ELA) has led to the increase in instructional minutes in these areas and the decrease in minutes devoted to other content, as well as the complete elimination of other areas, specifically the arts and music (Judson, 2012; Gerde et al., 2017; Grinell & Rabin, 2017). A school climate that values literacy and mathematics over all other content has drastically decreased student exposure to science and scientific literacy during their early years in the educational system (Grinell & Rabin, 2017; Hayes & Trexler, 2016). This lack of science content instruction has led to low science engagement and a literacy epidemic, and students deciding not to pursue STEM majors in university or STEM careers post-graduation (Blank, 2013; DeJarnette, 2010; Judson, 2012). While this may seem impossible with the nationwide push over the past decade towards STEM education to equalize education and improve the U.S. economy, these good-intentioned reform efforts have yet to translate into meaningful improvements (Weiss et al., 2015). Surface level changes that do not address the heart of instruction and an exclusive focus on secondary grades have produced a mostly ineffectual reform movement, with few, if any, notable achievements to hang public education's hat on (Weiss et al., 2015).

Instructional minutes of science are also proving to be an equity issue. Students from a higher socio-economic (SES) background have more opportunities to participate in science as well as science learning at home with help from their parent(s) and other outside educational opportunities (Kohlhaas et al., 2010; Blank, 2013). This lack of informal opportunities in low SES communities and communities of color to participate in science underscores the need for increased high-quality science instruction in elementary schools.

## Description of the Problem

In the United States, elementary students receive fewer minutes of high-quality science instruction, leading to a lack of scientific literacy and engagement and a gap in pursuing occupations in scientific fields amongst adults educated in the U.S. versus other countries. The need for more high-quality instructional time for science has contributed to an ever-growing performance gap between the U.S. and much of the world. The United States has been unable to keep up with the rest of the developed world regarding K-12 educational successes. Over the past decades, the United States has been participating in the Programme for International Student Assessment (PISA), administered by the Organization for Economic Cooperation and Development (OECD) every three years; this slip in performance has come into stark relief (OECD, 2016). Among the 35 countries participating in the program, the U.S. has recently performed around average in science and reading and below average in mathematics. While other countries of the global north are seeing their performance rise in terms of educational achievement, the United States has remained stagnant (Provasnik et al., 2012). New research points to the inclusion of science literacy as a way to close this performance gap (DeJarentte, 2012; Blank, 2013).

Finland, Singapore, and Canada are international exemplars for the United States to model their science education reforms after as it tries to keep up with the performance of the rest of the world (OECD, 2016). International benchmarking tests such as PISA and TIMSS show that the United States is consistently average, even though it spends significantly more money on its educational system than other countries and has some of the best teacher education programs in the world (OECD, 2011). There are many things to be learned from these three exemplary countries in forming a plan of attack for states to begin improving their elementary science programs. Most specifically, pre-service teachers' successful education and training in these three countries should be identified and used as a model for enhancing local elementary programs. For example, future teachers in pre-service programs in Finland must take courses that emphasize both content knowledge and pedagogical content knowledge (Evagorou et al., 2015). This results in levels of reported self-efficacy in teaching science being much higher in Finland than in the United States.

In addition to the performance gap with other countries, the United States is experiencing unique problems that I argue have a direct correlation to a lack of science in our populations' K-12 careers (He et al., 2021). As an illustrative example, climate change is widely recognized worldwide as an anthropogenic issue that can only be solved through human-based solutions. However, here in the US, there is an unsettlingly large contingent of the population that does not believe humans cause climate change, and therefore, it is not necessary to make changes to the status quo (Sommerville & Hassol, 2011). Even the climate data showing the constant increase in global temperatures has been up for debate. Facts backed up by peer-reviewed numbers have historically been unimpeachable. Still, the lack of knowledge needed to interpret primary scientific data makes it all the easier to question what should be unambiguous fact. A lack of proper foundational teaching in a student's early education has led to these uniquely American deficiencies (Anyanwu, 2019).

Decreasing minutes of science instruction and a lack of scientific literacy are problems with root causes. Standardized testing, shifting priorities, and teacher preference and competence are all culprits in this educational deficit. Many elementary teachers feel unprepared to teach science, even at the foundational level (Bell & Sexton, 2012; Gerde et al., 2017). Only about 25% of elementary teachers report feeling qualified to teach science (Grinell & Rabin, 2017). In addition to feeling unqualified, teachers also report holding negative attitudes toward science, which can translate into a lack of science teaching in the classroom. These negative feelings and sense of being unprepared have resulted in many teachers losing the drive to implement effective science instruction. In addition, elementary teachers may lack foundational knowledge in science and thus feel less confident in their content knowledge. As a result, they shy away from any content they do not think they can explain (Gerde et al., 2017; DeJarnette, 2010). Research indicates that when teachers feel greater self-efficacy in science and science pedagogy, they are more likely to implement high-quality science instruction and provide students with more significant enrichment opportunities in science (Gerde et al., 2017). Research has also found a direct connection between taking science methods courses during their pre-service training and a teacher's feelings of self-efficacy in teaching science (Gunning & Mensah, 2011). As seen in the Finnish preparation programs, including pedagogical and content courses are fundamental to the confidence elementary teachers report in teaching science. Improving science knowledge and skills among students is directly connected to a teacher's ability to teach and confidence in teaching science (Menon & Sadler, 2016; Gunning & Mensah, 2011). The necessary confidence and ability to teach high-quality science can be achieved through robust science methods courses during a teacher's credentialing program.

## Purpose Statement

The purpose of this multiple-case study was to understand better the perceived barriers to implementing science methods in the multiple-subject credentialing programs studied and to develop recommendations for improving the preparation of teachers to teach science.

## Research Questions

1. What are the perceived barriers to implementing science methods in elementary teacher preparation programs at my chosen universities?
2. In what ways can teacher preparation programs better prepare elementary teachers to implement high-quality science instruction at these institutions?

## Significance

The lack of science in elementary schools in California and the rest of the United States has many consequences throughout students' school careers and into their working years. Many of these consequences can be boiled down, ultimately, to ones of educational equity. Students in Title I schools and/or lower-performing schools are much more likely to suffer from a lack of science instruction. English language learners (ELs) are also more at risk, as many schools conduct their designated English Language Development (ELD) programs during the minimal science instruction that may be occurring (California Department of Education, 2020). Even though this practice is against federal EL program guidance and can even be an illegal practice if it is deemed to be detrimental to a student achieving content mastery along with their peers (Department of Justice, 2015), many schools will still chance sacrificing the minimal amount of science students do get in favor of maximizing the time students are learning tested subjects. As stated earlier, students not exposed to high-quality science instruction at an early age are far less likely to enter STEM careers and enjoy the financial benefits that these careers can offer. This has led to STEM occupations being far whiter and much more male than the racial and gender makeups of the rest of the country. Again, this is an educational equity issue affecting the students of California and the U.S. in long-term ways, as well as the earning potential of our economy over the long term.

In addition to equity, a healthy citizenry must understand science at its most basic foundational level for society to function (Peri et al., 2015; Braund, 2021). I have already discussed the example of views on climate change in the United States, but this is by no means the only example of the destruction wrought by a lack of science literacy in the United States. Anyone who has watched the news during the outbreak of the COVID-19 pandemic has seen reports of people not understanding the difference between a virus and bacteria or the basic design and uses of vaccines. It is vital to the ending of this global pandemic that people get a vaccine, yet so many do not understand the basics of the science behind it. They are claiming a "hesitancy" or downright mistrust and fear of the vaccine that can elongate the emergency for many more months and cause the death and illness of hundreds of thousands more people (Braund, 2021). I assert that part of the reason COVID-19 is so much worse in the United States than it could have been is due to decades of failure to prepare our students with basic science understanding.

A fair bit of research has already been conducted around the importance of science as a subject to be taught in schools. Many scholarly articles have even been dedicated to the importance of teaching science in the early grades. This dissertation sought to help fill in the gaps in the research as to why teachers may not be implementing science in elementary classrooms, even with all the research saying how vital science is. Closing this gap in the research can help pre-service teacher education programs better prepare teacher candidates to engage in highly effective science teaching at all grade levels.

## Theoretical Framework

The theoretical framework this study and subsequent recommendations are based on is the Opportunity to Learn (OTL) framework first outlined by John B. Carroll in 1963. OTL is a simple concept, with Carroll defining OTL as "the amount of time allowed for learning, for example, by a school schedule or program." (Carroll, 1989). OTL is generally focused on the classroom as the unit of measurement, with instructional time and the quality of instruction as the core elements of measuring student achievement (Elliot & Bartlett, 2016). The OTL framework was further defined in 1996 by Floraline Stevens to include four common elements: content coverage, content exposure, content emphasis, and quality of instructional delivery (Stevens, 1996). It is these four common elements that helped to direct my research and the creation of the subsequent recommendations.

It seems a relatively simple concept; students learn what they are given time and opportunity to learn. However, what would appear simple is actually an integral aspect of addressing the variability in learning found in American classrooms. Prior research shows that OTL can be more important in addressing achievement than socio-economic status (SES) may be (Barnard-Brak et al., 2018) in that OTL can mediate the effects of SES (Santibanez & Fagioli, 2016). Further scholarship has shown the importance of making teachers aware of the significance of OTL in student achievement and allowing students to learn in various ways (Wang, 1998). Any teacher preparation program will need to consider OTL concepts when designing curriculum and help teachers understand the importance of giving students equal time to digest standards and concepts for the health of their future learning.

## Researcher Perspective

I come to this research with a background as a former high school science teacher and with experience as a science consultant for the California Department of Education. These experiences mean that I have a personal view of how to teach science in a K-12 setting and prior knowledge of teachers' difficulties in navigating accountability pressures while still teaching the required standards. This may also mean that I enter this process with prior opinions on why science may not be implemented currently in elementary classrooms.

## Delimitations

This study had the main goals of discovering from teacher preparation programs what, if any, science methods or preparation is being imparted to pre-service teachers and what these programs needed to increase the quantity and quality of science methods instruction. This study will not solve pressures from accountability measures that keep teachers from implementing science, nor does it claim to be able to raise test scores in other content areas due to the implementation of science in early grades. This research is meant to add to the discussion around helping elementary teachers grow their self-efficacy in science instruction and help teacher preparation programs better prepare elementary teachers to teach science from day one of the school year. Ultimately, it will still be the responsibility of district administrators to understand why science is essential to the education of their students and make the appropriate changes to their schedules as well as new teachers, seeing they can provide high-quality science instruction and why science is so important to include in their curriculum.

## Essential Definitions

**Accountability**

*District, County, or Statewide summative assessments, results are reported publicly and serve to identify the performance of a school.*

**High-Quality Science Instruction**

*An effective standards-based science curriculum that provides excellent and equitable science education for all students and provides for a deep understanding of essential science concepts.*

**In-service Teacher**

*Teachers who are currently teaching in a classroom*

**Instructional Minutes**

*Amount of time in a day and/or week that a particular content is taught in the classroom.*

**Pre-Service Teacher**

*Teachers in training*

**Professional Learning**

*Training teachers participate in during the school year, often around pedagogical methods and equitable teaching practices.*

**STEM**

*Science, Technology, Engineering, and Mathematics*.

## Summary

Science has long been a frame of reference for knowledge used to make sense of the world around us. Unfortunately, this frame of reference is not taught at the earliest levels of a student's education. As a result, fewer students report engagement with science during secondary education and are not pursuing STEM careers after college. The lack of high-quality science instruction in early elementary can be tracked to three primary sources: pressure from administrators to increase test scores in ELA and math to the exclusion of other content, a lack of content knowledge on the part of elementary teachers that leads to a lack of self-efficacy, and finally, missing training of science pedagogical practices during pre-service programs. The gap in science of instruction has become an educational equity issue as students with a lower SES often do not receive the informal science education that their peers do at home to compensate for the lack of formal education, nor do they have the same opportunity to learn science that other students may be receiving.

# CHAPTER 2: REVIEW OF THE LITERATURE

## Introduction

Recent global events such as the COVID-19 pandemic have made clear the importance of having a solid foundation of scientific knowledge; even something as small as knowing the difference between a virus and bacteria and their inherent risks can be the difference between life and death in our current times. Unfortunately, recent events have also highlighted the gaps in, and outright absence of, science education occurring in the United States K-12 education system. Beginning in elementary schools across the country, many students are getting little to no access to high-quality science instruction, and this is having serious knock-on effects on the science achievements of the population of the United States, let alone the knowledge needed for ordinary everyday life in the times of pandemics and climate change.

This literature review sought to outline the history of science education in the United States as well as the current trends in science education, define the importance of having equity in and access to high-quality science education in elementary school, and finally, show that high-quality science instruction in elementary schools is possible through outlining the performance of three international exemplars, Finland, Singapore, and Canada, and make an argument as to the reasons for these successful performances.

## History of Science Education in the United States

### Science Education Before 1980

For most of the history of public education in the United States, education has followed the same prevalent, and wrong, American axiom: if you work hard, you will learn, be successful, and be upwardly mobile. Science instruction and its approach were no exception to this rule

(National Academies of Sciences, Engineering, and Medicine, 2019). It was seen as appropriate and necessary preparation for life, with reasoning, inductivity, and having a basic understanding of scientific and technological advancement as the foundation of a prepared citizenry. However, before the 20th century, education was not seen as a method of preparing students for the workforce; no mention was made of vocational studies in the National Education Association's policies before 1918 (DeBoer, 1991). It was not until the beginning of the 20th century that education began to be seen as a social utility, a means of integrating into society, the large groups of immigrant populations arriving every day from Europe. At this time, education began to be a means for municipalities to prepare their new arrivals to enter the workforce and indoctrinate "American" culture, preparing them to be citizens of their adopted country (DeBoer, 1991). Between the 1920s and the 1950s, many discussions on the part of scientists and educational leaders took place as to the best way to educate students about science; however, the unfortunate result is that curriculum and practice remained much the same as during the 19th century.

In addition to this lack of documented change, there is not a lot known about the specific pedagogies used to teach science before the outbreak of WWII (National Academies of Sciences, Engineering, and Medicine, 2019). A gap exists in the scholarly work about how science was taught in public schools. However, this soon changed with the beginning of WWII, signaling a sea change in the importance of science and engineering in K-12 education.

**WWII Changes the Game**

World War II was the spotlight science education needed to highlight severe shortages of technical expertise in the workforce, especially on national security. In 1946, President Harry Truman declared science to be strategically important to the success of the military and the economy (National Academies of Sciences, Engineering, and Medicine, 2019). This declaration was quickly followed up with a government report from the American Association for the Advancement of Sciences (AAAS) outlining the need to emphasize not only the training of future scientists but also how essential it is to produce a populace that has a solid understanding of science (Bianchini et al., 2013). This increased emphasis from the federal government would give rise to the familiar secondary course sequences we still use today: a year of biology, a year of chemistry, and if the student shows an aptitude for their science courses, they will continue for another year or two of advanced science (DeBoer, 1991; National Academies of Sciences, Engineering, and Medicine, 2019). This model, emphasizing the structures and principles of the scientific disciplines, would continue through the 1970s, when a new emphasis on scientific literacy would come into fashion (National et al. Association, 1971).

The post-WWII years, however, would also bring into stark relief the knowledge that a significant gap was missing in the education of many American students. This period was characterized by considerable scientific, technical, and medical shortages, putting heavy pressure on educators to provide qualified candidates for these positions (DeBoer, 1991). This pressure then revealed another ugly truth hiding beneath the surface, a lack of qualified science teachers. As DeBoer put it in his 1991 book, “Salaries were unattractive, there were shortages of qualified science teachers, and there was a belief that the professional training of many teachers was substandard.” It was widely recognized that not only did the curriculum need to change, but the way teachers were trained to deliver it also needed to be revamped.

**The Space Race**

The launch of Sputnik by the Soviet Union in 1957 was another important event for the government and US students concerning science and technology.  During this time, the Soviet Union began investing heavily in science and technology. Improving education was seen as a way for the U.S. to counter these moves and bring the U.S. back up to par with its enemy (DeBoer, 1991). The National Defense Education Act (NDEA) was signed into law in 1958 as a way to increase the “mental resources and technical skills” of students, as well as increase the number of students going into STEM fields (Bianchini et al., 2013).

However, as soon as one deficiency in STEM education was identified, another soon would rear its head. Even though STEM education was acknowledged as essential to the health of the US economy and national security, all of the reforms tended to be geared toward general education students in the “mainstream” and schools with plenty of resources. Later analyses of courses from the time showed that the average high school student did not have the skills necessary to access the science curriculum due to its theoretical and abstract nature (Bianchini et al., 2013). Clearly, a more accessible science curriculum needed to be developed and implemented (DeBoer, 1991; Bianchini et al., 2013). By the early 1970s, attention had shifted from keeping pace with the Soviets to providing all students with an equitable education (DeBoer, 1991). This included science instruction, and the next 50 years of education reform would, at least on the surface, show a shift to equity-based pedagogies.

## Current Trends of Science Education in the United States

Accountability through standardized assessment has been a driving force in U.S. education for the last 60 or more years. Numerous pieces of legislation have been written to help facilitate the process of testing, as well as make it mandatory for states to implement. The most recent and notorious example is the No Child Left Behind legislation from the George W. Bush administration.

