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Comparative Analysis of In-Person, Online, and Hybrid Modalities in Pre-College Life Science Research Programs: A Statistical Inquiry

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Comparative Analysis of In-Person, Online, and Hybrid Modalities in Precollege Life Science Research Programs: A Statistical Inquiry

A Dissertation submitted in partial satisfaction of the
requirements for the degree of Doctor of Education

in

Educational Leadership

by

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2024

The Dissertation of Maysoon Lehmeidi is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

University of California San Diego

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2024

EPIGRAPH

"Education is the practice of freedom, the means by which men and women deal critically and creatively with reality and discover how to participate in the transformation of their world."

Bell Hooks

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VITA

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ABSTRACT OF THE DISSERTATION

The Effects of Precollege Research Immersion Courses on Fostering High School Student Interest in STEM Majors and Career Paths

by

Maysoon Lehmeidi

Doctor of Education in Educational Leadership

University of California San Diego, 2024
California State University, San Marcos, 2024

Christopher Halter, Chair

The number of students interested in pursuing STEM in post-secondary institutions is on the decline. This is due to several factors, one being a lack of effective and innovative science enrichment (summer or after-school) programs for high school students (Baran et al., 2019; Kong et al., 2014). While traditional lecture-based science courses effectively communicate theoretical knowledge, concerns have been raised regarding their ability to maintain students' interest in science and the lack of practical application of the learned technical information (Kong et al., 2014). Using social cognitive theory as a foundation, this quantitative study evaluated the efficacy of precollege life science research immersion programs that changed modality as a result of the Covid-19 pandemic. The primary research question is to determine if the delivery methods of the university-based, precollege life-science research immersion programs (in-person, online, and hybrid) because of the Covid-19 pandemic affected the efficacy of the instruction. Findings reveal nuanced impacts of instructional methods on student outcomes, highlighting the importance of tailored approaches grounded in social cognitive theory. This study underscores the significance of early engagement in research and the role of diverse instructional methods in fostering students' interest and proficiency in STEM fields.

Chapter 1 INTRODUCTION

Our nation's future economic and social development relies heavily on educating youth in various disciplines (Gayles & Ampaw, 2011; Venkataraman, 2010; Young et al., 2017). Issues such as global warming, pandemics, and declining bee populations impact everyone, and addressing them is critical for advancing the human population (Venkataraman, 2010; Young et al., 2017). There is a general consensus among educators and world leaders that significant investment in STEM (science, technology, engineering, and mathematics) education is needed to solve these problems (Gayles & Ampaw, 2011; Maltese & Tai, 2011; Venkataraman, 2010; Young et al., 2017). STEM education creates critical thinkers and enables the next generation of problem-solvers and innovators.

Statement of the Problem

The STEM field covers many occupations, such as engineers, physicians, scientists, and mathematicians. The U.S. Bureau of Labor Statistics (BLS) defines STEM occupations as professional and technical careers in science, technology, engineering, and mathematics (Noonan, 2017). In 2015, STEM occupations comprised about 6% of the U.S. workforce, increasing by about 5% since 2010 (Noonan, 2017; Xue & Larson, 2015). According to the BLS, 800,000 new jobs in STEM will be created by 2029, an increase of 8% from 2019 (BLS, 2021). The U.S. Department of Commerce projects growth to be around 9% (Noonan, 2017). In comparison, non-STEM occupations will only increase by 3% - 6% by 2029, depending on the definition of STEM occupations used (Noonan, 2017; BLS, 2021). To meet the demand for

STEM jobs, universities need to increase the number of students who obtain STEM degrees by prioritizing STEM enrollment and retention (Chen & Soldner, 2013; Maltese & Tai, 2011; Venkataraman, 2010). However, there is an alarming downward trend in the number of students graduating in STEM fields from postsecondary institutions (Gayles & Ampaw, 2011; Maltese & Tai, 2011). In 2004, the number of students graduating with STEM bachelor's degrees was as high as 28%, but only 15%-18% of bachelor’s degrees are currently awarded in STEM fields (Chen, 2009; NCES, 2021).

The U.S. is also currently behind several other countries in terms of the proportion of students graduating with STEM degrees. As of 2018, countries such as China, India, Russia, and the UK have about 30% or more of total graduates coming from STEM majors (UNESCO, 2021). If the U.S. wants to maintain a strong global influence in technological innovation, it needs to prioritize addressing the decline in STEM graduates from postsecondary institutions. STEM fields are vital to the U.S. economy and investing in STEM education is the best way to reaffirm our role in the world's technological, scientific, and innovation spaces (Gayles & Ampaw, 2011; Maltese & Tai, 2011; Venkataraman, 2010; Young et al., 2017). Compared to their peers from other industrialized nations across the globe, U.S. students are considered average in STEM subjects. The Programme for International Student Assessment (PISA) measures literacy rates, math skills, and science skills of fifteen-year-olds across developing nations. In 2015, the U.S. ranked 38 out of 71 countries in math and 24 out of 71 in science, with Singapore, Japan, and Hong Kong leading in these subjects. Younger students did not fare well either in a similar assessment known as the National Assessment of Educational Progress: only 40% of 4th graders and 33% of 8th graders are "proficient" or "advanced" in math. These numbers decline further as students advance to higher grade levels. Only 25% of 12th graders are "proficient" or "advanced" in math. Thirty-eight percent of 12th graders scored in the lowest category in math in 2015, and this has been relatively consistent since 2005 (Pew Research Center, 2017). Clearly, there is a trend of decreasing performance in math skills as students advance from middle to high school.

To examine the apparent decline of high school students' interest in pursuing STEM at post-secondary institutions, it is crucial to closely analyze the STEM education pipeline from elementary through high school. There are opportunities to stimulate interest and retain students in STEM at every grade level within a child's academic career, but there are multiple leaks in the pipeline (Green & Sanderson, 2018). One must also consider the role stereotypes have on students' STEM interests. Both interest in STEM and academic performance can be impacted by parents, teachers, and peers as early as middle school (Ambady et al., 2001; Shapiro & Williams, 2012; Tillinghast & Mansouri, 2020). Additionally, school leadership plays a significant role in retaining students in the STEM pipeline (Kim et al., 2020; Mau et al., 2016; Woods & Domina, 2014). Students need support and encouragement from their teachers, counselors, and principals to achieve academic success. Finally, the rapidity with which schools had to shift online due to the Covid-19 pandemic caused a lot of stress on students, teachers, parents, and administrators; increased stress levels can negatively impact student persistence and academic achievement (Eccles, 2005; Gavin et al., 2020; Grubic et al., 2020). While there is no single solution to address the issue of declining interest in STEM, it is important to look at the issue holistically.

Exposing students to STEM research opportunities with access to universities, faculty, and graduate students can help bridge the gaps and increase participation in STEM majors and careers (Kong et al., 2014). If we can stimulate interest in students at a younger age, they are more likely to challenge themselves and take on the rigorous academic courses associated with majoring in STEM (Tillinghast & Mansouri, 2020). Demand for STEM jobs will only increase as the world's problems become more complex, requiring our investment in education (Venkataraman, 2010; Young et al., 2017). The development of such practical and applied STEM skills should ensure more retention in STEM majors during schooling and in STEM careers beyond academic experience. We need to prepare students to become problem-solvers for the future.

Purpose of the Study

My interest in precollege programs results from my professional work at a large prominent university in southern California. Through collaborative efforts with diverse local and international nonprofit organizations, my work has primarily revolved around offering after-school and summer research opportunities to high school students. Since 2019, one essential partnership has yielded numerous student cohorts participating in life-science research immersion courses offered in various modalities, forming the basis of this study.

In this particular collaboration, the university partnered with a local non-profit organization specializing in curriculum development and teaching various life science topics. The initial design of the courses was tailored for traditional, in-person instruction in a physical wet lab setting. Students attended all lectures in person, conducted fieldwork to collect samples for their research, and executed experiments in the wet lab. However, unforeseen circumstances emerged with the onset of the Covid-19 pandemic and the subsequent school closures nationwide.