## No Child Left Behind (NCLB)

The No Child Left Behind (NCLB) Act of 2001 was signed into law by President George W. Bush on January 8, 2002, to much fanfare and expectation. It was described by lawmakers, both Republicans and Democrats, as the most ambitious and wide-reaching educational reform act in the history of the U.S. federal government (Marx & Harris, 2006). In fact, Bush described NCLB as the "cornerstone" of his presidential administration (Department of Education [ED], 2004). The text of the NCLB Act stated that the intention was to "ensure that all children have a fair, equal, and significant opportunity to obtain a high-quality education and reach, at a minimum, proficiency on challenging State academic achievement standards and state academic assessments." (No Child Left Behind [NCLB], 2002). The resulting 20 years of implementation have proved the far-reaching effects of NCLB; however, not necessarily in the ways lawmakers may have anticipated or intended.

## Description and Goals

The Bush Administration intended NCLB to be an educational game-changer for students, and the requirements they attached to it were a part of that calculation. NCLB required all students, within a decade, to perform at a "proficient" level on state-wide assessments (Simpson et al., 2004). The definition of proficiency was left up to the individual states to decide. At the heart of the law, this proficiency achievement was intended to signify the closing of the achievement gap, and all student sub-groups were required to achieve it (NCLB, 2002).

Adequate Yearly Progress, or AYP, was a central component of the accountability measures of the legislation and measured the yearly growth in a student's test scores as they moved toward or maintained proficiency on state-wide ELA and mathematics assessments. 95% of the student population at any school must take the test, again regardless of student sub-group, including special education and English learner status, for the school's AYP to be calculated (NCLB, 2002). Schools were identified as "needing improvement" if they failed to make AYP among every subgroup of students in every grade two years in a row or if they failed to meet other indicators, such as not improving graduation rates (Center on Education Policy, 2004). Schools that do not meet AYP also received considerable attention and publicity, and not the good kind teachers and administrators may have wanted to see, a marked difference from the previous educational laws.

**Effects and Consequences on Current Education**

Accountability of schools and teachers is the overarching theme running through the NCLB legislation, and the effects of this can be seen in every student's daily educational life. NCLB created substantial rewards and punishments for schools and districts based on student performance. Schools that perform well may receive financial rewards as well as public attention for their achievements (Center on Education Policy, 2004). Schools that perform poorly may receive sanctions and even risk a state takeover, not to mention the bad publicity that comes with poor performance, as noted above (Simpson et al., 2004). Unfortunately, while its stated goal was to close the achievement gap, NCLB did not consider that the contributors to the achievement gap would not magically disappear with the implementation of accountability. Students were still coming to school hungry, still living with homelessness, and still facing the many other stumbling blocks that can prevent learning and achievement, including learning difficulties and the ability to speak enough English to understand the curriculum. For these and many other reasons, the proficiency requirements of NCLB were an especially difficult hurdle for certain student subgroups, particularly special education, English language learners, and students from a low socio-economic background (Simpson et al., 2004; Marx & Harris, 2006).

Schools quickly began to narrow their curriculum to match the tested subjects and give teachers more time to cover and re-cover mathematics and ELA standards to increase performance on state testing (Berliner, 2011). The Center on Education Policy wrote in 2008 that “the shifts in instructional time toward ELA and mathematics and away from other subjects were relatively large in most school districts” and accounted for a considerable narrowing of the curriculum at the elementary level.

Significant increases in instructional minutes devoted to ELA and math resulted in significant decreases in other subjects like science. Schools that increased ELA and mathematics did so by about 43% on average; this time has to come from somewhere, and unfortunately, one of those places was science instruction (Center for Education Policy, 2004; Berliner, 2011).

Accountability has had three significant impacts on science education: (1) assessments take up instructional time that may have been used for other content area learning, (2) consume a large part of the educational budget, and (3) contribute to the loss of student interest in science and subsequent motivation to pursue STEM careers (Ness et al., 2016). The resulting strain of NCLB on teachers to focus on the high-stakes subjects of ELA and mathematics has limited the number of instructional minutes and experiences students are allowed. This has the drastic knock-on effect of decreasing student motivation and interest, which in turn reduces the likelihood that a student will pursue STEM-based college degrees and careers. This diminishes the strength of social and human capital in the U.S. (Ness et al., 2016; Marx & Harris, 2006). Alternatively, as Berliner put it in his 2011 article, “this (science) curriculum that might help ensure America’s economic competitiveness in the 21$^{st}$ century and surely will help contribute to an intelligent citizenship … has been sacrificed for the possibility of scoring a bit higher in a high stakes test.”

As teachers and schools began to examine the initial effects of NCLB implementation, they became keenly aware that elementary classrooms were becoming the canary in the coal mine for science instruction, where the current policy agenda was leaving little room for the necessary time, budget, and teacher training needed for a high-quality science experience (Marx & Harris, 2006). Science education and the standards behind it were about to enter their newest and best iteration in U.S. history. Still, the average elementary classroom was far from the place it needed to be to implement these changes.

**Next Generation Science Standards**

Understanding science, now more than ever, is necessary for everyone living on the planet. Increasingly, a working knowledge of science is required to engage in major public policy issues and make informed life decisions. Educators have always acknowledged science as an essential subject for students to learn; it is the mechanism through which students learn and understand science that has changed over the last century and a half of public education in the U.S. (National et al. [NRC], 2012). As with any other topic in education, science instruction has gone through different cycles of research into how best to teach it and what mastery of science content looks like in each grade. After 15 or more years after a revision cycle had been undergone, the federal government commissioned a change to the national science standards from which states could adapt and modify to suit their needs (NRC, 2012). These standards are called the Next Generation Science Standards (NGSS).

**Reversal of "A Mile Wide and an Inch Deep"**

Before the adoption of the NGSS in many states, state science standards were what many educators called "a mile wide and an inch deep." This was in reference to the immense breadth of topics teachers and students were expected to cover, but only superficially, almost guaranteeing a lack of student interest and understanding of the concepts. These previous standards emphasized learning discrete facts in a vacuum, much like having a pile of stones at your feet and calling it a house (California Department of Education [CDE], 2016). To use a story from my own school experience, I can still easily recite the mnemonic Mrs. Price taught us about the order of the planets in elementary school. My Very Eager Mother Just Sold Us Nine Pizzas (this was pre-Pluto expulsion, of course). While I would have gotten the multiple-choice question correct on the test, I would have been hard-pressed to explain why this was the order or do any other Earth-Moon-Sun system analyses. Even at an elementary level, students should be able to explain why things happen, not just the "what" of them, especially not just the "what" of the easily memorized parts (CDE, 2016). Pruitt (2014) states, "Historically, rigor in science has been based solely on the amount of discrete knowledge a student had to have to pass a course or grade level." Inquiry was included at some point in the course but as a separate standard and was rarely an assessed standard. The major shift has finally come with the integration of practice and context; through this integration, students can show a greater mastery of content.

**Key Instructional Shifts**

With NGSS implementation, science mastery has become about repeated opportunities for students to participate in meaningful, engaging, and successful learning experiences (Bybee, 2014; CDE, 2016). It is common in curricula in other countries successful in science instruction to see standards based on unifying ideas; NGSS has made this concept its foundation (Pruitt, 2014). Three critical instructional shifts in the NGSS make it markedly different from the previous science standards: (1) it is three-dimensional, (2) it is coherent across the curriculum, and (3) it is relevant to local communities and student interests (CDE, 2016; NRC, 2012).

### ***Three-dimensional Learning***

The three dimensions of the NGSS are intertwined to create a science learning experience for students that engenders lasting knowledge and the ability to problem-solve. In three-dimensional learning, students engage not just with the facts of science but with the methods and concepts of science (Bybee, 2014; CDE, 2016; NRC, 2012). The first of the three dimensions is the cross-cutting concepts, which cut across all science and engineering disciplines, creating connections for students between topics and through grade levels. The second dimension is the science and engineering practices (SEPs). These SEPs build on the idea that science is a set of practices, and scientists must be able to use this standard set of tools to understand and engage in science. The third and final dimension is the one teachers and students are most familiar and comfortable with, the disciplinary core idea (DCI). These DCIs are students' foundational knowledge to connect practice and concepts (Bybee, 2014; CDE, 2016).

### ***Coherence and Relevance***

Science learning must build on itself throughout the grade levels and across the curriculum. If you think about the way you learn something, it is not through memorizing a set of discrete facts; it is through making connections to what you already know and building on those connections to make them stronger or into bridges to new content (CDE, 2016; Pruitt, 2014). Relevance of the content to student lives is also essential to building knowledge (Bybee, 2014). Culturally relevant pedagogy that is high interest to students keeps them engaged and helps them to feel they are an essential part of their learning process (Penuel et al., 2015; CDE, 2016). One of the greatest assets science instruction can claim is that it touches all students in their lives every day. This relevancy can help grab a student and keep them learning for years to come. NGSS has begun the process of formally harnessing these assets.

# The Importance of Equity and Access in STEM Education

## Educational Equity

Issues of equity and access in U.S. schools have been a persistent problem since the founding of our republic (DeBoer, 1991). Granted, if we take the view that many children were barred from simply accessing an education for most of U.S. history, it may seem that the current state of the United States education system is to be emulated for its equity work. However, you do not have to scratch too deep below the surface to find this statement's inaccuracies (Coleman, 1966). During the drafting of the 1964 Civil Rights Act, a national survey on the state of equal educational opportunity was commissioned (Coleman, 1990). This was the first time that educational equity had been surveyed nationally. As a result of this survey came the Equality of Educational Opportunities Report in 1966, the findings of which did not come as news to parents and students of color. The report found that “the average minority pupil achieves less and is more affected by the quality of his school than the average white pupil…” (Coleman, 1966). There are many issues with this 1966 report when read through a contemporary lens, from terminology to narratives. However, the ultimate findings remain true of our nation’s educational system 54 years after its publication. Students of color and/or lower socio-economic status labor in a system that consistently perpetuates a lack of achievement equity. This lack of equity spans the content areas, particularly science (Curran & Kellogg, 2016).

### *Opportunity Gaps*

Research has shown that students enter Kindergarten with similar views and attitudes toward science. This changes rapidly as students of color and lower SES progress through underfunded and ill-prepared classrooms (Kolhaas et al., 2010; Curran & Kellogg, 2016). In fact, elementary achievement gaps can explain much of the science achievement gaps seen in the middle and secondary levels (Morgan et al., 2016). This documented achievement gap has lasting consequences not just on the academic achievement of students of color and students of a lower SES; it impacts their future earning potential and employment opportunities as well as their ability to participate in civic life, as they are less likely to understand public policy issues that require an understanding of science (Morgan et al., 2016; Curran, 2017).

As mentioned above, achievement gaps are not a new concept in the U.S. education system. They exist in reading levels, mathematics performance, and even physical education outcomes (Curran & Kellogg, 2016). What makes the science achievement gap so unique? Research from the National Assessment of Educational Progress (NAEP) shows that gaps in science achievement are as large or larger than mathematics and reading gaps, and these gaps are not merely a reflection of the achievement gaps in mathematics and reading foundational skills (Curran & Kellogg, 2016; Quinn & Cooc, 2015). This large gap in science achievement affects everything from a student's choice to pursue a STEM degree in higher education to their ability to make informed everyday life decisions that require scientific literacy (Tai et al., 2006; Quinn & Cooc, 2015). Current literature points to two specific causes of this early and persistent gap in achievement for students of color and students of lower SES and teacher quality.

### ***Effects of Socio-Economic Status (SES)***

Early exposure to STEM topics correlates to a higher rate of STEM degree pursuance. It is precisely this early exposure of students in higher income groups that makes them more likely to excel in the early years of science instruction, thus building a more robust science foundation for future use (Curran, 2017; Quinn & Cooc, 2015). On average, students with a higher SES have more out-of-school experiences with science, from outings to the zoo to completing science projects at home with a caregiver. Many of these experiences are before entering elementary school, meaning students from lower SES households are entering school already behind their peers (Curran, 2017; Morgan et al., 2016). This is born out in the data, as 4$^{th}$ and 8th-grade students eligible for the National School Lunch Program (NSCP) scored systematically lower than those not eligible on hands-on science assessments and interactive computer tasks (Morgan et al., 2016). These students are coming into school lacking the foundation already in place in students who can access resources outside of school; this gap is further perpetuated by the lack of science instruction occurring in elementary classrooms as well as under-prepared teachers that staff schools in lower SES areas (Morgan et al., 2016).

### ***Effects of Teacher Quality***

Teacher quality is consistently a factor in students' performance, which is never truer than for students at the losing end of the achievement gap. There already exists great rafts of research showing the importance of teacher quality on a student's performance and achievement (Goldhaber et al., 2015; Akram, 2019); indeed, this abundant research has shown that outside of non-school influences, such as home environment and SES, teacher quality is the most important factor for predicting student success (Backes et al., 2018). The impact of high-quality teachers can be measured in benchmarks such as a student's increased likelihood of attending college, earning higher salaries over their lifetime, and even a decreased chance of having children as teenagers (Chetty et al., 2014). Teacher quality is equally, if not more, important to students' achievement in STEM subjects. In their 2018 article, Backes et al. state that teachers are the "single most important factor in the K–12 education system…crucial to the strategy of preparing and inspiring students in STEM." However, the opposite can also prove disastrous for students, especially those needing the most support and encouragement.

Students on the lower end of the SES spectrum are often placed in schools with the least experienced teachers, the least number of resources, and the least amount of time for remediation in subjects not on state-wide testing regimes (Goldhaber et al., 2019). Less qualified teachers are likelier to teach in schools with a higher proportion of poor and lower-performing students than their highly qualified and experienced peers (Goldhaber et al., 2015). Unfortunately, research showing the positive impact teacher quality can have on a student's success has also shown the negative impact of an inexperienced or poor teacher. Learning conditions students at a lower SES may labor under, such as emotional stress and trauma, poor nutrition, and lack of sleep, just to name a few, are only exacerbated by poor teacher effectiveness and can have an impact on the entire academic career of a student (Reddy et al., 2020). Affecting a student's socio-economic status is out of the scope of most educational researchers, including this one; however, teacher quality can be changed with a relatively small investment in teacher training and support. A small change that research shows can have a tremendous impact over the length of a teacher's career. This dissertation will prove the relative ease with which teacher quality in science instruction can be affected at the early stages of training.

## STEM Needs of the United States

The global industrial revolution in the latter half of the 19$^{th}$ century ushered in a new era of employers needing scientific and technical expertise from their workforce. Employers have spent the last 150 years worrying over a lack of qualified employees entering the job market, which has continued to the present day (Yi & Larson, 2015; National Academies, 2007). Growth in STEM occupations has historically been followed by micro and macroeconomic growth, showing it is in the nation's best interest to keep up with this growth in demand through education of the future workforce (Peri et al., 2015). A strong science and technology sector has proven to be essential for economic prosperity nationally, as well as a way for individuals to rise into the middle class (Yi & Larson, 2015). It is crucial to the economic growth of the United States that students enter the workforce with a strong STEM background; it is also a proven way for individuals to increase their earning potential over their lifetime and increase generational wealth in a way that is achievable and sustainable (National Academies, 2011).

**Expansion of Opportunities for All**

The number of STEM occupations in the United States is set to grow by 8.9% from 2014 to 2024 (ACT, 2018), and with an average wage double that of the national average (Fayer et al., 2017), STEM jobs are an excellent way for someone in a lower SES bracket to move into the middle classes and above. Unfortunately, as these positions require above-average education levels (at least a bachelor's degree), many groups of color face higher barriers to entry when it comes to STEM jobs in the US (National Academies, 2011). In their 2011 report on the subject of an increasing gap in the STEM workforce, the National Academies of Science wrote that the US "must do much more to attract and retain underrepresented minorities, low-income students, and first-generation undergraduates who aspire to a major in STEM" as a way to increase the pool of qualified, home-grown, STEM workers.

I have already detailed above the many ways students of color and lower SES do not have access to a complete and robust K-12 education, especially in science. In fact, students of color are found to be about sixteen times less likely to be ready for credit-bearing STEM courses when they enter college than their white counterparts (ACT, 2018). Research shows it is essential that students are given a strong science foundation in elementary school and then follow that up with multiple rigorous science courses in secondary as a way to ensure their preparation for STEM degrees in university (ACT, 2018; Anderson & Kim, 2006). This may be an impossible task for students in higher poverty schools, as they are about 50% less likely even to offer the courses, like physics, necessary for students looking to enter a STEM occupation (ACT, 2018). These barriers to entry are not only influencing the student's ability to be successful in the future economy but also the health of the economy itself. Expanding the chances of a student of color being able to successfully navigate and graduate from university with a STEM degree not only improves the US economy but can also be the offramp a student needs to exit a cycle of generational poverty.

## COVID-19 as a Drastic Example

As a final example of the extreme importance of having a science-literate society, I would like to discuss the recent outbreak of COVID-19 and the responses the US population has had to it. Science literacy and its importance is not a new phenomenon; science educators worldwide have long held that facts alone cannot resist a pandemic or other natural disaster (Čavojová et al., 2020). The population must be able to use those facts to discern what is true and what is misinformation. The SARS-COV2 outbreak is merely another, albeit extreme, example of this long-held belief. In a world where more people report getting critical health information from social media than from their own doctors or official sources (Braund, 2021), we cannot rely on the journalistic or ethical morals of the sources of information to only give medically or scientifically accurate information; the population must be able to do it themselves.

Science literacy is broadly defined as a person's ability to understand the methods of science and combine that understanding with a set of scientific facts (He et al., 2021). This does not mean every person in the United States must be able to list every part of the immune system and the consequences of a cytokine storm to discern important information about COVID-19. It simply means that people can broadly understand how scientists and doctors determine how the

SARS-COV2 virus attacks certain cells in the immune system and what this means for their ability to resist the virus (Braund, 2021), as just an example. However, most public health officials would probably settle for most citizens knowing that antibiotics cannot treat a virus, which about a third of the US population actually believes (He et al., 2021). The critical time that could have been saved in preventing sickness and death from this pandemic if scientists and government officials did not have to explain that vaccines do not cause autism; please do not drink bleach because not only will it not kill the virus it may kill you instead, or even disputing that COVID-19 is no worse than the common flu could have been the difference between 500,000 lives lost and less than half that number (Čavojová et al., 2020; Braund, 2021). Starting the process of teaching science literacy as early as possible in a student's learning has become a literal life-and-death proposition.

## The "Possibility" of Science Instruction in the Early Grades

### International Exemplars

In the years following World War II, the United States was uniquely positioned to be the sole developed country with the remaining resources to expand its education system (OECD, 2011). Inevitably, the U.S. became a world leader in educational attainment. Perhaps the U.S. felt that this would always be the case or had a negative view of the potential of the rest of the world. Still, whatever the reason, many other countries soon surpassed it, and the US has fallen into a category best described as fair to middling (OECD, 2016). Three of the countries that have passed the U.S. in educational excellence are Finland, Singapore, and Canada.  All three of these will be discussed below.

**Finland**

Finland is about the size of Montana and boasts a population of just over 5.5 million people. In recent decades, Finland has been a beacon for technology startups and telecommunications companies (National Conference of State Legislatures, 2015). The education reform that Finland has undergone recently is similar to its societal transformation from an agrarian society to a knowledge-based society (Sahlberg, 2007). The consistently high performance of Finland's educational system has majorly contributed to Finland's reputation as an up-and-comer on the international stage. Finnish students have ranked in the top tier of countries over the past decade on the PISA test and the Trends in International Mathematics and Science Study (TIMSS) (OECD, 2016 & Provasnik et al., 2012). No other country participating in either program has had so slight a variation in their performance across all levels of society, regardless of language acquisition, immigrant status, and socio-economic status. (OECD, 2011). Table 1 below shows the mean scores that Finland students achieved between 2006 and 2015 concerning the OECD average scores.

**Table 1**

*PISA scores Finland versus OECD Averages 2006 - 2015*

| **Finland** | **PISA 2006** | **PISA 2009** | **PISA 2012** | **PISA 2015** |
|---|---|---|---|---|
| | Mean Scores | Mean Scores | Mean Scores | Mean Scores |
| Reading | 547 | 536 | 524 | 526 |
| Mathematics | 548 | 541 | 519 | 511 |
| Science | 563 | 554 | 545 | 531 |
| **OECD Average** | **PISA 2006** | **PISA 2009** | **PISA 2012** | **PISA 2015** |
| | Mean Scores | Mean Scores | Mean Scores | Mean Scores |

(Table 1 Continued)

| | | | | |
|---|---|---|---|---|
| Reading | 492 | 493 | 496 | 493 |
| Mathematics | 498 | 496 | 494 | 490 |
| Science | 500 | 501 | 501 | 493 |

This data, in comparison to the United States in Table 2, shows that the consistently high performance of Finnish students has outpaced the mediocre performance of U.S. students.

**Table 2**

*PISA scores United States versus OECD Averages 2009 - 2015*

| **United States** | **PISA 2006** | **PISA 2009** | **PISA 2012** | **PISA 2015** |
|---|---|---|---|---|
| | Mean Scores | Mean Scores | Mean Scores | Mean Scores |
| Reading | | 500 | 498 | 497 |
| Mathematics | 474 | 487 | 481 | 470 |
| Science | 489 | 502 | 497 | 496 |
| **OECD Average** | **PISA 2006** | **PISA 2009** | **PISA 2012** | **PISA 2015** |
| | Mean Scores | Mean Scores | Mean Scores | Mean Scores |
| Reading | 492 | 493 | 496 | 493 |
| Mathematics | 498 | 496 | 494 | 490 |
| Science | 500 | 501 | 501 | 493 |

To get an idea of the differences between the United States education system and the system in Finland, it is worth pointing out some small but critical differences in the structure and function of the two systems. In Finland, students begin primary school at age 7; however, the government highly subsidizes daycare, and 97% of students attend preschool at age 5 (National Conference of State Legislatures, 2015). There are very few mandatory standardized tests in

Finland, and where there are tests given, they are to determine a student's readiness for higher education. (OECD, 2011 & National Conference of State Legislatures, 2015). In Finland, a teacher usually stays with a student for five years, and the average class size is 20 students. This difference, in particular, comes into stark relief when compared with the increasingly large class sizes in the United States (National Conference of State Legislatures, 2015). The schools in Finland are small and well-equipped and are considered more of a caring community than an educational institution (Sahlberg, 2007). Finland provides "full-service" schools that offer daily hot meals, health and dental services, counseling and other mental health services for students and the whole family (OECD, 2011). None of these services are means-tested. These services reflect Finland's society and representative government's deep commitment to the well-being of families and children.

***All Standards, All Students, All the Time.***

Dovetailing with the national standard for welfare and equality amongst its citizens, Finland's education system has dedicated itself to equality amongst its students. This drive toward equality characterizes the Finnish system's history of learning and curricular goals (Pietarinen et al., 2017). Equality in education is prized in and of itself. Still, it is also recognized that in a small country like Finland, getting everyone educated and thus integrating into society is essential. All children are expected to achieve at high levels, including students with lower socio-economic status (SES), students with varied immigration statuses, or those with a differing home language (OECD, 2011).

Students with disabilities and mental health issues are also given much more care and thought due to the policies that have been implemented in Finland. All assessment of student learning grade-to-grade and within the school year is based on teacher-made tests rather than standardized external tests (Sahlberg, 2007). In fact, in the most recent PISA assessment student survey, only 7% of Finnish students reported feeling anxious when working on mathematics tests compared with 52% and 53% in Japan and France, respectively (OECD, 2016). Local control over assessment has also allowed for more mainstreaming of students with disabilities. In fact, after grade 5, numerical grades have been prohibited by law (Sahlberg, 2007). In the place of grades, students receive descriptive assessments and feedback. This relieves the pressure on students with disabilities and other learning barriers to compete with general education students.

Pasi Sahlberg (2007) has described the recent influx of immigrant populations into Finland and the unique ways the Finnish education system has adapted to the changes equitably. He writes, "Although ethnicity in Finland…is not as diverse and apparent as it is in some other European nations, migration trends since the early 1990s indicate that Finland is rapidly transforming into a multicultural society". The Ministry of Education and Culture in Finland has made a concerted effort to ensure that students with an immigrant background, either themselves or their parents, are seamlessly integrated into the general student population. (Ministry of Education and Culture, 2016) While socio-economic status and numbers of immigrant students vary from school to school, there is slight variation in student performance from school to school (OECD, 2016). This is reflected in the 2015 PISA data. Not only do Finnish students in lower SES tiers do better than all countries except for Macao, the difference between the disadvantaged and advantaged is also relatively small when compared to the rest of the OECD countries (OECD, 2016). This slight variation reflects the importance placed on all students achieving the same performance standards expected from students who attend schools from higher SES areas.

***Pre-Service and In-Service Teachers.***

The teaching profession in Finland enjoys a relatively high status and comes with a lot of local autonomy and trust (Kansanen, 2003 & OECD, 2011). Professionalized teaching is a hallmark of high-performing countries, meaning teachers are accorded the same status as other highly regarded professions. To achieve this, governments often do four things well: they attract the top performing graduates to become teachers, they develop these teachers into effective instructors through professional learning, incentives and support systems for teachers are put in place, and finally, systems are adopted that implement new and innovative approaches to staffing classrooms and schools (OECD, 2011). Finland has used all four of these hallmarks in their country's teacher education policies. Finland's teaching profession carries a high prestige professional autonomy at the local level and feeds into the national ethos of providing a service to society (Sahlberg, 2011).

The teaching profession is highly popular among high school graduates in Finland, making the competition to enter university as teacher candidates extremely tight. Only around 15% of the applicants are accepted at the eight universities that offer teacher education programs (Kansanen, 2003). However, once students are accepted into the program, the Finnish government provides all their tuition and associated fees (Sahlberg, 2011). All teachers, whether teaching primary or secondary students, must earn a Master's degree, which takes an average of four to five years to complete (Kansanen, 2003 & Sahlberg, 2011). In addition to theory and pedagogy coursework, pre-service teachers must complete practical classroom training. Rasmussen and Bayer (2014) especially draw attention to specialized "training schools" that Finland uses as part of their teacher education program to give pre-service teachers the practical training they need before entering the classroom. These skills include the application of the educational and learning theory they learned, as well as differentiation and classroom management techniques. This "practice teaching" is begun as soon as possible to familiarize pre-service teachers with all aspects of the classroom and student interactions (Kansanen, 2003).

Finland has made teaching one of the most highly sought-after professions for young Finns. This allows them to be very selective, raises the bar for entry, and gives teachers higher autonomy once they enter the classroom (OECD, 2011). Pasi Sahlberg (2011) writes that "instead of test-based accountability, the Finnish system relies on the expertise and professional accountability of teachers who are knowledgeable and committed." This professional accountability rather than accountability through standardized testing allows Finnish teachers more autonomy and freedom than teachers in the United States. This freedom has translated into higher rates of stable success throughout Finland (OECD, 2011 & Sahlberg, 2011 & Kansanen, 2003).

**Singapore**

Since its independence in 1965, Singapore has undergone many societal and, by extension, educational changes. In its early days, Singapore was a small, tropical island riven by poverty and recurring ethnic conflict. Today, it is a shining beacon of globalization and is known as one of the most successful of the "Asian Tigers" (OECD, 2011 & Shu-Shing et al., 2013). Singapore is a free-market, business-friendly economy and, much like Finland, very knowledge-based (OECD, 2011). Singapore's government is highly centralized and prides itself on being merit-based and bureaucratic. The overall impression of the Singaporean education system is one of a highly professionalized teaching staff and an increasing amount of peer-led school-based initiatives (Tan & Dimmock, 2014). It is characterized by a rapid increase in performance on international tests like PISA and TIMSS. Table 3 compares Singapore's test scores to the OECD average. The data needs no explanation as the scores clearly show a dominant performance compared to the international average, particularly in math and science.

**Table 3**

*PISA scores Singapore versus OECD Averages 2009 - 2015*

| **Singapore** | **PISA 2009*** | **PISA 2012** | **PISA 2015** |
|---|---|---|---|
| | Mean Scores | Mean Scores | Mean Scores |
| Reading | 526 | 542 | 535 |
| Mathematics | 562 | 573 | 564 |
| Science | 542 | 551 | 556 |
| **OECD Average** | **PISA 2009** | **PISA 2012** | **PISA 2015** |
| | Mean Scores | Mean Scores | Mean Scores |
| Reading | 493 | 496 | 493 |
| Mathematics | 496 | 494 | 490 |
| Science | 501 | 501 | 493 |

**Moving towards equity and access for all students**

When it comes to education, being a small island has worked to Singapore's benefit. Singapore's education system is more like that of a large city rather than an entire country (OECD, 2011). With around 522,000 students in 360 schools, if a change needs to be made to the curriculum or other structures, it can be made relatively quickly. The director of the National Institute of Education (NIE) has compared this to "turning around a kayak rather than a battleship" (OECD, 2011). The small size of the country has also meant that educational policy has been under the control of one party, meaning that policymaking is extraordinarily consistent and coherent (Tan & Dimmock, 2014).

The policy coherence has led to a clear trajectory and path toward closing the achievement gap amongst all Singaporean students, both socially and educationally (OECD, 2011). Underpinning the entire education system is the idea that Singaporean students of all ethnic backgrounds, of which there are many, and all ranges of ability can and should meet standards and expectations. While this goal is clear, test scores have yet to prove that this goal has been accomplished. For example, the lowest percentile of students has fallen dramatically behind the rest of the student groups in Singapore (Shu-Shing et al., 2013). To address this issue, teacher education programs have begun developing skills among pre-service teachers to help close the achievement gap among these low-performing students.

**Pre-Service and In-Service Teachers**

As it was in the Finnish system, teaching is a highly sought-after occupation in Singapore (OECD, 2011). Prospective candidates are chosen from the top one-third of graduating secondary students. In Singapore, teacher education is centralized and offered only through one university, the National Institute of Education (NIE) (Rasmussen & Bayer, 2014). There is a strong focus on pedagogical content at the university level and pre-service teachers are given a mentor teacher who is currently in the classroom (OECD, 2011). There are no divisions between the different departments of the NIE, meaning all teachers get instruction in all the different content areas to better prepare teachers for the classroom.

The central government maintains teacher employment and governance policies. However, a recent policy, labeled “decentralized centralism,” has been implemented where the government retains substantial control while giving schools and teachers greater autonomy (Tan & Dimmock, 2014). The government has recognized that teachers are professionals and should be allowed to design curricula and lessons according to their interests (Koh et al., 2014). In service of this recognition, teachers are given up to 100 hours of professional development per year, much of which is school-based and led by staff developers (OECD, 2011). To determine if teachers are utilizing their professional learning properly, teacher performance is assessed annually by a group of administrators based on 16 competencies. Teachers who do well on their performance assessment receive bonus pay. The annual assessment is also used as a recruiting tool for leadership positions. After three years of teaching, teachers are eligible for leadership positions and are identified and mentored into this path if deemed suitable.

According to the Organization for Economic Cooperation and Development (2011), Singapore could be the “poster child” for education development. More than any other country assessed with the PISA or TIMSS, Singapore has pursued a path of advancing by systematically benchmarking the world’s performance and creating a world-class education system based on the learning garnered from said benchmarking. (OECD, 2011). After 60 years of independence, the Singaporean powerhouse has transformed every aspect of its society, including the education system.

**Canada**

Canada is often plagued by its comparisons to its neighbor to the south, the U.S. It has also been overlooked due to this comparison.  That is until PISA results made it clear that Canada consistently performed successfully on its tests, with strong average scores with little variation between performance among its high and low-socio-economic status students (OECD, 2011). Canada has a highly decentralized federal system characterized by a need for more communication across the provinces, with no federal office or department of education to monitor or guide the provinces (Walker and Von Bergmann, 2013 & OECD, 2011). Instead, The system is divided into ten provinces and three territories responsible for 15,000 public schools

(Dunleavy, 2007). Education is compulsory, generally beginning at age six and continuing until age 16. Canada is a bilingual country, with both French and English classified as official languages. Canada also has a strong welfare program, which has affected the stability of student home life, increasing students' ability to focus on school (OECD, 2011). This long history of national welfare has led to a strong belief that the educational welfare of all children is a collective responsibility of all Canadian citizens. PISA results show that Canadian students are, on average, one school year ahead of students in the U.S. It also shows that Canadians are at a much lower risk of poor educational outcomes than their American counterparts. Table 4 compares Canadian PISA data with the overall average of OECD countries.

**Table 4**

*PISA scores Canada versus OECD Averages 2006 - 2015*

| **Canada** | **PISA 2006** | **PISA 2009** | **PISA 2012** | **PISA 2015** |
|---|---|---|---|---|
| | Mean Scores | Mean Scores | Mean Scores | Mean Scores |
| Reading | 527 | 524 | 523 | 527 |
| Mathematics | 527 | 527 | 519 | 518 |
| Science | 534 | 529 | 525 | 528 |
| **OECD Average** | **PISA 2006** | **PISA 2009** | **PISA 2012** | **PISA 2015** |
| | Mean Scores | Mean Scores | Mean Scores | Mean Scores |
| Reading | 492 | 493 | 496 | 493 |
| Mathematics | 498 | 496 | 494 | 490 |
| Science | 500 | 501 | 501 | 493 |

**Pre-service and In-service Teachers**

Teaching has historically been a respected profession in Canada and, like the other countries discussed above, draws pre-service teacher candidates from the top third of secondary school graduates (OECD, 2011). Having said that, over the last 60 years, teacher education in Canada has undergone radical changes (Walker & Von Bergmann, 2013). Beginning in the 1990s, Canadian teacher education institutions saw their autonomy undermined while “choice” and “competition” pervaded the school system. This has affected the ways the 13 universities that offer pre-service teacher education have developed their programs (Rasmussen & Bayer, 2014). The universities are trying to claw back some of their autonomy and pushing for a “normalization” of the education programs across the provinces.

Until the early 2000s, each province had its own credentialing rules and policies. This began to change in 2006 when teachers could apply for an interprovincial license, meaning teachers could move between provinces without going through another licensing program (Walker & Von Bergmann, 2013). However, as more and more teachers are beginning to move interprovincially, they are encountering three different approaches to teaching depending on their province. Some provinces see teachers as a political group, meaning teachers are public servants. Some see them as an institution, meaning they are considered a public intellectual. The last category teachers can be found in is labeled as professional, seeing teachers as skilled practitioners. These different lenses affect the autonomy the province allows the individual teachers in their classrooms (OECD, 2011 & Walker and Von Bergmann, 2013).

Canada is the only international exemplar that does not have a coherent national educational strategy (OECD, 2011). However, Canada's success on the PISA tests is across all provinces and is not isolated to just one area. The best explanation for this phenomenon is that the provinces tend to bleed into one another and that teacher education programs may be more standardized in their training than was once thought. There is much room here for further development. Even with these inconsistencies, Canada is ripe for the picking in terms of the U.S. using it as a model for educational reforms.