Faced with the need to adapt, the program shifted its initial curriculum implementation. The research-based courses transitioned to a fully online program with synchronous and asynchronous elements. Synchronous teaching involves real-time instruction through web-based applications such as Zoom. In contrast, asynchronous teaching involves multiple pedagogical resources, such as pre-recorded videos and reading assignments for self-paced learning.

As the nation began witnessing the gradual reopening of schools, allowing for in-person instruction once again, a need for a different instructional model arose, prompting the program to adopt the hybrid instructional model. This hybrid model consisted of students taking elements of their courses online with both synchronous and asynchronous elements (learning theoretical science fundamentals, hypothesis formulation and experimental design, data management, analysis, and writing) and working in the lab in person to learn practical and technical components of research. The hybrid model took elements of the previous two modalities and combined them.

For this study, terms such as the "precovid" environment allude to in-person courses conducted without restrictions before the pandemic. Conversely, the "postcovid" teaching environment refers to courses taught in person after the state government deemed it safe to resume face-to-face instruction in schools.

Research Questions

The principal objective of this quantitative study is to investigate the influence of course modality (in-person, online, and hybrid) within life-science research immersion programs on the interests and attitudes of research scholars toward science, along with the consequential effects on their scientific skills and knowledge. To explore this primary objective, this study addresses the following two secondary research questions:

(1) Did the delivery method of the life science research immersion program have an impact on research scholars' perceptions, interests, and attitudes toward science following participation in either the in-person, online, or hybrid research program?

(2) Did the delivery method of the life science research immersion program have an impact on research scholars' changes in scientific skills and knowledge?

Methodology

This study is a quantitative analysis of a precollege research immersion program that shifted the modality of instruction due to the Covid-19 pandemic. The research scholars took courses 1) in-person pre-pandemic, 2) online during the pandemic, and 3) in a hybrid format post-pandemic. Data collection and analysis was conducted over three phases. In Phase I, student demographics data, Test of Science Related Attitudes (TOSRA) survey data, and scientific assessment data was collected for all three modalities. In Phase II, the data was analyzed for each modality separately to determine effects based on course modality. Phase III is a comparative analysis of all three program modalities for the TOSRA and the scientific assessment data to determine if there were any significant differences. A more detailed description of the phases and data collection instruments is provided in Chapter 3.

Significance of the Study

The significance of this study is twofold. First, there are many lessons to be learned concerning implementing research programs for young students during a pandemic. Research immersion programs can be applied to many different learning models to cultivate student interest in STEM education, and this study highlights the need to be innovative in turbulent times. Secondly, this study can be used to justify pursuing additional funding through grants. Resources can be limited for lab space, supplies, and support staff, and this study can help provide data on the significant impact on the STEM education pipeline.

Organization of the Study

The structure of this study has been designed to articulate the rationale for undertaking the research and provide a foundation for the methodology employed. In the introduction chapter, I provide an overview of the problem, the study's purpose, and the research questions. This chapter also includes a brief description of the study methodology.

The second chapter focuses on a review of the literature on existing precollege programs. This chapter contains five primary sections; to establish the foundation for the literature surrounding precollege programs' impact on the STEM education pipeline, I first introduce the social cognitive theory (SCT) as a theoretical framework for framing the data analysis and findings; next, I include research on the differentiated approach to exposing students to STEM precollege programs through various stages of their educational journey; I also review the literature surrounding student attitudes toward STEM majors and careers. This chapter concludes with a review of university partnerships' impact on retaining students in STEM majors, the role parents, counselors, and teachers play in maintaining students' interest in STEM, and finally, the challenges created by the Covid-19 pandemic.

The third chapter, methodology, provides an overview of the research design of the quantitative study. This chapter outlines the data instruments, the population, the statistical analysis methods, and the study's limitations. The fourth chapter summarizes the statistical analyses outlined in Chapter 3. This study concludes with Chapter 5, a summary of the key findings in relation to the theoretical framework outlined in Chapter 2, the limitations of the study and the theoretical framework, and finally, the implications and significance of the study for educational leadership, social justice, and additional research. I have included copies of the student application for the research immersion program, the TOSRA survey, and the course assessments within the Appendices. Finally, the reference list completes this study.

Chapter 2 REVIEW OF LITERATURE

Students enter the STEM pipeline as early as elementary school. It is essential to explore what enables them to persist through the pipelines, take challenging STEM courses in high school, major in STEM fields in college, and pursue a STEM career. Students fall out of the pipelines at various stages of their lives (Green & Sanderson, 2018; Tai et al., 2006). This declining trend is more pronounced for young women, historically underrepresented students, and low-income students who typically have more negative attitudes toward STEM subjects and participate in out-of-school activities less than their White peers (Baram-Tsabari & Yarden, 2008; Basu & Barton, 2007). It is critical to identify the gaps and what different stakeholders (teachers, counselors, high school administrators, non-profit organizations, and universities) can do to stop the leak. Analysis of what enables students to persist in STEM careers and different methods for preventing the leak in the pipeline can help inform education policy and funding for STEM programs at various stages of the pipeline (Green & Sanderson, 2018).

STEM persistence is more important than ever when considering the lack of diversity among those who graduate from college with STEM degrees and then pursue STEM careers. The lack of diversity in STEM fields can be tied to barriers that the dominant cultures do not face (Tai et al., 2017). These barriers include socio-economic factors (the cycle of poverty), systems of oppression (welfare and mental health services for people of color), and entitlement (the idea that White people are more deserving than people of color because they work harder) (Lindsey et al., 2018; Welborn, 2019). Breaking these barriers can increase student achievement and confidence in STEM, leading to students furthering their interests in higher education and later in the workforce.

The purpose of the literature review is to establish a foundation for the proposed research. Given the research questions I posed in the introduction, a solid foundation of literature surrounding key elements that influence a student's decision to pursue STEM precollege activities and later persist in STEM majors and careers is necessary. The SCT theoretical framework establishes the context for this study and is discussed in the first part of the literature review. The next part of this literature review explores how persistent exposure to STEM activities can affect students' interests and perceived abilities in STEM subject areas through various stages of their academic experiences (elementary through high school). Subsequently, the third subsection reviews students' attitudes towards persisting through the STEM pipeline, including marginalized students' experiences. This section also examines the role of university partnerships and parents in influencing students' attitudes towards STEM subjects and careers. The fourth subsection of this literature review explores the impact formal and informal leaders (such as counselors, teachers, and principals) have on students' persistence and achievement toward STEM degrees and careers. The literature review concludes with current literature on the impact the Covid-19 pandemic had on precollege programs.

Theoretical Framework - Social Cognitive Theory

This dissertation is based on the hypothesis that students' learning is affected by cognitive, behavioral, and environmental factors (Bandura, 1991). Social cognitive theory (SCT) is rooted in the concept of the human self, in which people are agents of their own cognitive development and through their own actions, can achieve their goals. Individuals possess self-convictions that enable them to have a measure of control over their own actions, aspirations, and interests (Bandura, 1991).

There are three major constructs that interact and influence human behavior and as a result, students' learning: personal factors, environmental factors, and the aspects of the behavior itself (Bandura, 1977; 1986). Personal factors include age, previous educational experiences, expectations, and attitudes; environmental factors include family life, influence from peers, and influence from teachers or administrators at school; behavioral aspects include skills and self-efficacy (Bandura, 1977; 1986). As a result, the development of career aspirations, interests, and persistence in STEM is a reaction from the complex interactions of the three major constructs. Factors such as family, socio-economic status, school environment, and personal characteristics can either be sources of strength or a liability when it comes to shaping a students' academic perceptions of STEM fields and career. Understanding how these factors interact can influence the development of academic performance in STEM and choice of professional careers.

Self-efficacy

Self-efficacy is a core concept of SCT (Bandura, 1986). Bandura defines self-efficacy as a person's judgment or beliefs of their own capabilities to exercise control over events that affect their lives (1986). Furthermore, thinking positively or negatively can influence how someone approaches tasks that may be perceived as challenging, such as a math problem in a challenging calculus course (Bandura, 1994; 2008). Self-efficacy is a strong predictor of how effectively students can perform on challenging tasks despite potential setbacks. Students with high self-efficacy believed they could excel in STEM and thus were more likely to graduate with a degree in STEM (Heilbronner, 2011). Perceptions are typically developed from four sources: (1) interpreted results from past performance; (2) observing others performing the same task; (3) verbal encouragement; and (4) individual physical and emotional state (Bandura, 1997). Developing mastery of a task can create a positive influence and develop further confidence in a student's ability to accomplish similar tasks in the future. The behavior of peers with perceived similar capabilities can be influential as students will observe their peers' success and failure and draw parallels to their perceived capabilities. Encouragement from parents, teachers, and counselors helps students persist through challenging academic courses. Finally, when students are consistently under stress or receive consistent negative reinforcement, efficacy beliefs are diminished, while optimism and positivity can enhance efficacy (Bandura, 1986).

Self-efficacy can be improved through educational experiences, such as precollege programs. When students are engaged in activities that are interactive and challenging, they are more likely to pursue STEM degrees in college (Heilbronner, 2011). These activities can be formal coursework in high school or enrichment programs that students choose to participate in outside of their school curriculum. The more opportunities a high school student has to engage in STEM learning activities, the higher the correlation with success in first-year college STEM courses (Maltese & Tai, 2011). The importance of self-efficacy in STEM education reinforces the need for a diverse approach to fostering interest and ability in STEM education at every stage of education.

Persistent Exposure to STEM

Fostering interest and abilities in STEM fields will allow the US to keep up with the demand for STEM jobs to help solve future problems (Beier & Rittmayer, 2008; Young et al., 2017). As students age and advance in the education pipeline, their cognitive skills develop and mature. As a result of the changing cognitive skills, a differentiated approach is needed to maintain student interest in STEM subjects. Exposure to STEM concepts for students in the 3rd grade will look different than exposure in the 7th grade, and even more different for those enrolled in high school. Furthermore, interest in STEM typically declines as students leave elementary school and go through middle and high school (Sheridan et al., 2011). This troubling trend highlights the need for a differentiated approach in programs due to grade level. Fighting the trend is an undertaking requiring non-profit organizations, community organizations, K-12 schools, funding agencies, and universities to work together to provide students with a variety of STEM opportunities ranging from fun workshops to full immersion and research programs (Gayle & Ampaw, 2011; Sheridan et al., 2011). What follows is a review of student interest and persistence in STEM subjects based on the standard groupings of grade levels in the public school system in the United States.

Elementary School Exposure to STEM

Early and continued experiences and exposure to STEM activities are advantageous in maintaining interest in STEM fields. Students exposed to STEM at younger ages are more likely to pursue STEM majors in college (Green & Sanderson, 2018; Maltese & Tai, 2010). Students as young as kindergarten age are capable of understanding STEM concepts. While students as young as the age of five years old find it challenging to grasp fundamental engineering and mathematics concepts, there are many ways to create age-appropriate activities based on students' ability to get them to start thinking about how the world works. Camps and field trips for young students increase scientific understanding and enable them to envision what it means to be a scientist or an engineer. Younger students need activities that allow them to play while learning simple fundamental concepts to explore and be inquisitive. Several programs enable young elementary students to explore science in a fun way. These activities help students build more robust vocabulary at younger ages and foster a STEM mindset as a part of their everyday lives (Cunningham et al., 2018; Cunningham & Lachapelle, 2014; Elkin, 2012; Tillinghast & Mansouri, 2020). Creating a deeper connection with STEM will help bring career awareness and enable students to persist through more challenging STEM courses as they get older.

Middle School Exposure to STEM

Exposure to STEM goes beyond field trips, day camps, and fun playtime. Middle school programs can provide more focused and more advanced programs to aid in achieving a higher awareness of STEM majors and career opportunities (Tillinghast & Mansouri, 2020). As students get older, the simple activities they were exposed to in elementary school will not be sufficient to maintain their interest. As their cognitive abilities develop over time, so will their need for more advanced STEM opportunities (Tillinghast & Mansouri, 2020). Many students will presume STEM subjects to be too dull or challenging by the 8th grade and, as a result, fall out of the STEM pipeline (Gibson & Chase, 2002; Staus et al., 2020; Venkataraman et al., 2010). Developing opportunities to expose students to detailed and more advanced STEM concepts and activities before they make those conclusions in the 8th grade is a critical component of persistence in STEM degrees in college.

While many scientists and engineers can recall the time when they were first interested in STEM or what initially led to their interest in STEM, very little research tracing early interest and potential correlations to future careers exists. Students who reported an interest in science subjects in the 8th grade were three times more likely to persist through college and obtain a STEM degree and a career in science when compared to those who did not show any interest in science (Tai et al., 2006; Venkataraman et al., 2010). Math achievement in middle school does play a role in the odds of matriculating to college and obtaining a STEM degree and then a career in the sciences. Eighth graders who showed an interest in science subjects and were considered high math achievers were 34% more likely to obtain a STEM bachelor's degree and have a career in the sciences (Tai et al., 2006). Interest in science is a crucial component of persistence, but math skill development at a young age can also detract students from the STEM path or encourage them to persist.

Middle school is a unique transition point for students when considering the development of STEM interests (Sheridan et al., 2011). Students allow their peers to impact their interests in STEM courses (Ambady et al., 2001; Shapiro & Williams, 2012; Tillinghast & Mansouri, 2020). Young students face enormous pressure in middle school to be well-liked by their peers and be popular (Cridge & Cridge, 2015). Devoting time to STEM activities can be seen as "nerdy," causing students to downplay their interest in STEM to fit in with their peers. The converse is true as well - students who had peers engaged in STEM activities were more likely to engage in them themselves with the support of their peers (Cridge & Cridge, 2015). Additionally, young girls decide which classes to take based on the friends they have in those classes (Tillinghast & Mansouri, 2020; Cridge & Cridge, 2015). These influences reinforce the importance of peer interactions at a critical stage in a student's educational development and demonstrate the impact on the STEM education pipeline.

Gender stereotypes also play a significant role in students' activities in middle school (Ambady et al., 2001; Shapiro & Williams, 2012). As noted earlier, middle school is the time when females begin to lose interest in STEM activities due to the pressure to fit in with their peers. Additionally, young women tend to perform lower than their male peers and lose confidence in their abilities to do well in STEM due to a perception of female inferiority in STEM subjects (Else-Quest et al., 2010; Young et al., 2017). Furthermore, performance in math is a predictor of persistence in STEM (Else-Quest et al., 2010). Middle school-aged boys are more confident in their math abilities and more motivated to do well than girls at the same grade level. Young girls tend to internalize negative gender stereotypes, causing stress and a lack of perceived confidence leading to lower scores than their male peers in math concepts and exams (Else-Quest et al., 2010). Efforts to quell the impact of stereotypes are needed to ensure young students are not discouraged before they have had a real opportunity to explore the depth and breadth of STEM.

Besides peer influence, students' interest in STEM can also be affected by parents' and teachers' perceptions of gender and aptitude in math and other STEM subjects (Ambady et al., 2001; Cridge & Cridge, 2015; Shapiro & Williams, 2012). These perceptions can be transferred to young women and thus play a critical role in their interests (Shapiro & Williams, 2012). By the time students are in middle school, their beliefs about what they can achieve tend to resemble the stereotypes held by adults around them (Cridge & Cridge, 2015; Ambady et al., 2001). Furthermore, gender stereotypes can shape a mother's beliefs about her children's attitudes. Career choices and internal ideas about whether a student can achieve success in math and science courses are heavily influenced by the mother at a young age, which is not surprising since mothers tend to be the primary caregivers of children at this age (Cridge & Cridge, 2015; Eccles, 2011). Gender equity in education, especially in middle school, where students tend to solidify their self-perceptions about their capabilities in STEM, is essential for building girls' self-confidence and valuing of STEM education. Building confidence in abilities can translate into young women persisting through rigorous STEM courses in high school and college and bring us closer to fixing the leaky STEM career pipeline (Cridge & Cridge, 2015).