## The Opportunity to Learn Theoretical Framework

### Carrol's Original Framework

The theoretical framework this study and subsequent recommendations are based on is the Opportunity to Learn (OTL) framework first outlined by John B. Carroll in 1963. OTL is a simple concept, with Carroll defining OTL as "the amount of time allowed for quality learning, for example, by a school schedule or program." (Carroll, 1989). OTL is generally focused on the classroom as the unit of measurement, with instructional time and the quality of instruction as the core elements of measuring student achievement (Elliot & Bartlett, 2016). Carroll was careful to define "time" as not simply the amount of time a teacher spent on a specific content area but the amount of time a student needed to learn the task (Carroll, 1963). Elapsed time alone was not enough to guarantee a student would learn; "the time spent on the act of learning…and engaged in learning" is the metric by which to judge whether there is a sufficiency of time allowed for all students to be successful in their learning (Carroll, 1963).

#### *Original Model Components*

When Carroll first published his OTL model in 1963, he included five essential components for student success. The first three were on an individual level, and the last two were based on the learning environment (Carroll, 1963). The first tranche of components to the model are aptitude, the ability to understand instruction, and, finally, perseverance. Aptitude, in the case of this model, is defined as the "amount of time needed to learn the task under optimal instructional conditions (Carroll, 1963). Carroll is the first to point out, however, that optimal instructional conditions rarely, if ever, exist in the real world of the classroom, necessitating the inclusion of the two other components of his individual model. A student's ability to understand the instruction is included because it significantly impacts the time a student needs to learn the content; less ability to understand a concept obliges more time, and vice versa. Perseverance in learning is a concept many educators are familiar with. Carroll defined it for his model as the amount of time a student is willing to spend engaging with a learning activity. These three components are then enhanced by two external conditions that must be considered.

The most quantifiable component of Carroll's model is opportunity, or the time allowed for a student to learn. Carroll admitted in his initial model that many were surprised that schools might not allow adequate time to understand a concept. However, it is prevalent, especially in underserved schools, for a teacher to be forced to move on to the next topic regardless of whether most of their students have successfully learned the taught concept (Carroll, 1963; Carroll, 1989). The final external component in the OTL model is teacher quality. Carroll called teacher quality the most "elusive quantity" of his model. He described it as the ability of the teacher to present the material so that it will not require additional time for instruction for student mastery (Carroll, 1963), but readily acceded that it is challenging to measure.

**Building on the Original**

The OTL framework was further defined in 1996 by Floraline Stevens to include four common elements: content coverage, content exposure, content emphasis, and quality of instructional delivery (Stevens, 1996). These four common elements will help direct my research and the creation of the model program for pre-service elementary teachers.  It seems a relatively simple concept; students learn what they are given time and opportunity to learn. However, what would appear simple is actually an integral aspect of addressing the variability in learning found in American classrooms. Prior research shows that OTL can be more important in addressing achievement than socio-economic status (SES) may be (Barnard-Brak et al., 2018) in that OTL can mediate the effects of SES (Santibanez & Fagioli, 2016). Further scholarship has shown the importance of making teachers aware of the significance of OTL in student achievement and allowing students to learn in various ways (Wang, 1998). Any teacher preparation program will need to consider OTL concepts when designing curriculum and help teachers understand the importance of giving students equal time to digest standards and concepts for the health of their future learning and for the sake of content mastery.

## Conclusion

Achievement or opportunity gaps are a persistent problem in the United States education system, especially when it comes to science learning. Outcomes such as diminished earning potential, loss of employment opportunities, and even a loss of civic engagement in issues and policies requiring scientific literacy can be followed back to earlier student achievement gaps in science. Two primary causes of the gaps in learning between white students and students of color are socioeconomic status and a lack of highly qualified and prepared teachers with a broad science content knowledge. This study cannot solve the issue of child poverty and its accompanying contributions to the opportunity gap. However, it can contribute to the closing of the gap caused by a need for more prepared teachers ready to engage in science teaching at every grade level.

Finland, Singapore, and Canada are international exemplars for the United States to model their education reforms after as it tries to keep up with the performance of the rest of the world. International benchmarking tests such as PISA and TIMSS show that the United States is consistently average, even though it spends significantly more money on its educational system than other countries and has some of the best teacher education programs in the world (OECD, 2011). There are many avenues for future research as to what went wrong in the past with the U.S. system. However, moving forward, these three example countries should be used as templates and inspiration for designing a new U.S. education system. Most specifically, the U.S. should identify the successful education and training of pre-service and in-service teachers in these three countries and use them as a model for improvement.

# CHAPTER 3: METHODOLOGY

## Introduction

Science instruction in the early years of a student's life can signal the opening of new and fascinating worlds. From an obsession with all things dinosaurs to discovering the natural world surrounding them, science in the elementary classroom is the classic example of engaging instruction. Unfortunately, this essential engagement is being systematically pushed out of elementary classrooms across the state of California and the rest of the United States as a whole. The effects of which are just now beginning to show as the 90s babies are beginning to enter the workforce and take positions of power in government. The lack of science instruction in elementary schools has also become a significant equity issue, as students of color and lower socio-economic status (SES) have been the most impacted. This study sought to understand the barriers elementary teachers face in implementing high-quality science instruction in their classrooms and the ways teacher preparation programs are preparing new teachers to start once again helping our young students capture the wonders of science.

### Focus of the Study

In the United States, elementary students are receiving fewer minutes of high-quality science instruction, leading to a lack of scientific literacy and engagement in students and, ultimately, a gap in the pursuit of occupations in scientific fields amongst adults educated in the U.S. versus other countries, further widening of the income inequality gap. This study aims to make recommendations at the university level that will better prepare elementary teachers to implement high-quality science instruction in their classrooms.

**Research Questions**

1. What are the barriers to implementation of science methods in elementary teacher preparation programs?
2. In what ways can teacher preparations programs better prepare elementary teachers to implement high-quality science instruction?

**Chapter Road Map**

This methodology chapter will adhere to the following order. I will first discuss the qualitative research method approach and its appropriateness for my study. Next will be a description of my participants, followed by my data collection and analysis plans. I will then outline my methodology and the methods that I used in solving my problem of practice. Next, I will explain my perspective as a researcher in the reliability and trustworthiness section. The final parts of the chapter will cover the limitations of the study.

## Inquiry Approach

This study took a qualitative research approach to collecting data. The following section will explain the appropriateness of qualitative research in discovering the solution to my problem of ineffective or missing science instruction in elementary classrooms.

**Appropriateness**

The first aim of my study was to confirm the barriers to implementing high-quality instruction of science methods in the teacher preparation programs I am working with. Multiple case-study analysis is appropriate for this study because it is the pathway to discovering the meaning behind decisions made and the resulting outcomes of those decisions (Yin, 2018). I wanted to discover why some teacher education programs are teaching science methods and some are not and the tools needed by these programs to increase the teaching of science methods to better serve the students of California. By using the multiple case-study approach, I was able to illuminate what works and what does not for those programs under study, as well as develop recommendations for how to move forward (Yin, 2018). This multiple case-study analysis consisted of interviews and observations as data collection methods as these are not only the most common methods of data collection in a case study framework, but they also allowed me as a researcher to dig deep into the decision-making processes of the group as well as its results (Hancock & Algozzine, 2017).

## Methodology

### Context

This inquiry occurred virtually, with interviews and classroom observations taking place over Zoom due to the continuing COVID-19 Pandemic. The specific classrooms I observed were decided once initial selections were made as to which university programs were to participate and which courses offer multiple subject methods, specifically science, if possible. My research benefited the participants in the study by highlighting their best practices and providing a window into their areas for improvement. Teacher education programs can use my recommendations to improve their courses and overall programs, making it easier for new teachers to implement high-quality science instruction in their classrooms.

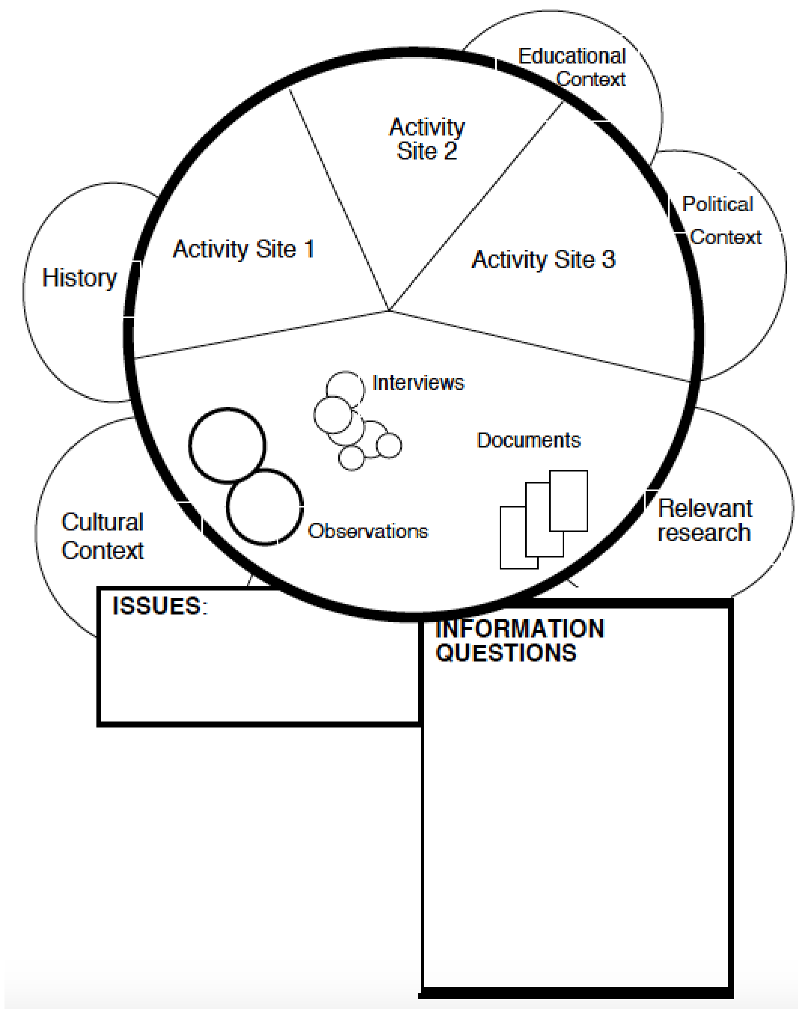
### Design Structure

The design of this study followed the outline provided by Robert Stake in his book Multiple Case Study Analysis (2005). In his book, Stake delineates between the single cases being studied and the overall picture that analyzing these cases as a whole will allow the researcher to see (Stake, 2005). Stake calls this overall picture a “quintain” and describes this quintain as “an object or phenomenon or condition to be studied – a target but not a bull’s eye.”

(Stake, 2005, p. 6). For the purposes of my research, the quintain was the preparation of new teachers as they prepare to teach science in an elementary classroom setting. I used the traditional single case study methods of interviews, observations, and document review for two pre-selected teacher education programs. I put that data into the Stake quintain model to better understand examples of how teachers are being prepared to teach science in elementary classrooms. In his book, Stake uses a visual model to better explain the quintain and how data will be organized and analyzed to create this understanding of the condition being studied.

**Figure 1**

Robert Stake's "Quintain"




This visual allowed me, as the researcher, to organize the data from the single cases into a coherent conclusion and draw recommendations from this conclusion that will enhance teacher education programs' abilities to prepare teachers to teach science in the elementary classroom.

**Goals and Aims for the Study**

This study aimed to develop recommendations for pre-service multiple-subject programs that will help prepare participants to be effective teachers of science in the classroom. Before this, however, interviews and observations were conducted to fully diagnose the problem of practice as current practitioners at the programs I am studying truly see it. Recent literature points to the reasons for my problem of practice: declining effective science instruction in elementary classrooms. Nevertheless, it was essential to be sure that these proposed theories were the causes of the problem at my study sites. The recommendations for the pre-service program I created can only be fully effective if I could discover the actual reasons for the decline in science instruction, at least at the universities I am studying.

**Role of the Researcher**

It is important to state at the outset of this section that I have particular biases as a researcher regarding high-quality science in the classroom. I began my career in education as a secondary science teacher, and I am firmly in the camp of educators and administrators who believe science is an integral and essential part of K-12 education and beyond. I also have opinions about what makes for a high-quality science program and how to educate new teachers about teaching science. I bring over a decade of experience as a science instructor to this research.

Most qualitative researchers take on a constructivist view of their data collection and analysis (Stake, 1995). Stake writes that no person comes into a phenomenon devoid of their own experiences, nor can they divorce their own lived reality entirely from the facts they are studying (Stake, 1995). Essentially, as a researcher, I bring in my reality as a former science teacher, and now as a state-wide leader in science curriculum and instruction, to the research, and I used those experiences to make sense of the reality that I was observing and hearing in interviews to make conclusions about the cases that I was studying. I used this constructivist epistemology to make sense of the data I collected and check any conclusions I came to as a researcher that were not supported by the data I collected.

## Participants

Deciding on the participants for my study was the first important step in finding the answers to my research questions. To accomplish this goal, I decided first to investigate the publicly available information from the California State University (CSU) system of schools and the University of California (UC) system of schools with teacher preparation programs to determine what, if any, science methods instruction was occurring. I examined the course descriptions of each CSU and UC's required teacher preparation courses, their recruiting materials, and other publicly available information on the school’s website. From this information, I assigned the school a score of 1-5, 1 being no mention or description of science methods in their multiple subject preparation courses or their recruitment materials, and 5 being a robust course, or courses, on teaching science methods as well as a focus on science in their recruitment materials and on their website. From here, I selected a school from the top third of scores and a school from the bottom third of scores as a focus for my multiple case study analysis. This method of choosing participants allowed me to discover the best practices of the schools that are teaching science methods as well as the needs they may have to improve their program and compare it to a school that is not teaching science methods as well as their results and what they state they need to begin teaching science methods. Ultimately, I wanted to know what makes a “successful” school successful and what makes another school “unsuccessful” at preparing their future teachers for a science classroom.

# Methods

## Interviews

The purpose of an interview in educational research is to understand the lived experiences of the subject (Seidman, 2019). I wanted to discover barriers to implementation these select university programs face in providing their participants with high-quality science methods instruction. I also wanted to understand how these barriers may impact the pre-service teachers in the program and their feelings of readiness to teach science in their classrooms. Interviews are the portal through which I could understand the lived experiences of these groups because, ultimately, these same groups will implement the changes needed to ensure students receive a high-quality science education.

## Data Collection

I interviewed three groups for this study: program administrators at the university, professors teaching in the program, and pre-service teachers in the program to earn their teaching credential. I chose these three groups to better understand their barriers to implementing science methods instruction and the resulting experiences of the participating teachers who will need to teach science in their classrooms. I chose two program administrators currently overseeing the multiple subject credentialing programs at their university. I did these interviews via Zoom in deference to the current pandemic and for ease of scheduling for the subjects. I also interviewed two professors currently teaching multiple subject methods at the university, one of which was presently teaching elementary science methods. I also conducted these interviews over Zoom for the same reasons as above. The final group I interviewed was pre-service teachers currently in the multiple-subject credentialing program. I chose two pre-service teachers to interview. These interviews were done over Zoom.

## Observations

The Coronavirus pandemic has changed many things in education, including how doctoral students conduct research. I am not immune to these changes either, unfortunately. In-person observations are a key part of collecting data for a multiple-case study analysis (Stake, 2005). This is especially true when doing classroom observations; some of the most important aspects of classroom dynamics must be observed in person. I had planned to conduct up to two sets of observations, one virtually and one in person. However, due to the timing of my observations, I could only conduct observations via an online platform.

## Data Collection

I conducted observations of classroom teaching virtually for both universities researched. One set of observations was conducted during the teaching of multiple subject methods, particularly science methods, at the university level. I conducted two observations of the multiple-subject courses over the course of a week. While an in-person observation is always better, it was only possible to perform these observations virtually. The second set of observations that I had planned to conduct were to be done in person. This was because I planned to conduct up to three observations of pre-service teachers teaching science in their elementary classrooms. As previously mentioned, it is essential to conduct K-12 observations in person to see how the students interact with the teaching and learning and how the teacher conducts the non-verbal parts of their classroom. As it was impossible to do this second set of observations in person, I did not include them in my study.

# Data

## Data Analysis

Data analysis in a multiple case study is about finding patterns (Stake, 1995). Patterns in what your interview subjects tell you, in what you observe, and in the documents you review. Stake describes the search for meaning in a case study as "a search for patterns, a search for consistency, consistency within certain conditions…" (Stake, 1995, p. 78). He even had a particular name for these patterns: correspondence. The search for this correspondence was at the heart of my data analysis plan.

I first created written transcripts of all the interviews I conducted and began to code for themes from these transcripts. I then looked for correspondence of these themes through the data software NVIVO, which allowed me to more efficiently find apparent patterns and discover more complicated patterns that I may not have seen on my own. This software also helped with interview transcription. I also went through my observation data and coded for themes. I then used the same process with the NVIVO software to find correspondence in the data.

The overall timeline for data analysis began when I started my participant selection process, as this was when I did the document review. In the table below is my timeline for data collection.

**Table 5**

*Timeline for Data Analysis*

| Timeline | Action |
|---|---|
| 1 week | Conduct document review of online information to select participants |
| 1 week | Reach out to selected participants and set up interviews and observations |
| 4 weeks | Conduct interviews and observations |
| 2 weeks | Transcribe interviews and analyze data with NVIVO to identify themes. |

## Reliability

Reliability is critical when conducting qualitative research (Stake, 1995). At the heart of ensuring trustworthiness in qualitative research is carefully conceptualizing the study's design and the plan for conducting and analyzing data (Merriam & Tisdell, 2016). I ensured the reliability of my study through a few methods. First, the interviewees were all asked the same questions for the interviews. This meant that the answers I got from the participants could be themed, and I could feel confident that the themes could be applied to the larger context of all elementary classrooms. I also created an observation protocol that I used in all the observations I conducted as part of the study. Again, this meant I could apply a larger context to the collected data and ensure I was paying attention to the same issues in all observation settings. While case study research is only sometimes generalizable, I hope that by creating as reliable a protocol as possible, I can show how my conclusions can apply to other cases and settings.

## Ethical Considerations

I limited any ethical issues that could arise during my study by ensuring the design reduces or eliminates any potential openings for an ethical issue. All universities chosen had no direct connection to me, nor could it be construed that participation in the study could have any impact on the participants' jobs. The universities that participated were anonymous and referred to only by a code, as were the human participants I interviewed and observed. My study's results did not impact my participants' occupational status, nor will my findings be released to support or denigrate any person or university. During my observations, I did not interact with any of the students to not impact the teaching and learning happening at the moment. I also did not interact with any participants under the age of 18, nor did I ask for any data covered by educational privacy laws and thus subjected to an extra level of security.

## Limitations

There are a few limitations to the study. I cannot require that teachers follow my recommendations with fidelity or that they even implement them at all. I also cannot force administrators to allow elementary teachers the time in their daily schedules to do science every day. Administrators often have a lot of say in what contents are taught and at what time in the instructional day they are taught. If they do not allow the teachers instructional discretion, then I could create the best program available, and it would not matter much if teachers cannot take that knowledge and use it in their classrooms.

## Summary

This study aimed to determine what makes one university successful in teaching science methods to pre-service teachers and what makes another university unsuccessful. To do that, I conducted a multiple case study analysis between two different universities. These universities were chosen through an online document review of publicly available information. Interviews were then conducted with program administrators, professors teaching in the program, and students within the program getting their teaching credentials. I also conducted classroom observations within the university. I used Robert Stake's concept of the "quintain" to complete this data collection. Data analysis was done using the software NVIVO to discover themes and to ensure the validity of these themes. Ultimately, I used these thematic findings to create a set of recommendations for universities on how to improve their preparation of multiple subject teachers to teach high-quality science in their classrooms.

# CHAPTER. 4: FINDINGS

## Preparation is the Key

In this chapter, I will describe the findings from my document review, classroom observations, and interviews. The purpose of this multi-case study was to understand better the perceived barriers to implementing science methods in the multiple-subject credentialing programs studied and to develop recommendations for improving the preparation of teachers to teach science. The data collected has been analyzed using the following research questions as guidance:

1. What are the perceived barriers to implementation of science methods in elementary teacher preparation programs at my chosen universities?
2. In what ways can teacher preparation programs better prepare elementary teachers to implement high-quality science instruction at these institutions?

Data was collected using traditional case study methodology through an initial document review to aid in selecting participants, classroom observations, and a series of interviews.

### Document Review for Selection of Participants

An initial document review was conducted as an avenue of selection for which two universities should be selected as participants in this study. The online course catalogs and program webpages from all 23 California State Universities and all 10 Universities of California were studied initially to understand how these universities' respective teacher preparation programs were organizing their programs. Programmatic web pages were reviewed to understand how programs were structured and better understand the sequence of courses students were required to complete. Next, a review of the university course catalogs was conducted to understand better what students were learning and the goals of each science methods course. Below is a table representing the categories of analysis and the final scores for each institution in the document review.

**Table 6**

*Results of University Document Review*

| SCHOOL NAME | HAS COURSE | MENTIONS NGSS | MENTIONS CURRICULUM | MENTIONS LESSON PLANNING | MENTIONS ACTIVE LEARNING | PAIRED WITH OTHER CONTENT | SCORE |
|---|---|---|---|---|---|---|---|
| Cal Poly Pomona | ✓ | | ✓ | ✓ | | ✓ | 3.5 |
| Cal Poly San Luis Obispo | ✓ | | ✓ | | ✓ | | 3 |
| Cal State East Bay | ✓ | ✓ | ✓ | ✓ | ✓ | | 5 |
| Cal State Fullerton | ✓ | | ✓ | | ✓ | | 3 |
| Cal State LA | ✓ | | | | | | 1 |
| Cal State Long Beach | ✓ | ✓ | | | | | 2 |
| Cal State San Bernardino | ✓ | ✓ | ✓ | | | ✓ | 2.5 |
| Chico State | ✓ | ✓ | ✓ | ✓ | | | 4 |
| CSU Bakersfield | ✓ | | ✓ | ✓ | ✓ | | 4 |
| CSU Channel Islands | ✓ | | | | | ✓ | 1 |
| CSU Dominguez Hills | ✓ | | ✓ | ✓ | ✓ | | 4 |
| CSU Monterey Bay | ✓ | ✓ | ✓ | ✓ | ✓ | | 5 |
| CSU San Marcos | ✓ | | ✓ | ✓ | ✓ | | 4 |
| CSUN | ✓ | ✓ | ✓ | ✓ | ✓ | | 5 |

(Table 6 Continued)

| SCHOOL NAME | HAS COURSE | MENTIONS NGSS | MENTIONS CURRICULUM | MENTIONS LESSON PLANNING | MENTIONS ACTIVE LEARNING | PAIRED WITH OTHER CONTENT | SCORE |
|---|---|---|---|---|---|---|---|
| Fresno State | ✓ | | | | | | 1 |
| Humboldt State | ✓ | | ✓ | ✓ | | ✓ | 4 |
| Sac State | ✓ | | | | ✓ | | 2 |
| San Diego State | ✓ | | ✓ | | | | 2 |
| San Francisco State | ✓ | ✓ | ✓ | ✓ | ✓ | | 5 |
| San Jose State | ✓ | | ✓ | | | | 1.5 |
| Sonoma State | ✓ | ✓ | | ✓ | | ✓ | 3.5 |
| Stanislaus State | ✓ | | ✓ | ✓ | | ✓ | 3.5 |
| UC Berkeley | ✓ | ✓ | | | | | 2 |
| UC Davis | ✓ | | | | | | 1 |
| UC Irvine | ✓ | ✓ | ✓ | | | | 3 |
| UC Merced | ✓ | | | | | | 1 |
| UC Riverside | ✓ | | ✓ | | | ✓ | 2.5 |
| UC San Diego | ✓ | | | | | | 1 |
| UC Santa Barbara | | | | | | | 0 |
| UC Santa Cruz | ✓ | | ✓ | ✓ | | | 3 |
| UCLA | | | | | | | 0 |

Schools were first ranked by whether they had a science methods course in their course catalog designed explicitly for their multiple-subject credential programs. If they did have a course, the course description was analyzed for noteworthy mentions of NGSS, curriculum development, lesson planning, active learning of some form, and whether they had paired science instruction with other content areas. These areas were chosen as integral parts of a course as they are the current expectations for instruction in the CA Standards for the Teaching Profession. Universities were given a score based on the presence of these descriptors. As you can see in the table above, the scores ranged from a maximum of 5 to a minimum of 0. A university was chosen from the group of 4 universities that scored a five, and one was selected from the five universities that scored a one or a 0.

The selection of the two universities participating in this multi-case study was an integral part of the process. A university was chosen from one of the top scorers of the document review as a suspected example of good preparation for future teachers. Alternately, a university was chosen from the bottom tier of scorers as a suspected example of a program with room to grow in preparing elementary teachers to teach science. The intention of this selection process was to get a range of experiences from the interview subjects.

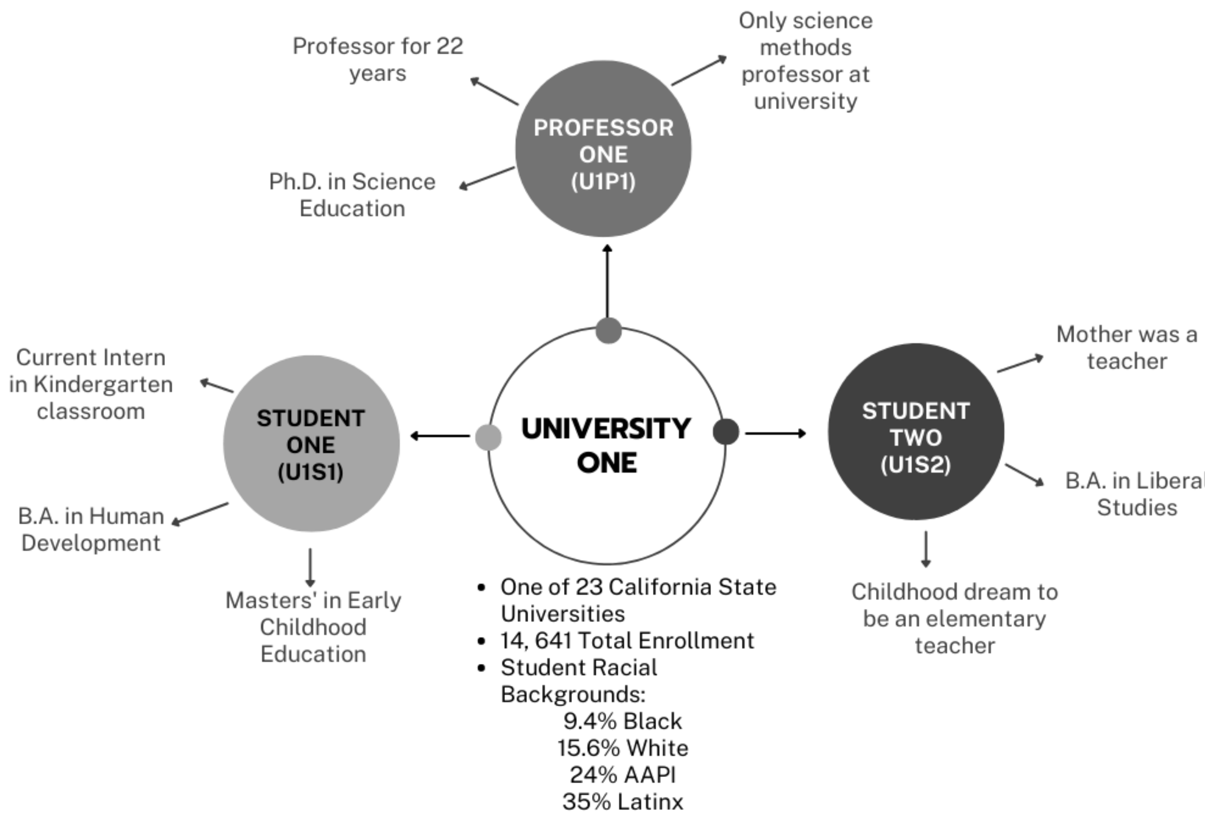
## Research Question One

What are the perceived barriers to implementation of science methods in elementary teacher preparation programs at my chosen universities?

**University One**

**Figure 2**

*University One Characteristics*




As seen in the graphic above, University 1 is one of the 23 Cal State Universities with a total enrollment of just over 14,600, encompassing both undergraduate and graduate programs. The school is quite diverse, with the largest population of students identifying as Latinx. Two students were interviewed; one was a traditional TPP student preparing to be the teacher of record in a classroom the following year, and one was already the teacher of record as a district intern. These two students were satisfied overall with their experience with their program.

Student U1S2 said about the program, "…the science mathematics was fabulous. I am so glad that I had that…". However, this does not mean the students report feeling prepared to teach science in their classrooms. As I began to ask questions about the levels of readiness felt by the students to implement science instruction in their classes, it soon became apparent that while the students were happy with their programs, that did not necessarily translate into readiness.

### ***Classroom Observations***

The COVID-19 Pandemic disrupted most aspects of daily life throughout its duration and may continue to do so. Education was not spared from its effects. Originally, classroom observations were meant to be done in person as this is the best way to observe instruction and student reactions. However, with the restrictions on in-person gatherings, observations were forced into a virtual format. There was still a lot to be learned from observing instruction. Both universities had a large cohort of students. University 1 had a classroom of 32 students, and University 2 had 35 students. At the time of my observations, students had been going through virtual classes for about a year already. As a result, most of the students were already familiar with the different aspects of the software and how to navigate through their class sessions.

During my observations at University 1, I saw many engagement techniques and teaching techniques students could transfer to their classrooms. The professor welcomed every student as they joined the Zoom room and projected an agenda of what they would be working on that day at the start of class. A pre-test was administered at the beginning of the 2-hour class, and a discussion was held about the prior classes' activities. These things were followed up with a classroom investigation that the students completed as a task and then discussed how they could use it in their classrooms. The last third of the class time was spent discussing articles the class was asked to read for homework; the topics included science-focused read-along books and an article on Science and Engineering Practices (SEPs)

***Interviews***

The third prong of my data collection relied on interviews with university students, professors, and leadership of the TPP programs. I was able to interview two students from both universities and at least one program professor from each university. At University Two, I was able to interview a second professor who was also the department chair for the multiple-subject credential program. These interviews were very insightful as to how each university ran its programs regarding science content, as well as the program's efficacy as experienced by the students.

The first central theme to emerge during my research was that students feel they need more confidence in their science content knowledge, leading them to overlook or pass over science instruction.  It was clear that science needed to be added to their list regarding actual classroom instruction.

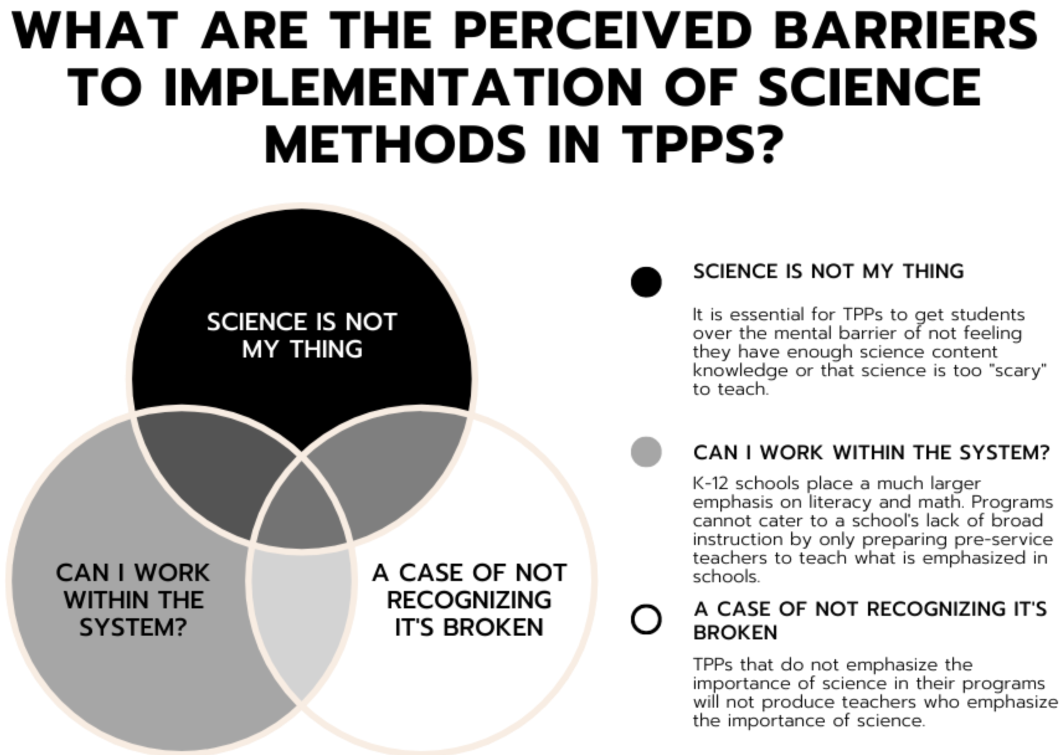
*"So, it's having that classroom management that you're trying to get through. So that has been a true struggle. And then now everyone's talking about testing, etc. It's report card time. I'm still finishing the assessments that I have to do for my kids that are one on one, but it's hard to do that when there's eight million kids in your class and it's loud." – U1S1.*

While some of this frustration is the nature of being a first-year teacher or a pre-service teacher, it cannot all be explained away with this answer regarding science instruction. Both students reported feeling less knowledgeable about science content, making them less confident in their teaching.  U1S1 said, "…the places where I know I struggle, or it's like been 800 years since I've learned that, that's where it's harder." In addition to this personal feeling of falling short, the schools the students were assigned to did not provide them much time to implement what they learned in their classrooms. Interviewee U1S2 said about her student teaching assignment, "From eight to nine, they have their science for an hour, for one day a week. That's all they get." These themes were consistent for the two students at University One and University Two. The common themes in relation to the first research question of this study were three-fold.

As shown in the figure below, the feelings of the students and professors could be summed up in three themes, “science is not my thing,” can I work within the system, and a “case of not recognizing it is broken”.