High School Exposure to STEM

When students advance to high school, they begin to concentrate more on where they want to go to college, what to major in, and what career paths they may have available to them (Tillinghast & Mansouri, 2020). There are multiple avenues to foster interest in STEM at this age. After-school and summer enrichment programs play a significant role in promoting interest and increasing academic achievement in STEM (Baran et al., 2019; Heise et al., 2020; Young et al., 2017). These programs enable students to develop critical problem-solving skills and explore different STEM areas that are missing in a traditional school setting (Dierking, 2007). Furthermore, high school programs with only significant academic components are less effective at promoting and sustaining student interest in STEM. These results highlight the need for well-rounded programs that build upon many skills, not just technical or STEM-related skills. In order to work in STEM fields, students will need to develop soft skills and learn how to socialize and be effective communicators as much as they need to know advanced mathematics and science (Young et al., 2017). In comparing various meta-analyses of the effects of out-of-school enrichment programs, results indicate that out-of-school programs for high school students focusing on achievement can positively affect students' interest in STEM (Cooper et al., 2000; Lauer et al., 2006; Young et al., 2017).

The achievement gap observed among high school students from low socioeconomic backgrounds versus those from high socioeconomic backgrounds is partially attributed to their different experiences in summer programs (Alexander et al., 2007; Tran, 2010). Out-of-school experiences and summer programs are valuable resources and assist with improving student learning and retaining diverse students in the STEM education pipeline. Out-of-school programs that link learning outcomes to the curriculum taught in a high school classroom provide students with more significant learning gains (Tran, 2010). For example, students could apply concepts and knowledge about magnetism and electricity from a field trip to an interactive science museum to what they learned in the classroom. They displayed higher levels of expertise due to the field trip (Anderson et al., 2000; Tran, 2010). Furthermore, if STEM programs are relevant to students' home lives and their communities, students are more likely to develop emotional connections to the curriculum they learn in school (Dierking, 2007). For example, students who participate in community-based science projects, such as urban planning and gardening, helped increase their interest in science by seeing how science affected their communities (Fusco, 2001; Tran, 2010). These emotional connections will help motivate students to major in STEM degrees, persist through challenging courses, and pursue careers more aligned with their passions (Dierking, 2007; Young et al., 2017). Participation in STEM Summer programs and out-of-school programs in high school can have a long-lasting impact on academic achievement (Baran et al., 2019; Heise et al., 2020; Young et al., 2017).

Student Attitudes Toward STEM Majors and Careers

Many studies have explored the STEM education pipeline from high school to college. There are many connections between performance in high school, perceptions of STEM majors and careers, and the choices students make when it's time to pick their major in college. For example, those who scored higher on the Scholastic Aptitude Test (SAT), had higher GPAs, and took advanced mathematics courses such as calculus, were more likely to have favorable views of STEM subjects and persist in graduating with a STEM degree from college. Those who pursued advanced placement (AP) courses such as AP calculus and AP physics in high school were also more likely to have favorable views of STEM subjects and were more likely to obtain a STEM degree; similar trends were discovered when looking at high school science grades (Gayle & Ampaw, 2011; Green & Sanderson, 2018).

STEM enrichment programs (out-of-school or during summer breaks) can enhance academic performance and achievement in high school. Several STEM programs for high school students have reported an impact on student attitudes and persistence in STEM (Baran et al., 2019; Kong et al., 2014; Markowitz, 2004; Saw et al., 2019; Winkelby, 2007). Students who participate in STEM programs have reported feeling more prepared for advanced science courses such as AP biology and gained a competitive edge over other students by learning advanced techniques beyond what they would have access to in a high school environment. Students also reported increased confidence in scientific abilities and increased motivation to excel in their classes after the STEM program was complete (Markowitz, 2004; Saw et al., 2019; Winkleby, 2007). In some cases, students felt inspired to seek additional opportunities after completing one formal STEM program linked to a university (Kong et al., 2014; Markowitz, 2004; Winkleby, 2007).

Marginalized Students

Many historically underrepresented students (Black, Brown, and Indigenous) tend to grow up in the U.S. in lower or middle-class families and with parents who worked blue-collar jobs without much upward mobility (Lui et al., 2006; Thomas & Moye, 2015). Students from low socio-economic backgrounds don't have as many opportunities to attend STEM out-of-school programs due to their costs, creating a gap in their learning (Alexander et al., 2007; Tran, 2010). As a result, these students tend to have more negative perceptions of STEM majors and careers due to a lack of exposure and awareness of what STEM means (Alexander et al., 2007; Dierking, 2007). Falling out of the pipeline is a reality for historically underrepresented students compared to their White counterparts, and it is essential to acknowledge this creates an achievement gap (Singleton & Linton, 2006). Strategies need to be developed at every stage of a student's education experience - from elementary school through higher education - to fully close the achievement gap and provide quality education to all students equally (Singleton & Linton, 2006).

Being stereotyped for academic achievement or failure can affect attitudes, performance, and persistence through the STEM pipeline (Lui et al., 2006; McGee, 2018; Thomas & Moye, 2015). Asians are typically the most successful group in STEM education and careers, and as a result, their STEM education to career pipeline is often considered problem-free. The most common narrative of Asians is of the model minority due to their high levels of academic success and higher income levels. However, this narrative about Asians is often used as a divisive strategy that pits Asians and Blacks against each other. When Black students received higher grades in STEM courses than their Asian or White peers, it was considered a fluke, and Asians who scored lower than expected were often seen as failures. Black students have to fight the intellectual inferiority narrative society has placed on them in STEM subjects. The strain of negative stereotypes can be enough for Black students to either work relentlessly to push through them or choose to leave under the pressure of societal expectations, racial discrimination, imposter syndrome, lack of representation, and cultural isolation and fall out of the STEM pipeline (McGee, 2018). These negative stereotypes affect self-efficacy and, thus, retention in STEM education.

What follows is a review of the reciprocal impact of university partnerships with K-12 institutions on building positive attitudes towards STEM majors and careers. Parents' role in creating a supportive environment at home that builds and fosters STEM interest will also be discussed.

University Partnerships

Formalized educational programs with linkages to universities and research programs are associated with students' positive attitudes towards majoring in STEM and pursuing careers in STEM (Baran et al., 2019; Bischoff et al., 2008; Heise et al., 2020; Kong et al., 2014; Winkleby, 2007). High school students who participated in university-sponsored programs showed significant positive differences between the pre-and posttests on student attitudes towards STEM and an increased interest in STEM careers (Baran et al., 2019; Saw et al., 2019). Even formalized programs for students in middle school are more likely to encourage students to pursue careers in STEM (Kong et al., 2014). These findings, however, are not consistent across all university backed enrichment programs, whether they are after school or during the summer. For example, the assessment of the Summer Science Exploration Program at Hampshire College Amherst in Massachusetts (a partnership with three urban high schools) revealed that every participant became less interested in STEM as they got older. Some students realized STEM wasn't their passion, as noted in program surveys, and others may have been affected by the program's lack of engagement or appropriate level of instruction (Gibson & Chase, 2002). The seven-week Prefreshman Engineering Program at the University of Texas, on the other hand, reported very positive results; high school students who participated in this out-of-school program indicated higher levels of positive attitudes towards math and math-related careers (Saw et al., 2019). The success of programs is likely to vary due to program length, depth, breadth, and experience of faculty and graduate students teaching the program.

While university partnerships with K-12 institutions to develop STEM programs are beneficial for the students, there are also many benefits for the participating universities. When faculty and graduate students of a research institution engage with the public in various formal and informal ways, they improve their science communication skills and publish at higher rates than those who do not engage with the public (Brownell et al., 2013; Clark et al., 2016). Both graduate students and faculty can use opportunities to work with students and the public to refine how they communicate their scientific findings to the general population (Brownell et al., 2013).

Moreover, there are more funding opportunities for faculty who participate in outreach activities. For example, the National Science Foundation (NSF) has made it a requirement for all grant proposals to include a section on contributing to the achievement of society. These funding opportunities encourage faculty to work with schools and the community and incorporate educational outreach components into grant proposals (Clark et al., 2016). Overall, the benefits are two-fold: scientists can have greater funding opportunities by incorporating educational outreach in their grants, and students can work with faculty and graduate students on cutting-edge research.

The Role of Parents

Parents are an essential part of a child's life from the moment they are born, and they have the power to influence a child's education and attitudes towards academic subjects. A parent's influence typically extends beyond just academic subjects and on to careers and future aspirations as well (Cridge & Cridge, 2015). Parents can even have a more substantial influence on their child's career aspirations and choices than their teachers and counselors at school (Ing, 2013; Trusty, 1996).

Parents can influence their children's beliefs and goals, either directly or indirectly, through various measures at home. For example, parents can set high expectations for advanced mathematics courses, which are predictors for future STEM success, or encourage their children to participate in out-of-school enrichment programs (Tai et al., 2006). Parents can also encourage their children to consider the intrinsic motivations for being in a STEM career - mainly all the opportunities to help people and solve future problems plaguing our country. Parents who focus on motivating their children through intrinsic means and providing support in mathematics significantly influenced their child's persistence in STEM careers. In contrast, parents who focused only on extrinsic motivations saw a negative influence on their children's STEM interests and career goals (Ing, 2013). Parental involvement in a child's academic pursuits benefits the children's learning as well as the success of the school (Hoover-Dempsey et al., 2002). Various achievement factors improve with parental involvement, such as attendance, classroom behavior, positive perceptions about more challenging courses, and higher aspirations for postsecondary education (Hoover-Dempsey et al., 2002, Ingram et al., 2007). Parents can also influence their children through their own career choices and career paths. Children as young as four years old are aware of their parents' work and careers, and they begin to internalize the positive and negative impressions of those careers. If young children see their parents struggle while working in STEM careers, they will internalize the negative aspects of those careers at a very young age, and it could influence them when it comes time to make their own decisions about pursuing STEM careers. Conversely, if children at young ages have a positive impression of their parents working in STEM careers, they are less likely to be intimidated or fear the challenging academic courses necessary to succeed in the STEM education pipeline (Buzzanell et al., 2011; Cridge & Cridge, 2015).

Parents also play a crucial role financing college degrees. Parents who have navigated the college system are more equipped to assist their children with applying and paying for college than those who have not attended college. Parents unfamiliar with the demands of college and the cost of attending STEM institutions may negatively reinforce these beliefs and prevent a child from even pursuing a STEM degree. Typically, low-income students and/or marginalized students are more affected when their parents are not prepared to pay for college (Cridge & Cridge, 2015; Downs et al., 2008). Overall, the long-term effects of family dynamics can influence a student's college selection and career decision-making.

The Role of Formal and Informal Leaders

While universities can partner with K-12 institutions across all grade levels to ensure a steady flow of quality learning and engagement, formal and informal leaders within K-12 are equally essential to ensuring the leaky pipeline gets fixed. What follows is a review of the importance of informal leaders, such as counselors and teachers, and formal leaders, such as principals, in fostering students for success in STEM fields. Formal leaders in education, such as principals, have the power and authority to influence change. Also, while informal leaders (counselors and teachers) lack high-level authority in the school environment, they still impact students' success and achievement (Lindsey et al., 2018).

The Role of Counselors

Counselors play a vital role in the academic success of middle and high school students; their role is very broad and can vary with location and student demographics (Kim et al., 2020; Mau et al., 2016; Woods & Domina, 2014). As curriculum and schools transform, so should the services provided by counselors. Their attitudes toward students can impact students' personal, social, and academic achievement, highlighting the need for quality counselors (Kim et al., 2020; Mau et al., 2016). High schools with comprehensive and outcome-based counseling programs provide comprehensive support services to their students. These schools have many high-achieving students who feel better prepared for college (Lapan et al., 2001; Lapan et al., 1997; Mau et al., 2016). Counselors typically spend their time with students based on what they perceive as essential for their role as leaders in a school setting. They spend a significant portion of their time helping students with course selection and navigating the college admissions and financial aid process, indicating the level of importance counselors play in the higher education choices of students (Bridgeland & Bruce, 2011; Freeman, 1997; Masse et al., 2010; Mau et al., 2016). Counselors also spend a considerable amount of time helping students with academic and career development by providing information on enrichment programs to increase their chances of getting into highly selective universities (Woods & Domina, 2014).

The ratio of students to counselors is also an important factor for student success in schools. Schools with smaller counselor ratios are more effective at targeting students and assisting them with their academic needs (Farmer-Hinton, 2008; Farmer-Hinton & McCullough, 2008; Rosenbaum et al., 2010; Woods & Domina, 2014). Counselors are obligated to work with all students in an equitable manner. These students can be gifted, first-time English learners, or come from immigrant households with severe socio-economic challenges. Large caseloads can prevent counselors from equitably serving all students (Farmer-Hinton, 2008; Farmer-Hinton & McCullough, 2008; Rosenbaum et al., 2010). For example, students who attend high schools with smaller caseloads for counselors are about 7% more likely to talk to counselors about college compared to their peers at schools with larger caseloads and larger ratios of students to counselors. By the 12th grade (a crucial year for college decision-making and planning), this gap increases to 10% (Woods & Domina, 2014).

Schools with smaller counselor caseloads are also better able to assist their students with taking necessary college admissions exams such as the SAT and American College Testing (ACT). Fifty-nine percent of high school students who attend schools with high counselor-to-student ratios take the SAT or ACT. This rate increases to seventy percent when looking at the number of high school students who take the SAT and ACT but attend schools with low counselor-to-student ratios (Woods & Domina, 2014). These results suggest a correlation between counselor caseload and taking the necessary exams to go to college or apply for national scholarships. Students attending high schools with the largest counselor caseloads attend 4-year colleges at the lowest rates (39%) compared to students in schools with the smallest caseloads (49%) (Woods & Domina, 2014).

The Role of Teachers

School teachers play a significant role in fostering STEM subjects and careers, given how many hours and days a week a student spends in school or working on school assignments. Teachers can influence the future jobs students are interested in and can contribute up to thirty percent of the variance in student achievement, indicating the importance of quality teaching (Cridge & Cridge, 2015; Hattie, 2004; Maltese & Tai, 2011; Wright et al., 2018). The sciences, in general, are complex subjects to master and teach (Cridge & Cridge, 2015). A great science teacher could change student expectations for what it means to have a future in a science career. Quality STEM instruction is essential for retaining students in the STEM education to career pipeline (Han & Hur, 2021; Wright et al., 2018). Thus, quality teachers in biology or chemistry, for example, impact students' interest in biology and chemistry and career aspirations tied to these subjects (Wright et al., 2018).

Despite the importance of STEM teachers, the US is currently experiencing a shortage of quality K-12 STEM teachers (Han & Hur, 2021; Wright et al., 2018). To increase the number of STEM students who graduate high school and pursue STEM in college, the factors leading to high teacher turnover need better understanding. Turnover is usually a result of teachers leaving a school to pursue a teaching job at a different school due to organizational issues or leaving the field altogether (Han & Hur, 2021; Wright et al., 2018). The shortage of quality teachers is even more pronounced in STEM subjects since courses such as math and science are general requirements for graduating high school across the nation (Han & Hur, 2021, Borman & Dowling, 2008). The education level (bachelor's, master's, or Ph.D.) also plays a role in STEM teachers' upward mobility. Experienced STEM teachers with more advanced degrees are more likely to switch schools for better opportunities (schools in wealthier districts) than experienced STEM teachers with just bachelor's degrees and are less likely to leave the teaching field due to dissatisfaction than novice STEM teachers (Han & Hur, 2021). However, the increased advancement opportunities decrease the odds of novice STEM teachers leaving the teaching field by nearly 44% (Han & Hur, 2021). More qualified STEM teachers ensure that more students will get quality STEM education and are more likely to stay on track to pursuing STEM in college (Han & Hur, 2021; Maltese & Tai, 2010, 2011). Teacher retention rates are a national problem with ramifications for the future of the STEM workforce if left unaddressed.