**Figure 3**

*Research Question One Findings Venn Diagram*




The second theme that emerged early in my research was the difficulty of working within an established K-12 system that clearly emphasized literacy and math with little to no time for science instruction. The student teachers reported coming up against many barriers to implementing what they had learned in their science method courses. U1S1 reported, “It's not given as much emphasis as we're supposed to be implementing as much as we can, but it's like less time is given to science as we pore over the ELA and the math and testing and et cetera, et cetera.”. The professor at university one was also aware of these institutional barriers experienced by her students. She acknowledged that students could have a hard time finding space to practice what they were learning in her course, saying, “I think they're still working with some cooperating teachers or in their school where they're just like, here's our curriculum and we don't veer out of this.". Students are tasked with not only learning how to teach science but also how to navigate the entrenched attitudes and schedules at their student teaching placements.

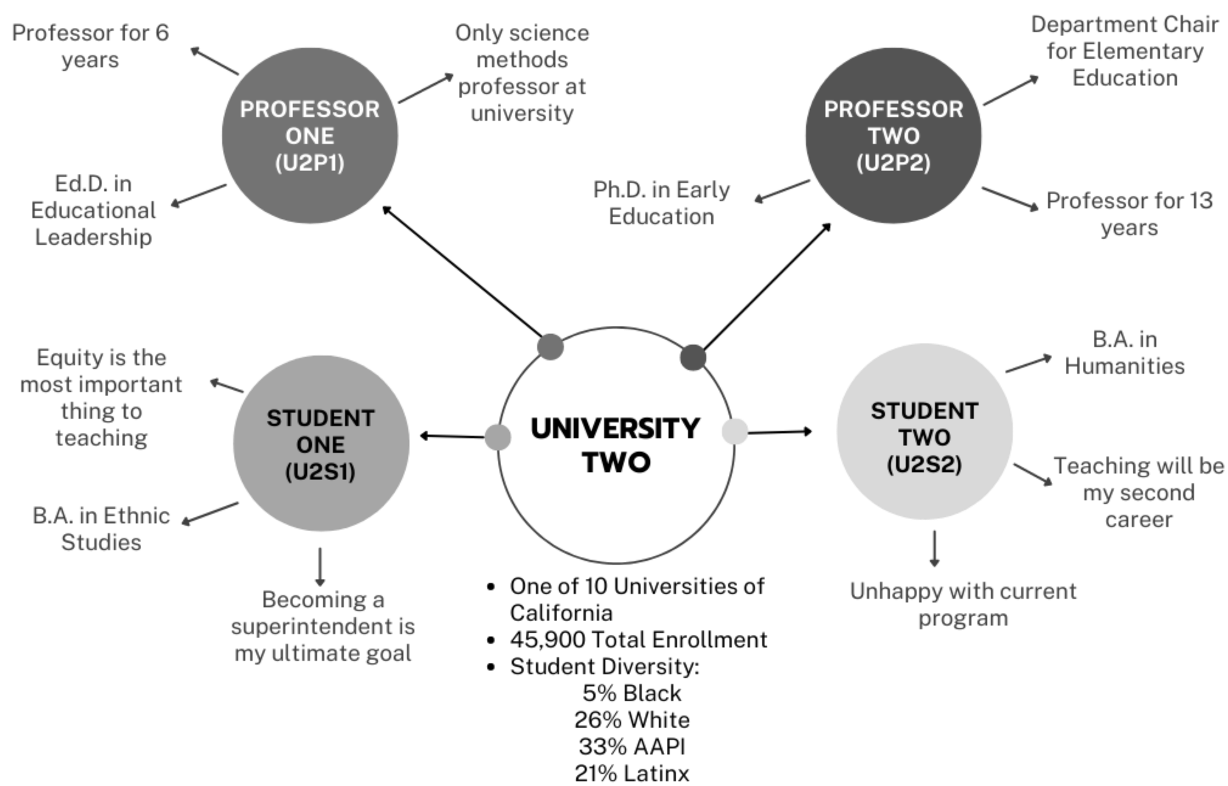
The third central theme to present was the importance of the university's role in imparting the importance of science instruction to their students. This theme became most evident when I compared the interviews from both participating universities, noticing not just the professors' approach to teaching science methods but also the students' attitudes to science instruction in the classroom. For example, students in university one's program shared that science was important for the students, especially at an early age. They noted its high interest for students and that this interest can be transferred to other subjects, with student U1S2 stating the following:

*"I feel like it's very important to teach it because you hit those kids that might not be good at English or writing, but then they, like, they come to life when they have to, like, write about what they're looking at with, you know, and how the trees change. And it's like, Oh my gosh, she can't write an essay, but you can write on how you look at a picture, and you're looking at several pictures and how they've changed over time and why."*

**University Two**

**Figure 4**

*University Two Characteristics*




University Two was one of the 10 Universities of California with a large total enrollment, encompassing both its undergraduate and graduate programs. The students at University Two had more unmet expectations for their preparation program, with U2S2 being the most disappointed in the preparation he was receiving. The professor charged with teaching elementary science methods came from a strong science background but with secondary science. Their field experience with elementary science was little to none. The chair of the multiple-subject department had experience teaching science in their elementary classroom but admitted their experience with science even then needed to be more emphasized.

### *Observations*

Observations at University Two were also conducted virtually but were quite different from those at University One. The class started similarly with welcomes and an overview of the agenda. The remaining 90-minute class was conducted in a traditional lecture style, with students listening to the professor discuss many topics around learning styles for early learners. Science was mentioned as one of the topics with high interest, but no specifics were given as to how to leverage that interest into any deeper science learning for students. Most of the discussion was on how to improve literacy among students. Engagement is challenging to gauge in an online platform; however, the amount of student participation is not. The number of times students were asked to participate in University One far outweighed the times during the class for University Two and the number of questions asked was also much lower at University Two.

### *Interviews*

The three themes previously identified for University One were also present at University Two. Not only did students report feeling less prepared to teach science content due to their lack of science knowledge, but they also reported difficulties getting time to practice and implement in their student teaching placements. The only difference between the two universities regarding research question #1 emerged at the third theme. While students at University One reported being told multiple times how important it is to make science instruction a priority, students at University Two reported that if not a de-emphasizing of science, definitely less importance being placed on it.

**Themes 1 & 2**

In much the same vein as University One, students at University Two had profound doubts about their science content knowledge, which transferred to their willingness to teach science in the classroom. U2S1 discussed feeling like it just had been too long since he had any science instruction and did not feel prepared, “things like that (physical science) when it gets to the stuff where you're talking about motion and everything like that. I was not strong in physics.”. The students reported significant reluctance to implement science instruction in their teaching placements due to feeling like they do not have a strong enough foundation in science to teach it to their students, even at the lower elementary level. This theme of unpreparedness and inadequacy in science content knowledge was the most robust theme to emerge from both universities.

The second theme of difficulty navigating the K-12 education system and the schools where they have been placed also emerged as an eerily similar issue for students at University Two. The students reported, “You know, they're (the school where they are placed) is used to just like, let's do some worksheets on Friday. We'll call that science.” as well as professor U2P2 describing the difficulty of knowing how much guidance to give their students in terms of science because, “who at the district level do we share with to make sure that, you know, we're not stepping on toes as far as like PD or if you have a science director in a district.”. The presence of these two similar themes between student and professor experience at both universities was easy to identify. The third theme, however, presented itself as more of a contrast between the two rather than a similarity.

**Theme 3**

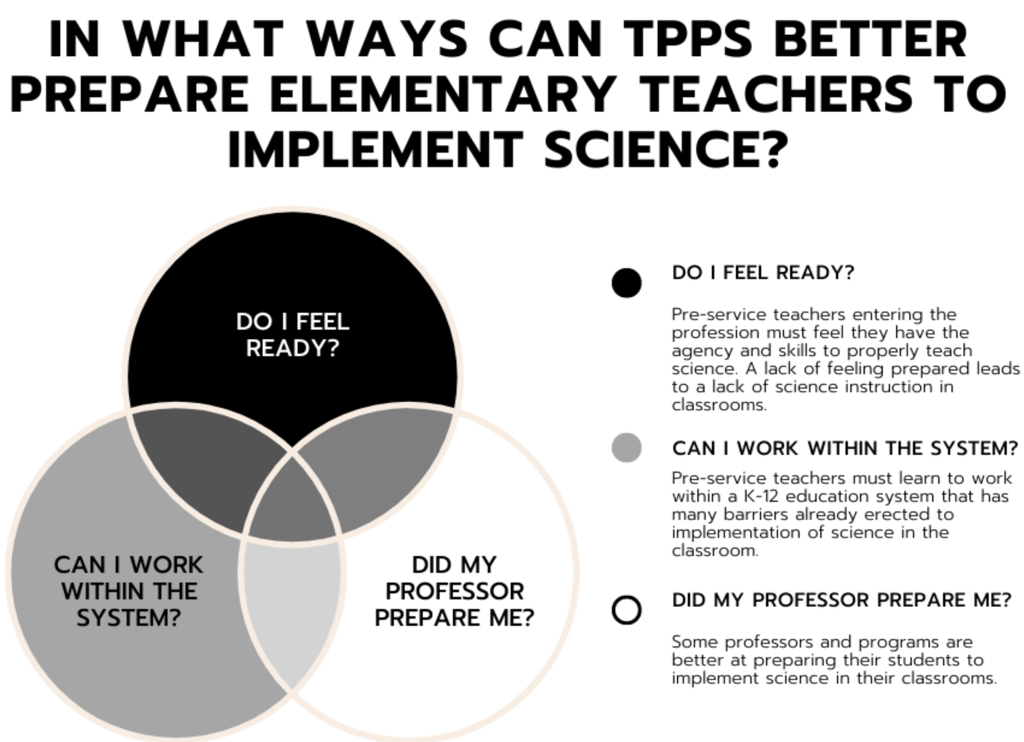
The two students I interviewed used much of their time to vent about issues they felt they were having with their TPP. In this venting, I could see the third theme of my research emerge where students and professors said that of course all content areas were equally important, but the reality on the ground at university two did not show this. I identified the professors, even the science methods professor, as being the primary reason for the differences in student experience at both universities regarding science. Professor U2P1 told me, “It has just been felt in the past that a science specific methods course isn't needed at the elementary teacher level.” This surprised me, especially since it was said so openly. Another surprising line of thought to emerge for this theme came from U2P2, with her saying, “We don't have a professor with elementary science experience. But it is not that difficult to translate secondary experience into elementary standards”.  I felt this was also quite a bold statement for someone whose expertise was not in science methods and, if I may, an incorrect statement. Students in University Two’s program either consciously or subconsciously picked up on this lack of expressed importance in science, and their answers reflected their professors’ attitudes during the interview. It cannot be overemphasized that this line of thinking can have disastrous and long-term effects not only on the teaching and learning of pre-service teachers but also on the educational trajectory of students throughout California. This theme also led perfectly to investigating answers to my second research question.

**Research Question Two**

In what ways can teacher preparation programs better prepare elementary teachers to implement high-quality science instruction at these institutions?

**Figure 5**

*Research Question Two Findings Venn Diagram*




The above diagram shows the themes that emerged from research question two. The themes are similar to those seen in research question one, a significant difference being that the institution can directly address these issues to better prepare students to teach science. I have presented these themes in the form of questions that students should be able to answer in the affirmative at the end of their program: Do I feel ready? Can I work within the system, and Did my professors prepare me?

**University One**

As I have already discussed in the findings from the previous research question, students must feel comfortable with the science content itself before they feel prepared to teach it in their classrooms. Both students from university one reported feeling more confident about the science itself after taking their science methods course. The professor not only modeled how to teach science, but she also modeled for the students how to go about re-learning the science content that they may have yet to interact with since they were in K-12 themselves. Student U1S1 reported feeling that, “For me, I'll be looking at something ahead of time before I go and talk to the kids because I want to be ready for the questions that they have. Because for me, it's like, Dude, I'm learning this with you.”. This was a strategy directly taught by the professor as a way to familiarize themselves with content they were not familiar with. Along these same lines, students were taught coherently and concisely how to find the information they needed to refresh themselves on the science content. Student U1S2, for example, said, “I would say that I wasn't like, Oh my gosh, I can be a science teacher. But I kind of had the basic knowledge of like, Hey, here are some resources” and “the professors that, like, I've gained the most knowledge from and like, take away from because it's very... it's like the guided practice. It's like she's showing me how to teach, which makes me feel comfortable in then teaching it.” The skill of the professor(s) in preparing the students to not only teach science but also to be comfortable teaching something when they don’t feel they know the content is essential to enabling teachers to feel ready to teach science.

This feeling of readiness leads into the theme of feeling prepared by the program to enter an elementary classroom equipped to teach science. At university one, while content areas are not equally emphasized, a concerted effort is made to promote science's importance and appropriately prepare students. As their science methods course was ending, I could ask my interviewees about their feelings of preparedness for teaching science. Student U1S1 stated, "I'm feeling more confident in being able to navigate NGSS just as a whole and how to implement that into my future classroom." She was still nervous about teaching science, I think just nervous in general about having her own classroom, but felt she had been given the skills she needed to feel ready to teach the science content and the science methods information needed to know how to teach the content. This starkly contrasted the approach to science at University Two and the students' reported feelings about readiness and preparedness.

The last theme I would like to discuss for research question two is the strength of the program in showing their students how to navigate through the complicated system that is K-12 education and being a new teacher. As discussed in Chapter 2, there are quite a few barriers to implementing high-quality science instruction in elementary classrooms. A good TPP needs to give the students tools to pull out of their toolbox when these barriers need to be scaled. Professor U1P1 discussed the amount of sheer stress the students have overall when they are put in the field for the first time and how a lot of them are just trying to survive and keep their heads above water, let alone implement high-quality lesson plans. The students also reported feeling this stress from the schools and the students they were placed with.

A good program, which I believe university one to be, will work to prepare students for the sheer mayhem that teaching can be, how to overcome this, and still implement high-quality science instruction. Even at university one student U1S1 told me, "I feel very overwhelmed.

Honestly, just getting through the day without a major mistake is a win for me. I want to have good lessons, but I think that may have to come later." This predictable stress must also be navigated in an environment where it is most likely more manageable for a new teacher to omit science instruction altogether in favor of the more emphasized literacy and math. Students must be shown how important it is for science to be taught in their classrooms', faithfully and with high quality, even when they may find it easier just to put it aside.

**University Two**

I was surprised by the differences in program experiences reported by students and professors from University Two compared to University One. Whereas students at University One reported feeling prepared to teach science and were enrolled in at least one science methods course, students at University Two did not even have the benefit of a specific class devoted to science during their training. Student U2S1 reported, "the professors have not focused on science. I have no idea how to read the standards and when I brought it up in class, I was told to ask my mentor teacher." Not only was this surprising for me to hear, it speaks to the program's lack of emphasis on science and contributes to the students potentially having to answer every question in my themes diagram in the negative.

In addressing the two related themes of feeling ready and being prepared by faculty to teach science, it became clear during interviews that not only was preparation and readiness not happening, it wasn't seen as a priority for science. During an interview with Professor U2P1, it was explained to me that "It has just been felt in the past that a science specific methods course isn't needed at the elementary teacher level." As a former science teacher who has worked with science standards and methods, I know this to be a statement that pushes the boundaries of reality. In seeming defiance of this statement made by the professor, student U2S1 stated, "I really don't understand why we don't have a science methods class. I definitely could have used it." This was a repeating refrain during my interviews: the professors having one take on the importance of science and including it in the course work of their program, followed by the students having an almost diametric opinion or experience. All of this dissonance between faculty and students has led to a failure in the last thematic question from my research.

Students overwhelmingly reported being unable to navigate the school system and the classrooms they were teaching in when implementing science instruction. One of the topics brought up by the faculty I interviewed was that University Two is a research institution, and their program's goal is to impart pedagogy and educational theory; the practicality of day-to-day teaching is something they will learn from actually doing the act of teaching. It wasn't something students could learn from their program, and it needed to be learned by doing. For example, professor U2P2 told me, "The students have to be able to learn things on the fly. I mean, we give them some tools, but teaching is more like an apprenticeship than it is something you can learn in a lecture." This isn't necessarily an incorrect sentiment; teaching is something you get better at with practice, much like medicine. However, it would become clear from my research that it is possible to teach theory while also doing better at preparing students for the realities of teaching. A good program can teach its students about learning theory and pedagogy while at the same time helping them understand how to ensure high-quality science instruction is an integral part of their daily lessons.

## Conclusion

Going into my data collection, I must admit that I was unprepared for the enormous gulf of student experience between my two chosen universities. Anyone who has spent time with new teachers or been one themselves can predict their overwhelming feelings of exhaustion and inadequacy. What I hadn't predicted was just how much a teaching preparation program could impact one particular content area and the likelihood it would get taught in the classroom of their graduates. Throughout my research, it became clear that high-quality science instruction and its implementation in the classroom depends mightily on the preparation done by their teaching programs. Students must feel that they are prepared to teach the content by their program, ready and qualified to teach the content, and they must be able to navigate the setbacks and barriers that may be in place when they enter the school's world. In the next chapter, I will outline some suggestions for how TPPs can better prepare students to teach science now that I have discovered how important they can be.

# CHAPTER 5 – DISCUSSION

## There Are Better Ways to Do This

The purpose of this multi-case study was to develop a greater understanding of the perceived barriers to the implementation of science methods in the multiple-subject credentialing programs studied and to develop recommendations for improving their preparation of teachers to teach science. This chapter includes a discussion of significant findings as related to the literature on current trends in education in the U.S., the importance of access and equity in STEM education, the growing needs of the U.S. in terms of the STEM workforce, and what implications may be valuable for universities and other teacher preparation programs as they continue to prepare the next generations of elementary teachers. Also included is a discussion on the connections to the Opportunities to Learn theoretical framework. This chapter concludes with the study's limitations, further opportunities for research, and a summary.

This chapter includes discussion and future research opportunities to help answer this study's research questions:

1. What are the perceived barriers to implementation of science methods in elementary teacher preparation programs at my chosen universities?
2. In what ways can teacher preparation programs better prepare elementary teachers to implement high-quality science instruction at these institutions?

During my research, three major themes presented themselves for each of my research questions, with significant overlap between the six, with one in particular being present for both research questions. For new elementary teachers to enter the classroom feeling ready to teach high-quality science, they must (a) feel they have the underlying content knowledge necessary to teach science, (b) understand how to work within a K-12 system that may not emphasize the importance of high-quality science instruction (this was a theme present for both research questions), (c) understand themselves the importance of science instruction in the early grades, (d) feel their TPP professors prepared them to teach high-quality science, and finally (e) feel prepared to teach science when they are all alone in the classroom for the first time. Some of these themes resulted from TPPs following current trends in K-12 education, while others were personal biases on the part of professors and students. The bottom line from my research is that pre-service teachers will not feel ready to teach science in their classrooms unless they are fully prepared to do so by their TPP.

## Summary of Findings

While their feelings about readiness to teach in general varied for everyone, the five common themes found in this study were prominent for each of the pre-service teachers interviewed for this study. Students were heavily influenced by the emphasis placed on science instruction by their TPPs and the amount of time dedicated to teaching elementary science methods. Each theme is described in detail in the following section.

### Confidence in Science Content Knowledge

A high percentage of the teachers interviewed for this study self-reported feelings of inadequacy with their science content knowledge, even at the elementary level. This could be a function of the fact that this new generation of pre-service teachers were K-12 learners themselves during the onset of NCLB legislation, which drastically reduced the amount of exposure students had with science content in their classrooms (Center for Education Policy, 2004; Berliner 2011). It could be a function of a lack of interaction with the content as they progressed through their educational careers, or simply a function of their lack of interest in science, thus resulting in a lack of knowledge. Whatever the reason for the lack in confidence in their own science content knowledge, it was a large factor in students reporting their feelings of readiness to teach science.

**Understanding and Overcoming Barriers to Science Instruction Within the K-12 System**

A theme that emerged for both research questions in this study was the students' ability to navigate over and through the barriers to implementation of high-quality science instruction within the K-12 system. One of the hard lessons for new teachers to learn is that they must figure out how to fit in to the existing structures at the school or district they enter. This may mean a resistance to science instruction, as it is seen as taking away from the instructional minutes for mathematics and ELA (Berliner, 2011). Students reported feeling frustration, and ultimately resignation, when coming up against these barriers when it came to their plans for science instruction. Accountability, and the response to it, has already narrowed the curriculum for most elementary students, particularly those in typically underrepresented subgroups (Simpson et al, 2004; Marx & Harris, 2006). It is up to TPPs to better prepare pre-service teachers to overcome these barriers before they enter the classroom.

This theme of narrowing the curriculum as a K-12 systemic issue, is the reason for this study's theoretical framework Opportunity to Learn (OTL), originally proposed by John B. Carroll in 1963. OTL is a simple concept, with Carroll defining OTL as "the amount of time allowed for quality learning, for example by a school schedule or program." (Carroll, 1989). A major tenet of OTL involves teachers and their attitudes towards certain subjects as well as the importance of making teachers aware of the importance of OTL in student achievement and giving students the opportunity to learn in various ways (Wang, 1998). For meaningful learning and achievement in science and other STEM subjects, teachers must be able to work around barriers of opportunities for students to learn science that have been erected by the schools and districts they will soon be employed at. Development of the skills necessary for working within the K-12 system has to begin at the university level in their preparation programs.

**Knowing the Importance of High-Quality Science Instruction in the Early Grades**

Of the two universities that participated in this study, one stood head and shoulders above the other in communicating to its students the importance of high-quality science instruction at all grade levels. As a result, these students self-reported feeling that making science a part of their core curriculum was essential. The other research group reported science as an important subject, but something that could wait until later elementary or even middle school. The research done on science instruction adamantly supports the first group's attitudes. For learning to be "sticky" for students, it must build on prior knowledge and create connections to other things they know. As a result, much of the science achievement gaps seen at the middle and secondary levels can be explained by elementary achievement gaps (Morgan et al, 2016). These achievement gaps are really opportunity gaps, a consequence of teachers not understanding the importance of high-quality science instruction at every grade level and as a result not providing the students the opportunity to regularly interact with science content.

**Elementary Science Methods Preparation in the TPP**

Much in the same vein as the previous theme, preparing the students to teach elementary science was a tale of two halves for the universities studied. One of the programs had a stand-alone science elementary methods course, dedicated solely to teaching their students how to teach science. The other program did a cursory overview of science methods in a larger course designed to discuss all non-math and ELA content areas. As my research bore out during the interviews, this cursory overview was not enough to give pre-service teachers the knowledge of NGSS and the teaching of inquiry that would allow them to implement in their classrooms with any sort of quality or quantity. Teachers did not feel they had the knowledge necessary, leading to a distinct lack of confidence in their abilities. Pre-service teachers in the other program, while certainly weren't overflowing with confidence, felt they had the knowledge and skills necessary to attempt to teach as well as the ability to get better with practice.

### Confidence and Readiness to Teach Science

All of the previous themes discussed have led into the final theme discovered during my research. If pre-service teachers are not given the skills necessary to implement science, they simply won't. And this doesn't only mean having a science methods course, it means knowing how to navigate the school system as well as feeling comfortable with their knowledge of the science content itself. The key to high quality science instruction is about repeated opportunities for students to participate in meaningful, engaging, and successful learning experiences (Bybee, 2014; CDE, 2016). Without these repeated opportunities, students at the elementary level will not develop the science knowledge and skills necessary to be successful in science in their later grades. This Opportunity to Learn is meant to address the variability of learning amongst students. Prior research also shows OTL can be more important in addressing achievement than socio-economic status (SES) may be (Barnard-Brak et al, 2018) in that OTL can mediate the effects of SES (Santibanez & Fagioli, 2016). The implications of a teacher that does not feel confident and ready to implement science can have serious and lasting effects on their students for their entire lives, not just during their school careers.

## Implications for Practice

The central finding of this study, that teachers need to feel prepared and ready to implement high-quality science instruction or they simply won't, is not something that couldn't have been guessed or imagined. What I found to be the most surprising was that the universities I worked with during this study didn't seem to understand this seemingly obvious conclusion. My first years of classroom teaching did not overflow with opportunities to learn new standards and methods on my own. I stuck to the things that were taught by my TPP and what I was able to borrow from my master teacher during my semester of student teaching. If the TPP I attended had assumed that I would learn how to teach an entire content area on my own, I would have been completely lost. Ultimately, this would have meant either low-quality teaching on my part or simply skipping over that content area entirely. My anecdotal experience was proven to also be the experience of the average teacher during my research. If the pedagogies and methods of instruction are not taught by the program preparing teachers to teach, the content will not get taught.

As I have mentioned previously, high-quality science instruction is incredibly important, not just because science is fun or high-interest but because it is a matter of educational equity. Research has shown that our most vulnerable student groups are being deprived of high-quality science instruction at much higher rates than other students. If this lack of instruction is followed to its most likely conclusion, vulnerable student populations are not entering STEM majors in college and attaining STEM occupations. This bars them from entering an upwardly mobile and lucrative professional path as well as potentially deprives all of us of the impact these students may have had on all of our lives.

**Figure 6**

*Research Implications*


**Implication #1**

The above overall finding has led to three major implications for future programming in elementary TPPs. The first implication is the necessity for a stand-alone, series of courses that prepare teachers to teach science. This can take many forms, including the form of methods that I observed at University One. I would recommend going even further however and suggest a pre-requisite course that covered science content at the foundational level to serve as a chance for students to brush-up on their science content knowledge and help them become more comfortable with the content. This course would be followed by an elementary science methods course that taught students how to navigate the standards as well as the pedagogy necessary to implement these standards in a high-quality manner. This would be the first step to helping new teachers become ready to teach science when they first enter their own classrooms.

**Implication #2**

The second implication my research exposed is that TPPs must do a better job of preparing new teachers to navigate the often-entrenched attitudes toward teaching science in an elementary classroom. Of all the pre-service teachers I interviewed, none reported being prepared by their programs to overcome barriers erected by the school site itself. Teachers cannot change the reality on the ground of high-stakes assessments and the impact they may have on the daily teaching schedule; they must be taught by their preparation programs how to work within this reality and still be able to bring high-quality science instruction to their students. This could take the form of preparing new teachers to integrate science and literacy methods, so that science content can be taught during scheduled literacy minutes. The same can be said for integrating mathematics and science, making it easier for teachers to include science instruction during scheduled math minutes. Science is a very high-interest subject when done properly and can be used as the hook into almost any content area. Integrating the content areas is one way to ensure that science receives the same number of instructional minutes as other contents.

This may necessitate TPPs to create a course dedicated to supporting elementary pre-service teachers in integrating their curriculum or at the very least to dedicate some instructional time in other courses to integrating instruction. It is my assertion that including science in other content area instruction will increase student interest, participation, and success due to it being so high-interest and easily accessible for students, a descriptor students don’t always use for mathematics and/or ELA. Student success with science integrated instruction is an area for further research.

**Implication #3**

The final implication of my findings emphasizes the theoretical framework used in my research design. In much the same way that Opportunity to Learn in the K-12 classroom is essential for understanding and overcoming prior knowledge hurdles as well as other SES barriers (Santibanez & Fagioli, 2016), if pre-service teachers are not given the opportunity to learn how to teach science, there will be serious and lasting effects on their teaching practice. Assuming high-quality science instruction can be “picked up” as the new teacher progresses throughout their career is a dangerous one, one that can have lasting impacts on students. If nothing else, my research has shown that pre-service teachers must be supported in their learning of not only science methods, but also the re-learning of science content to support those methods with sufficient time given to them in the classroom to learn it. The very same pre-service teachers participating in this study self-reporting feeling uncomfortable with their science content knowledge could very well be proof themselves of the essentialness of high-quality science instruction in the early years of a student’s career.

## Limitations and Implications for Future Research

By its very nature, a case study is simply a snapshot in time of the specific case that you are studying and can only show you what is happening in and around that case. I chose to do a comparative case study so that I would have the ability to compare my data, however this is still just two specific cases that are being compared. While it would be easy to generalize the experiences of the students in the two universities I studied, it wouldn’t necessarily be correct. The results are valid in that they can provide a window into the experiences, needs, and wants of the students that attend the two universities studied and can provide a place for further research to grow from, however a generalization of the results to all TPPs would be a dangerous trap to fall in to. For a more generalizable study, a mixed methods approach would be needed.

If this study were to be a mixed methods study, the results would have been more generalizable, however I would not have been able to compare two cases so in depth. Collecting quantitative data through a survey or analyzing university feedback data would have given me a chance to review generalizable data on a surface level for more TPPs. This would have given me a broader idea of the feelings of preparedness among pre-service teachers throughout the state or country. However, it may have been more difficult to drill into this surface data to find the underlying reasons a multiple-subject credentialing student may feel less prepared to teach science. This type of study may be an opportunity for future research into this topic.

Additional topics of research to be pursued related to the preparedness of multiple-subject pre-service teachers include investigating alternative credentialing programs, programs outside of the state of California, as well as developing a program to be implemented at TPPs that can better prepare candidates and testing it in different university settings. I am particularly interested in the latter suggestion, as it would give me a chance to begin solving this problem of practice after having identified it. This avenue of further research could potentially be a long one, as there are many opportunities for action research and design thinking, as well as multiple design iterations. Identifying a problem of practice and its potential causes is the first step to solving the problem, the next steps would be to investigate whether this issue is a generalizable one that is experienced throughout the state and/or country, then further to develop solutions that can be implemented in a wide array of institutions that has been thoroughly tested.

As a former science teacher, I may be biased, however further research into providing support to our future elementary teachers to teach science needs to be a priority. My research has shown that we cannot rely on universities and other teacher preparation programs to understand how important it is to start high-quality science instruction as soon as a student enters school. Further research needs to be done to force these programs to see the necessity of science in early learning and the support our future elementary teachers will need to be able to implement high-quality science in their classroom.

## Conclusion

Recent global events such as the COVID-19 pandemic have made clear the importance of having a strong foundation of science knowledge; even something as small as knowing the difference between a virus and bacteria, and their inherent risks, can be the difference between life and death in our current times. Unfortunately, these recent events have also shone a light on the gaps in, and outright absence of, science education occurring in the United States K-12 education system. Beginning in elementary schools across the country, many students are getting little to no access to high-quality science instruction, and this is having serious knock-on effects for the science achievements of the population of the United States, let alone the knowledge needed for common everyday life in the times of pandemics and climate change.

I set out with this study to identify the self-reported levels of preparedness to teach high-quality science by multiple-subject pre-service teachers at two university teacher preparation programs as well as any barriers these programs may have to preparing students to teach science. This comparative case study looked at two university TPPs with very different approaches to preparing elementary pre-service teachers to teach high-quality science. I first conducted a document review of publicly available information to determine which two universities to participate in the study. I then conducted observations of methods courses to get a better appreciation of how these programs prepared students. Finally, I conducted interviews with both students and professors in order to fully understand their perspectives and feelings about the program in which they were working. Through this research I was able to discover a few common themes, and their implications, between the experiences of the students.

No one I interviewed reported that high-quality science instruction was unnecessary in elementary school, specifically early elementary. However, their actions and responses to some questions showed many gaps in understanding and preparedness to implement this high-quality instruction. In particular, the gaps in understanding and preparedness were in relation to science content knowledge, tools to navigate the K-12 system and its potential barriers to science instruction, levels of comfort with science instructional methods and the ways all of these collected experiences resulted in teachers' inadequate implementation of high-quality science instruction in the elementary classroom.

These gaps in preparedness are not insurmountable. There are ways to better prepare teachers, so they feel ready to implement science instruction, this is evident even in the differences between the two programs studied in this research. Students participating in the TPP at University One reported greater levels of satisfaction with their program in relation to science preparation. The systems in place at University One can be a good foundation to any program as well as implementing a science content refresher course for incoming pre-service teachers, better preparing teachers to integrate their instruction so they may navigate barriers to implementation at the school level, and finally just ensuring that university programs must spend the time necessary to ensure that elementary pre-service teachers have the tools and the understanding of the importance of science to implement high-quality science instruction in their classrooms.

Opportunity gaps to learn science are becoming larger at the earliest levels of education. As a result, less students are reporting engagement with science during secondary education and are not pursuing STEM careers after college. This lack of instruction has become an educational equity issue as students with a lower SES often do not receive the informal science education that their peers do at home to compensate for the lack of formal education, nor do they have the same opportunity to learn science that other students may be receiving. The importance of even a basic understanding of science cannot be overstated. Pandemics, climate change, vaccines, preparing for natural disasters, even something as fundamental as how the food we eat is grown, all of these are aspects of modern life. It is essential that our education system prepare everyone to navigate these everyday modern occurrences. The implications of a populace that does not understand either the mechanisms of science nor the importance of science are beginning to have massive impacts on not just California or the United States, but the entire planet. Fighting these implications must begin early and must begin with teachers that are ready.

**References**


ACT. (2018). STEM education in the US: Where are we and what can we do. ACT.org/stem.

Akram, M. (2019). Relationship between Students' Perceptions of Teacher Effectiveness and Student Achievement at Secondary School Level. Bulletin of Education and Research, 41(2), 93–108.

Anderson, E., & Kim, D. B. (2006). Increasing the success of minority students in science and technology (4). American Council on Education.

Anyanwu, Raymond Ndubisi (2019). The nature of climate science: Challenges for the development of climate change science literacy in education. Africa International Journal of Multidisciplinary Research, 2 (5).

Backes, B., Goldhaber, D., Cade, W., Sullivan, K., & Dodson, M. (2018). Can U Teach? Assessing the relative effectiveness of STEM teachers. Economics of Education Review, 64, 184–198. https://0-doi.org.pacificatclassic.pacific.edu/10.1016/j.econedurev.2018.05.002

Barnard-Brak, L., Lan, W.Y., Yang, Z. (2018). Differences in mathematics achievement according to opportunity to learn: A 4pL item response theory examination. *Studies in Educational Evaluation*, 56, 1-7. http://dx.doi.org/10.1016/j.stueduc.2017.11.002

Bell, S. E., & Sexton, S. S. (2012). Science Education Professional Development for Primary/ Elementary Teachers: A Tale of Two Systems. *Science Education International*,*29*(2).

Berliner, David. (2011). Rational responses to high stakes testing: The case of curriculum narrowing and the harm that follows. Cambridge Journal of Education. 41. 287-302. 10.1080/0305764X.2011.607151.

Bianchini, J. A., Akerson, V. L., Barton, A. C., Lee, O., & Rodriguez, A. J. (2013). Science for all: historical perspectives in policy for science education reform. In *Moving the Equity Agenda Forward: Equity Research, Practice, and Policy in Science Education* (pp. 5–20), Springer Netherlands.

Blank, R. K. (2013). Science Instructional Time is Declining in Elementary Schools: What are the Implications for Student Achievement and Closing the Gap? *Science Education*.