The Role of Principals

Principals are also important in contributing to students' success in transitioning from high school to college. Studies have documented principals' beliefs on student achievement, and their leadership is vital for creating a culture promoting postsecondary education (Collins & O'Brien, 2011; Kim et al., 2020; Tingle et al., 2017; Woods & Domina, 2014). Principals' stances on school cultures can affect students' achievement in STEM subjects by either providing the necessary support structures or demotivating them by not prioritizing STEM. For example, the odds of taking STEM postsecondary classes increased by 22% when principals reported that helping students prepare for college was their school's most important goal for their high school counseling programs (Kim et al., 2020). It is essential principals create and help facilitate an environment where students are encouraged to pursue STEM in higher education through the effective hiring of qualified STEM teachers and an appropriate number of counselors to ensure low ratios.

An effective principal should be a successful agent of positive change within their schools, which requires adequate training. They are ultimately held accountable for academic success and college readiness (Davis and Darling-Hammond, 2012; Tingle et al., 2017). Academic success in STEM subjects hinges on the quality of the school leader; therefore, it would be logical for districts to invest in the training and development of their principals, who generally have more influence over teaching when they are directly involved with curriculum design: principals are more likely to influence student achievement when teaching and learning outcomes are the central focus of their work (Hatisaru et al., 2020; Pietsch & Tulowitzki, 2017; Tingle et al., 2017). The principal's role in enhancing STEM curriculum and achievement would depend mainly on how the principal believes STEM subjects should be taught, necessitating proper training (Hatisaru et al., 2020). The presence of the Covid-19 pandemic provided an added challenge for principals to be successful leaders. In addition to focusing on traditional aspects of leading schools and teachers and counselors, principals were expected to support students and parents in learning in a highly uncertain and rapidly changing environment.

Formal and informal educators faced the seemingly impossible task of supporting students and parents transitioning to online learning during the early onset of the Covid-19 pandemic. This created a unique set of problems that needed to be addressed in order for students to succeed in the new online environment, necessitated by government regulations surrounding safety concerns with in-person instruction. What follows is a discussion on how precollege programs were affected and later adapted to the Covid-19 pandemic.

Challenges Created by Covid-19 Pandemic

The Covid-19 pandemic created a number of challenges for high school students and precollege programs. The rapidity with which educators had to respond to school closures is unparalleled as the pandemic disrupted the normal school life of millions of students across the country. The pandemic inflicted a massive emotional burden that threatened the mental health of students (Gavin et al., 2020; Grubic et al., 2020). Positive and negative feelings (e.g., enjoyment, interest, burnout, and anxiety) are associated with students' attention, concentration, engagement, and persistence in academic activities and can positively or negatively correlate with academic achievements (Eccles, 2005; Madigan and Curran, 2020; Moeller et al., 2020). Students at all academic levels reported having negative overall feelings and low energy levels as a result of the nationwide school lockdowns (Camacho-Zuniga et al., 2021). It is crucial for educational institutions to remain aware of the negative mental health issues and take time to assist students in addressing the issues related to the Covid-19 pandemic. Precollege programs can be better equipped to design and implement programs that will address the negative emotions and feelings surrounding education while achieving the academic goals of their programs.

Precollege Programs Shifting Online During Covid-19

Precollege programs all over the world had to shift to online formats due to the Covid-19 pandemic and school lockdowns. Many precollege programs at universities that had previously offered on-campus and residential summer programs in various academic disciplines were shifting to online formats for the first time (Tewolde, 2021). Kettering University and Virginia Tech are examples of higher education institutions with a long-standing history of offering in-person and residential precollege programs that were forced to shift online in the summer of 2020 and 2021, respectively (Geary et al., 2022; Tewolde, 2021). Both programs are designed to attract and motivate high school students to the field of engineering (Geary et al., 2022; Tewolde, 2021). The program at Kettering University evolved from a residential in-person program to a remote program with each student receiving a supply kit that included various electronics and robotics materials. At the end of the program, Kettering University reported positive impacts on student experiences. 92.3% of students enrolled reported being satisfied with the program and 69.2% of students reported that the summer camp improved their awareness of the computer engineering field (Tewolde, 2021). Virginia Tech reported challenges with regard to student energy and zoom fatigue and decided to modify its program to reduce screen time. Participants also reported a lack of connections with people, which may have been attributed to the limiting nature of using Zoom and reducing the number of hours on screen (Gear et al., 2022). Overall, it is evident that the shift to the online environment as a result of the pandemic impacted the experiences of students in precollege programs. The impact yielded positive results in student satisfaction in some cases and negative results in others. Despite the challenging times, precollege programs can be successful if they understand the challenges students are facing in the Covid-19 environment and modify the curriculum and activities to ensure positive impacts.

Precollege Research Adaptations to Pandemic Restrictions

While some precollege programs were easier to shift online due to the ability to mail out kits or use web-browser based programs and Zoom, others were not so easy. Precollege biology research programs are fundamentally a hands-on process and Covid-19 posed additional challenges as students at home don’t have access to the same lab equipment they could have at a large research institution (Berg et al., 2021). Biology research programs are typically designed to simulate comprehensive and authentic experiments where students will learn basic laboratory skills and techniques and experience challenges of doing repeatable experiments, such as the Wisconsin Inquiry-based Scientist Teacher Education Partnership Program (WInSTEP) at the University of Wisconsin-Milwaukee (UWM). WInSTEP involved both a precollege program for middle school and high school students as well as a teacher training program, all funded by the

National Institute of Health. The researchers decided that it would still be possible for them to develop curriculum that would allow for students to think about experimental design (as opposed to actively designing experiments in person) as well as acquire real-time data for analysis similar to what students would have normally collected in person. The success would hinge on the ability to develop online substitutes for in-person experimentation as well as expert video-making and data science. Through collaboration between staff, researchers, and the Department of Film, Video, and Animation, and New Genres, the original curriculum for the high school students was eventually transitioned to a full online research immersion program (Berg et al., 2021).

The model presented by UWM provided students with the ability to have a research immersion experience and the virtual experiments made it possible for students to analyze as much data as they would have precovid. Furthermore, since the program staff were doing the data collection rather than the high school students, errors due to poor lab techniques were minimized. However, creating the online version required substantial technological expertise and created a deficit in student learning since students were not able to learn the physical habits of active scientific research (Berg et al., 2021). This study suggests the importance of using online components to complement student research experiences rather than replace hands-on student experimentation.

Precollege Program Modality and Student Success

There is a gap in the literature when it comes to precollege programs that transitioned to online during the pandemic and then re-transitioned back to in-person (or a hybrid format) post-pandemic, utilizing lessons learned from either modality. This suggests there is little evidence to determine if precollege program modality has an impact on maintaining student interest in

STEM or if there are correlations between program modality and retention in STEM by gender or race as a result of the Covid-19 pandemic.

Summary

The goal of this literature review is to provide a strong foundation of expertise that supports this research design. The review draws upon extensive research exploring the gaps in the STEM pipeline for students in elementary through high school. It is essential to analyze what encourages the interest in STEM subjects and the age it happens (Green & Sanderson, 2018; Young et al., 2017). This information will better equip K-12 institutions, universities, and communities to help spark and sustain interest in STEM subjects to fulfill the growing demand for STEM jobs and address future global issues (Gayle & Ampaw, 2011; Sheridan et al., 2011). It is also important to explore what enables students to persist through challenging STEM courses in high school and later in college (Gayles & Ampaw, 2011; Green & Sanderson, 2018). Clearly, a diverse approach to improve students' interest and retention in STEM is needed. Making future college and career decisions can be complex and involve many different internal factors (self-perception of ability) and external factors (family, income, classroom experiences, and out-of-school program experiences) that can be stressors. It is essential to create educational programs and initiatives to help combat stressors that lead students away from STEM fields and careers (Else-Quest et al., 2010; Young et al., 2017). The review of SCT and the core concept of self-efficacy provided a foundation for understanding how to frame prior research studies to support my research design. Therefore, this study's methodology is grounded in empirical research and a theoretical framework.

Chapter 3 METHODOLOGY

Review of Study Purpose

This study explored whether attitudes and interests toward science differ as a function of course modality in precollege life science research courses. In addition, this study explored whether scientific skills and knowledge differ as a function of course modality. The results of this study will help inform educators on how to remain innovative and cultivate STEM interests in turbulent times. The results will also help inform the partnership on which course modality is optimal for retaining student interest in the life sciences. Funding for laboratory space, equipment, and staff can be costly, and knowing which program modality is optimal will help ensure that efforts are appropriately maximized.

In this chapter, I first restate my research questions and discuss the research design process. I also review all data collection instruments and the study's participants and outline the statistical analyses performed. This chapter will conclude with a discussion of the study's limitations.

As a review, the primary focus of this study was to investigate the influence of course modality (in-person, online, and hybrid) within life-science research immersion programs on the interests and attitudes of research scholars toward science, along with the consequential effects on their scientific skills and knowledge. Two secondary questions help explore this primary question:

(1) Did the delivery method of the life science research immersion program have an impact on research scholars' perceptions, interests, and attitudes toward science following participation in either the in-person, online, or hybrid research program?

(2) Did the delivery method of the life science research immersion program have an impact on research scholars' changes in scientific skills and knowledge?

Research Design

This study is an analysis of a student data set from a research-based precollege program that encompasses three different program modalities. This quantitative analysis focused study used student data from sixteen (16) 10-week academic research immersion quarters. The data collected is under an existing IRB, and no new data outside of the scope of the IRB was analyzed. The data set included student demographic information collected through an online application before attending the program. Only local students from San Diego County who were accepted into the program and who completed the program (and all assessments) were included in the study. The decision to exclusively draw participants from San Diego County for this study, despite the program's broader inclusion of out-of-state and international students, enabled a concentrated examination of the local context and allowed for a nuanced analysis of the unique challenges, opportunities, and dynamics within the educational landscape of San Diego County. Furthermore, the localized focus facilitated a more effective comparative analysis as out-of-state and international students have different educational backgrounds that could significantly impact statistical analyses. The data set also included results from the TOSRA, a 70-question survey. The TOSRA is administered to participants at the beginning (pretest) and the end (posttest) of the course. Finally, scientific reasoning assessments were provided to participants at the beginning (pretest) and at the end (posttest) of the course. The data collection instruments section discusses the TOSRA survey and scientific reasoning assessments in more detail. All three of these data collection instruments are examined further below after a brief discussion on what each course modality entails.

About the Research Immersion Courses

Four different topics were used as the basis for the research immersion curricula: 1) relative genetic diversity of Shaw's agave and associated microbes with Point Loma Ecological Reserve, San Diego; 2) heat-shock induced gene expression changes in *Caenorhabditis elegans*; 3) sex-specific gene expression in *Drosophila melanogaster* heads; 4) transcriptional changes in *Caenorhabditis elegans* due to environmental toxicant exposure. Each of the four topics was managed by a lead project researcher in collaboration with three instructional assistants.

Students, regardless of modality, were expected to actively participate in all phases of scientific research: hypothesis building, experimental design, adequate sample size and biological replication, mastering relevant molecular biology concepts and executing experiments, data collection, and statistical analysis. All students worked in groups to create science posters presented at the end of the course in a formal symposium attended by their peers, parents, local life-science industry leaders, and science professionals from the sponsoring university. Professional development sessions were a part of the curriculum. These sessions helped students build resumes, cover letters, and prepare for internships in relevant STEM fields.

In-Person Courses

The in-person courses were taught at a wet lab sponsored by the university. For each ten-week research immersion course, students spent about ten hours per week participating in lectures, performing experiments, analyzing data, and formulating scientific communication. Every class session was in-person. Students went to the lab three days a week for two hours at a time in the evening and then spent about four hours a week on homework, reading assignments, and research projects. All quizzes and assessments were completed in person and in class.

Hybrid Courses

Students in hybrid courses attended lab sessions twice a week in the evening, each lasting two hours. These sessions were dedicated to conducting experiments and learning lab techniques. Additionally, they attended a two-hour online lecture through Zoom, where they discussed theoretical content, reading materials, data analysis, and group projects, supported by the instructional and research team. Hybrid courses also used Canvas as the learning management system. All Zoom lectures were recorded and available to students, with all instructional materials, assignments, quizzes, and assessments provided through Canvas.

Online Courses

The online courses used Canvas as the learning management system. Unlike in-person or hybrid students, online students did not perform experiments themselves. Instead, the research and instruction team conducted the experiments, and the data was integrated into the curriculum and lectures. Students attended synchronous online lectures via Zoom for about ten hours per week and analyzed data provided by the team.

Lectures were held three times a week in the evening, each lasting two hours. Students were expected to spend an additional four hours weekly on reading assignments, data analysis, and group research projects. Instead of conducting their own experiments, students focused on exploring experimental design with the instructional team and then working with the data they were provided to conduct their analyses and complete their research projects.

All Zoom lectures were recorded and accessible to students. Instructional materials, reading assignments, quizzes, and assessments were delivered through Canvas. Additionally, students created virtual science posters for a virtual symposium attended by peers, parents, and life-science industry leaders. Online students also participated in professional development sessions to enhance their resumes and prepare for STEM internships.

The study design included three phases. In Phase I, data from the in-person, online, and hybrid research courses was collected and aggregated. The in-person courses took place over three quarters (summer 2019, fall 2019, and winter 2020). The online courses took place over seven quarters (summer 2020, fall 2020, winter 2021, spring 2021, summer 2021, fall 2021, and winter 2022). The hybrid courses took place over six quarters (spring 2022, summer 2022, fall 2022, winter 2023, spring 2023, and summer 2023). Phase II included the analysis of each course modality separately. Phase III consisted of a comparative analysis across all three learning modalities.

Data Collection Instruments

There were three primary data collection instruments: (1) student application, (2) TOSRA, and (3) scientific reasoning assessment.

Student Application

The first instrument is the student application that every interested student fills out before being accepted into the research immersion course. Students are asked to provide basic demographics such as first and last name, full home address, phone number, citizenship status, gender, race, date of birth, current grade level, current high school, expected graduation date from high school, current GPA, parent or guardian contact information, parent or guardian highest level of education, number of people in the household, and household income. Students are also asked to provide a short 500-word essay on how the topic of the course they are applying to attend relates to their everyday lives. A copy of the application is included in the Appendices.

TOSRA

The second data collection instrument is the TOSRA. The TOSRA is a validated and standardized assessment tool commonly used to assess whether students' attitudes toward science can be influenced by their learning environment (Fraser, 1978, 1981). The survey contains 70 questions over seven categories: Social Implications of Science (S), Normality of Scientists (N), Attitudes to Scientific inquiry (I), Adoption of Scientific Attitudes (A), Enjoyment of Science Lessons (E), Leisure Interest in Science (L), and Career Interest in Science (C) (Fraser 1978, 1981). Each question is on a 5-point Likert scale (5 = "strongly agree" to 1 = "strongly disagree") and each category contains ten questions. Questions that indicate a negative outlook on science were transformed so that higher scores indicate a positive outlook on science while negative scores indicate a negative outlook on science (Schriesheim et al., 1991). A copy of the TOSRA is included in Appendix B.