Braund, M. (2021) Critical STEM Literacy and the COVID-19 Pandemic. Canadian Journal of Science, Mathematics, and Technical Education. https://doi.org/10.1007/s42330-021-00150-w

Bybee, R. (2014). NGSS and the Next Generation of Science Teachers. Journal of Science Teacher Education, 25(2), 211–221. https://0-doi.org.pacificatclassic.pacific.edu/10.1007/s10972-014-9381-4

California Department of Education. (2016). *Science framework for California public schools: Kindergarten through grade 12.* http://www.cde.ca.gov/ci/sc/cf/cascienceframework2016.asp

California Department of Education (2020). *English Learner Program Instrument 2020-2021.* https://www.cde.ca.gov/ta/cr/documents/elinstrument2122.docx

Carroll, J. B. (1963). A model of school learning. *Teachers College Record, 64*(8), 723–733.

Carroll, J. B. (1989) The Carroll model: A 25-year retrospective and prospective view. *Educational Researcher*, 18(1), 26-31.

Čavojová, V., Šrol, J., & Ballová Mikušková, E. (2022). How scientific reasoning correlates with health-related beliefs and behaviors during the COVID-19 pandemic. *Journal of Health Psychology*, 27(3):534-547. https://doi.org/10.1177/1359105320962266

Chetty, Raj, John N. Friedman, and Jonah E. Rockoff. 2014. "Measuring the Impacts of Teachers II: Teacher Value-Added and Student Outcomes in Adulthood." *American Economic Review,* 104 (9): 2633-79.DOI: 10.1257/aer.104.9.2633

Coleman, J. S. (1990). *Equality and Achievement in Education*. New York, NY: Routledge.

Coleman, J.S. (1966). *Equality of Educational Opportunity (Report No. OE-38001).* Washington, D.C., National Center for Educational Statistics.

Curran, F. C., & Kellogg, A. T. (2016). Understanding Science Achievement Gaps by Race/Ethnicity and Gender in Kindergarten and First Grade. *Educational Researcher, 45*(5), 273-282.

Curran, F. C. (2017). Income-Based Disparities in Early Elementary School Science Achievement. *The Elementary School Journal, 118*(2), 207-231.

DeBoer, G.E. (1991). A History of Ideas in Science Education: Implications for Practice. New York: Teachers College Press.

DeJarnette, N. K. (2012). America's Children: Providing Early Exposure to STEM (Science, Technology, Engineering, and Math) Initiatives. *Reading Improvement,*181-187.

Department of Education (ED). (2004, February 10). *Executive Summary.* U.S. Department of Education. https://www2.ed.gov/nclb/overview/intro/execsumm.html.

Department of Justice (DOJ). (January 7, 2015). *Guidance to ensure equal opportunities for English Learner Students: Dear Colleague Letter.* https://www.justice.gov/crt/guidance-ensure-equal-opportunities-english-learner-students

Dunleavy, J. (2007). Public Education in Canada: Facts, Trends, and Attitudes. *Canadian Education Association*, Toronto.

Elliot, S. N., & Bartlett, B.J. (2016). Opportunity to learn. *Oxford Handbooks Online.* DOI:10.1093/oxfordhb/9780199935291.013.70.

Evagorou, M., Dillon, J., Viiri, J., & Albe, V. (2015) Pre-service teacher preparation in Europe: Comparing pre-service teacher preparation programs in England, France, Finland, and Cyprus. *Journal of Science Teacher Education*, 26, 99-115. DOI: 10.1007/s10972-015-9421-8

Fayer, S., Lacey, A., & Watson, A. (2017). STEM occupations: Past, present, and future. U.S. Bureau of Labor Statistics. https://www.bls.gov/spotlight/2017/science-technology-engineering-and-mathematics-stem-occupations-past-present-and-future/pdf/science-technology-engineering-and-mathematics-stem-occupations-past-present-and-future.pdf

Gerde, H. K., Pierce, S. J., Lee, K., & Van Egeren, L. A. (2017). Early Childhood Educators' Self-Efficacy in Science, Math, and Literacy Instruction and Science Practice in the Classroom. *Early Education and Development*.

Grinell, S., & Rabin, C. (2017). Caring Enough to Teach Science. *Science and Education,26*, 813-839.

Goldhaber, D., Lavery, L., & Theobald, R. (2015). Uneven Playing Field? Assessing the Teacher Quality Gap Between Advantaged and Disadvantaged Students. Educational Researcher, 44(5), 293–307. https://0-doi.org.pacificatclassic.pacific.edu/10.3102/0013189X15592622

Goldhaber, D., Quince, V., & Theobald, R. (2019). Teacher quality gaps in U.S. public schools: Trends, sources, and implications. Phi Delta Kappan, 100(8), 14–19. https://0-doi.org.pacificatclassic.pacific.edu/10.1177/0031721719846883

Gunning, A.M. & Mensah, F.M. (2011). Pre-service teachers development of self-efficacy an confidence to teach science: A case study. *Journal of Science Teacher Education*, 22, 171-185. DOI: 10.1007/s10972-010-9198-8

Hancock, D.R. & Algozzine, B. (2017). Doing case study research: a practical guide for beginning researchers, New York, NY: Teachers College Press.

Hayes, K. N., & Trexler, C. J. (2016). Testing Predictors of Instructional Practice in Elementary Science Education: The Significant Role of Accountability. *Science Education,100*, 266-289.

He, L., Chen, Y., Xiong, X., Zou, X., & Lai, K. (2021). Does Science Literacy Guarantee Resistance to Health Rumors? The Moderating Effect of Self-Efficacy of Science Literacy in the Relationship between Science Literacy and Rumor Belief. International Journal of Environmental Research and Public Health, 18(5), 2243. doi:10.3390/ijerph18052243

Hippocrates, Lloyd, G. E. R., Chadwick, J., & Mann, W. N. (1983). Hippocratic writings. Harmondsworth: Penguin.

Judson, E. (2012). When Science Counts as Much as Reading and Mathematics: An Examination of Differing State Accountability Policies. *Education Policy Analysis Archives,20*(26).

Kansanen, P. (2003). Teacher Education in Finland: Current Models and New Developments. In B. Moon & V. Lazar (Eds.), *Institutional Approaches to Teacher Education within Higher Education in Europe: Current Models and New Developments* (Studies on Higher Education, pp. 85-91). Bucharest: UNESCO.

Koh, E., Ponnusamy, L., Tan, L., Lee, S., & Ramos, M. (2014). A Singapore case study of curriculum innovation in the twenty-first century: Demands, tensions and deliberations. *Asia-Pacific Education Researcher (Springer Science & Business Media B.V.), 23*(4), 851-860.

Kolhaas, K., Lin, H., & Chu, K. (2010). Science equity in the third grade. *The Elementary School Journal, 110*(3), 393-408.

Marx, R.W., & Harris, C.J. (2006). No Child Left Behind and science education: Opportunities, challenges, and risks. *The Elementary School Journal, 106(5)*, 467-477.

Menon, D. & Sadler, T.D. (2016). Pre-service elementary teachers' science self-efficacy beliefs and science content knowledge. *Journal of Science Teacher Education*, 27, 649-673. DOI: 10.1007/s10972-016-9479-y

Merriam, S.B. & Tisdell, E.J. (2016). Qualitative research: A guide to design and implementation (4ed). Jossey-Bass, San Francisco, CA.

Ministry of Education and Culture. (2016). *Meaningful in Finland Action Plan*. Ministry of Education and Culture, Finland.

Morgan, P. L., Farkas, G., Hillemeier, M. M., & Maczuga, S. (2016). Science Achievement Gaps Begin Very Early, Persist, and Are Largely Explained by Modifiable Factors. *Educational Researcher, 45*(1), 18-35.

National Academies of Sciences, Engineering, and Medicine. 2011. *Expanding underrepresented minority participation: America's science and technology talent at the crossroads.* Washington, DC: The National Academies Press

National Academies of Sciences, Engineering, and Medicine. 2019. *Science and engineering for grades 6-12: Investigation and design at the center*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25216.

National Conference of State Legislatures. (2015). The Finnish Formula. *State Legislatures, 41*(3), 31.

National Research Council. (2012). A framework for K-12 science education: Practices, cross-cutting concepts, & core ideas. Washington, DC: The National Academies Press.

National Science Teachers Association. (1971). NSTA position statement on school science education for the 70's. *The Science Teacher, 38*, 46–51.

Ness, D., Farenga, S.J., Shah, V., & Garofolo, S.G. (2016). Repositioning science reform efforts: Four practical recommendations from the field. *Impairing Schools, 19(3)*. 258-266. DOI: 10.1177/1365480216650312

No Child Left Behind Act, Pbl. L. No. 107-110, 115 Stat. 1425 (2002). https://www2.ed.gov/policy/elsec/leg/esea02/107-110.pdf

OECD. (2016). *PISA 2015 Results (Volume 1)*, PISA, OECD Publishing, Paris.

OECD. (2011). *Strong performers and successful reformers in education: Lessons from PISA for the United States,* PISA, OECD Publishing, Paris.

Penuel, W. R., Harris, C. J., & DeBarger, A. H. (2015). Implementing the Next Generation Science Standards. *Phi Delta Kappan, 96*(6), 45–49. https://0-doi.org.pacificatclassic.pacific.edu/10.1177/0031721715575299

Peri, G., Shih, K., & Sparber, C. (2015). STEM Workers, H-1B Visas, and Productivity in US Cities. *Journal of Labor Economics*, 33, S225–S255.

Pietarinen, J., Pyhalto, K., & Soini, T. (2017). Large-scale curriculum reform in Finland: Exploring the interrelation between implementation strategy, the function of the reform, and curriculum coherence. *The Curriculum Journal,28*(1), 22-40.

Pruitt, S.L. (2014). The Next Generation Science Standards: The features and the challenges. *Journal of Science Teacher Education, 25*. 145-56. DOI: 10.1007/s10972-014-9385-0

Provasnik, S., Kastberg, D., Ferraro, D., Lemanski, N., Roey, S., & Jenkins, F. (2012). *Highlights TIMSS 2011: Mathematics and Science Achievement of 4th and 8th Grade Students in an International Context.* National Center for Education Statistics, Institute for Education Sciences, U.S. Department of Education. Washington, D.C.

Quinn, D. M., & Cooc, N. (2015). Science Achievement Gaps by Gender and Race/Ethnicity in Elementary and Middle School. *Educational Researcher, 44*(6), 336-346.

Rasmussen, J. & Bayer, M. (2014). Comparative study of teaching content in teacher education programmes in Canada, Denmark, Finland and Singapore. *Curriculum Studies, 46*(6), 798-818.

Reddy, L. A., Lekwa, A., Dudek, C., Kettler, R., & Hua, A. (2020). Evaluation of teacher practices and student achievement in high-poverty schools. *Journal of Psychoeducational Assessment*, 38(7), 816–830. https://0-doi.org.pacificatclassic.pacific.edu/10.1177/0734282920913394

Sahlberg, P. (2007). Education policies for raising student learning: The Finnish approach. *Journal of Education Policy, 22*(2), 147-171.

Sahlberg, P. (2011a). Lessons from Finland. *American Educator, 35*(2), 34.

Sahlberg, P. (2011b). The Fourth Way of Finland. *Journal of Educational Change,12*, 173-185.

Santibanez, L. & Fagioli, L. (2016). Nothing succeeds like success? Equity, student outcomes, and opportunity to learn in high- and middle-income countries. I*nternational Journal of Behavioral Development,* 40(6), 517-525. DOI: 10.1177/0165025416642050

Seidman, I. (2019). Interviewing as qualitative research: A guide for researchers in education and the social sciences. Teachers College Press, NY, NY.

Shu-Shing Lee, Hung, D., & Teh, L. W. (2013). Moving Singapore from great to excellent: How educational research informs this shift. *KEDI Journal of Educational Policy, 10*(2), 267-291.

Simpson, R.L., LaCava, P.G., Sampson Graner, P.L. (2004). The No Child Left Behind Act: Challenges and implications for educators. *Intervention in School and Clinic, 40(2)*. 67-75

Sommerville, R.C., & Hassol, S.J. (2011). Communicating the science of climate change. *Physics Today*, 64(10). DOI: 10.1063/PT.3.1296

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

Stake, R.E. (2005). Multiple case study analysis. The Guilford Press, New York, NY.

Stevens, F. I. (1996). *The need to expand the opportunity to learn conceptual framework: Should students, parents, and school resources be included?* Paper presented at the annual meeting of the American Educational Research Association, New York, NY.

Tai, R. H., Liu, C. Q., Maltese, A. V., & Fan, X. (2006). Planning Early for Careers in Science. *Science, 12*. Retrieved 2020, from sciencemag.org

Tan, C. Y., & Dimmock, C. (2014). How a 'top-performing' Asian school system formulates and implements policy. *Educational Management Administration & Leadership, 42*(5), 743-763.

Walker, J., & Von Bergmann, H. (2013). Teacher education policy in Canada: Beyond professionalization and deregulation. *Canadian Journal of Education / Revue Canadienne De L'Éducation, 36*(4), 65-92.

Wang, J. (1998). Opportunity to Learn: The Impacts and Policy Implications. *Educational Evaluation and Policy Analysis*, 20(3), 137-156. DOI: 34.223.15.150

Weiss, L., Eisenhart, M., Cippollone, K., Stitch, A.E., Nikischer, A.B., Hansson, J., Liebrandt, S.O., Allen, C.D., & Dominguez, R. (2105) In the guise of STEM education reform: Opportunity Structures and Outcomes in Inclusive STEM-Focused High Schools. *American Educational Research Journal*, 52(26): 1024-1059. http://dx.doi.org/10.3102/0002831215604045

Yi Xue, & Larson, R. C. (2015). STEM crisis or STEM surplus? Yes and yes. Monthly Labor Review, 1–14. https://0-doi.org.pacificatclassic.pacific.edu/10.21916/mlr.2015.14

Yin, R. K. (2018). Case study research and applications: Design and methods (6ed). Sage Publications, Thousand Oaks, CA.

# APPENDIX A: CLASSROOM OBSERVATION PROTOCOL

Date: Location:

Time Observation Begin: End:

| **Describe the Room: Teacher set-up, student arrangement, walls…** |
|---|
| |

| **Time** | **Teacher Does** | **Student Does** |
|---|---|---|
| | | |

| **Summary and Important Quotes:** |
|---|
| |

# APPENDIX B: INTERVIEW PROTOCOLS

Institutions: ________________________________________________

Interviewee (Title and Name): __________________________________

Interviewer: ________________________________________________

Survey Section Used:

_____ A: Interview Background

_____ B: Institutional Perspective

_____ C: Department and Discipline

_____ D: Teaching and Learning

_____ E: Demographics (no specific questions)

Other Topics Discussed:_______________________________________

__________________________________________________________

Documents Obtained: _________________________________________

__________________________________________________________

__________________________________________________________

Post Interview Comments or Leads:

__________________________________________________________

## Introductory Protocol

*To facilitate our note-taking, I would like to audio tape our conversations today. For your information, only I will be privy to the tapes which will be eventually destroyed after they are transcribed. In addition, you must sign a form devised to meet my human subject requirements. Essentially, this document states that: (1) all information will be held confidential, (2) your participation is voluntary and you may stop at any time if you feel uncomfortable, and (3) we do not intend to inflict any harm. Thank you for your agreeing to participate.*

*I have planned this interview to last no longer than 90 minutes. During this time, I have several questions that I would like to cover.*

**Introduction**

You have been selected to speak with us today because you have been identified as someone who has a great deal to share about science methods in the multiple subject credentialing program. My research as a whole focuses on how science teaching methods are taught to pre-service teachers, with a focus on success and challenges. Ultimately the study will conclude in recommendations on improving science methods teaching in the programs. The study does not aim to evaluate your techniques or experiences. Rather, I am trying to learn more about your experiences, and hopefully learn about practices that can improve science methods instruction.

**A. Interviewee Background**

How long have you been …

_______ in your present position?

_______ at this institution?

Interesting background information on interviewee:

What is your highest degree? ____________________________________________

What is your field of study? _____________________________________________

1. Briefly describe your role (office, committee, classroom, etc.) as it relates to student learning and assessment (if appropriate).

Probes: How are you involved in science methods instruction?

How did you get involved?

2. What do you see as the importance, or lack thereof, of science methods instruction?

**B. Institutional Perspective**

1. What is the strategy at this institution for teaching science methods in multiple subject credentialing programs?

Probes: Is it working – why or why not?

Purpose, development, administration, recent initiatives

2. What resources are available for the teaching and learning of science methods?

3. What is changing about the teaching and learning of science methods at this institution?

Probe: What is being accomplished through these changes?

4. Have you or your colleagues encountered resistance to these reforms in your department? . . . on campus?

**C. Department and Discipline**

1. What are some of the major challenges your department faces in attempting to change the teaching and learning of science methods in multiple subject credentialing programs? What are the major opportunities?

Probes: How can barriers be overcome?

How can opportunities be maximized?

**D. Teaching and Learning**

1. Describe how science methods teaching and learning occurs at this institution.

Probe: How do you know? (criteria, evidence)

2. Is the teaching and learning of science methods a major focus of attention and discussion here?

Probe: why or why not? (reasons, influences)

3. What specific new practices have you implemented in your classes?

4. What types of faculty development opportunities do you see emerging on your campus that focus on the teaching and learning of science methods? (Institutional or disciplinary?)

Probes: What motivates you to participate in instructional development programs on campus?

How frequently do you attend such programs?

How are these programs advertised to faculty?

**E. Demographics**

Post Interview Comments and/or Observations:

*Adapted from "National Center for Postsecondary Improvement Sample Interview Protocol"*