Reliability

Fraser tested the reliability of the TOSRA categories using the Cronbach α coefficient, which yielded high values, indicating that each TOSRA category had acceptable internal consistency reliability (1981). Fraser further tested reliability by evaluating test-retest reliability of the TOSRA categories. His results indicated that all TOSRA categories displayed proficient test-retest reliability (Fraser, 1981). This is highly relevant as all students in the research immersion courses are given the TOSRA twice, once as a pretest on the first day of the course and then they repeat the test as a posttest on the final day of the course; the participants are given one hour to complete the test.

Validity

TOSRA category intercorrelations are very low (Frasier, 1981). The mean correlation of a given category with the other six categories had moderately low values. There were three categories with higher scale intercorrelations: Enjoyment of Science Lessons (E), Leisure Interest in Science (L), and Career Interest in Science (C). While they are separate categories with different questions, there is an expectation of intercorrelation as students who enjoy science lessons are also more likely to have a career interest in science and pursue leisure interests in science (Frasier, 1981). Despite this moderate intercorrelation between these three categories, the TOSRA categories are entirely separate:

> Furthermore, as all of the values of the scale intercorrelation were smaller than the square root of the product of the corresponding scale reliabilities, which is the value representing perfect conceptual equivalence, it was justifiable to maintain all seven TOSRA scales as separate dimensions. (p. 4)

This is useful for statistical analysis as each category will be analyzed separately, as mentioned in the data analysis section.

Scientific Reasoning Assessment

The third data collection instrument was the scientific reasoning assessment. Researchers and instructors created these assessments to assess critical thinking, reasoning, and scientific literacy capabilities. The researchers and instructors were also involved in the curriculum development and teaching of each course. The questions on the scientific reasoning assessment were based on learning objectives, including hypothesis formulation, experimental design, analytical skills through fluorescence and western blotting gel image interpretation, and data interpretation through bar graphs with complex experimental conditions. Students took the assessment at the beginning of the course (pretest) and at the end of the course (posttest) and were given one hour to complete it in each instance. The assessments were graded by the instructors assigned to teach each course. For the purpose of this study, one instructor was assigned the task of reviewing the scoring for all scientific reasoning assessments for students in this study to ensure grading consistency and a more reliable analysis of scores.

The students who took the in-person courses all had the same scientific reasoning assessment. The online and hybrid cohorts were exposed to two different versions. The two versions were designed to be of similar difficulty. The assessment, in all versions, contained five questions testing hypothesis formulation (Q1), experimental design (Q2), analytical skills through fluorescence (Q3), Western blotting gel image interpretation (Q4), and data interpretation through bar graphs with complex experimental conditions (Q5). For the online and hybrid cohorts, students were administered one version of the assessment at the beginning of each program and the other version at the end. Copies of all scientific reasoning assessments are included in Appendix C.

Sample and Population

The sample size of the study was limited to high school students in San Diego County who applied to the research immersion programs through a free online application. Local students were recruited for in-person and hybrid courses due to the need to be physically at the lab. Students across the country were recruited for the online courses. In either case, program managers at the sponsoring University used social media and partnership networks with local high school districts to promote the program. Program managers also attended local STEM conferences to market the courses and provided informational sessions to interested students and their families. Only San Diego County students who completed the courses were included in this study. There were a variety of prerequisites that limited the number of students who could be accepted into the courses. For example, in-person and hybrid courses require that students be at least sixteen years of age due to university policies regarding minors in a lab. There were also curricular prerequisites such as biology or introductory statistics. However, some students were admitted despite not meeting such prerequisites. The other limiting factor was the essay question on the application. All students were required to write a 500-word essay on how the course topic affected their daily lives. A program assistant from the sponsoring university reviewed the essays to ensure completeness. Plagiarism on the essay portion of the application was not accepted, and students were denied acceptance if plagiarism was seen. The final limiting factor to this study was the cost associated with participating in the research immersion program. While scholarships were offered every quarter, they were limited, and the tuition could have been cost-prohibitive, limiting those who wanted to apply and attend the program.

Quantitative Data Analysis

The data collection for this study took place over three phases, with Phase I focusing on the data collection of the three data instruments for the in-person courses, online courses, and hybrid courses. Phase II focused on analyzing the data collected in Phase I for each modality separately. The final phase included a comparative analysis of all three learning modalities to determine if there is a relationship between the change in student achievement or interest in pursuing STEM as a result of the modality of the course. Table 1 below summarizes analytical approaches and their correlation to the research questions.

Table 1.

Analytical Approaches to Addressing the Research Questions

Research Questions	Instrument	Statistical Tests
1) Did the delivery method of the life science research immersion program have an impact on research scholars' perceptions, interests, and attitudes toward science following participation in either the in-person, online, or hybrid research program?	TOSRA Pre and Post Tests	Wilcoxon T-Test Kruskal-Wallis Test
2) Did the delivery method of the life science research immersion program have an impact on research scholars' changes in scientific skills and knowledge?	Scientific Reasoning Pre and Post Assessments	Friedman Test ANOVA Kruskal-Wallis Test

I used JMP Pro v.16 for the data analysis in Table 1 above. The Wilcoxon signed-rank test was used to assess whether there were significant changes in attitudes from pretest to posttest within each of the three modalities of the TOSRA. This non-parametric test was chosen because the TOSRA data collected was not normally distributed. The analysis was repeated for each of the 70 questions in the TOSRA and one composite analysis for each of the seven categories (ten questions per category). The Kruskal-Wallis test was used to examine if there were significant differences in the mean pooled TOSRA posttest scores across the three modalities. The Kruskal-Wallis and Wilcoxon tests provided a comprehensive understanding of this data instrument. While the Kruskal-Wallis may be robust at comparing means, it may not capture individual-level changes, where the Wilcoxon test is more valuable. This dual approach enhances the reliability of this study and can provide practical insights for educators and curriculum designers by understanding both the overall impact of course modality and the individual-level changes in attitudes.

Similarly, I used the ANOVA and the Friedman test to analyze the pre and post-scientific reasoning assessment scores to answer question 2. The ANOVA was used to assess if there were significant differences in the mean scores of the assessment for the in-person courses in the study. The Friedman test is a non-parametric test used to determine if there were significant differences in the median scores of the scientific reasoning assessments across the study's online and hybrid courses due to the data's non-normality. It helped determine if there were any statistically significant changes in scientific reasoning assessment abilities within the two modalities. Finally, I pooled all pre-assessment and post-assessment scores to conduct a Kruskal-Wallis test to explore overall differences in mean pretest and posttest scores, providing a broader understanding of how the different course modalities could have impacted scientific reasoning abilities. Looking at the pretest data can provide insight into any significant changes that students may have prior to learning course content. By pooling the post-assessment data, I was able to examine the cumulative effect of various course modalities on scientific reasoning performance. This approach can help capture any general trends or distinctions that may exist across all modalities.

While some qualitative data may be available through automated institutional post-course surveys, they are anonymous. They cannot be tied to the demographics, the TOSRA, or the scientific reasoning assessment. These institutional post-course surveys given by the sponsoring university cannot be customized per program and are generic enough that the same post-course survey is given to all students who take courses at the university. Furthermore, they were not required, and the post-course survey completion rates were about 20% for the research immersion program. As a result, they were left out of the analysis. The essays students provided during the application process could also be another source of qualitative data. The essay was a broad and open-ended question prompting the student to explain how biodiversity influences their lives. (Appendix A) However, the essay was not used to exclude any applicants from the program (unless plagiarized), and the range of responses varied and typically included personal or educational motivations for wanting to participate in the program. The essay was used as a tool to have students think about the impact of biodiversity and provide insight for the instructional team on the types of students that were attending the program. There was no standard right or wrong response to the essay. Due to the purposeful lack of guidelines around the structure of the essay, the essay responses were left out of the analysis.

Positionality

As a practitioner in higher education at the post-secondary institution where the study took place, I brought a wealth of experience and insight into the context in which the research was situated. My familiarity with institutional policies, practices, and culture informed my interpretation of the study's findings. While my positionality could potentially introduce bias, it is important to note that I removed myself from the application processes, ensuring impartiality in participant recruitment. Additionally, I did not teach courses or play a role in creating, administering, or scoring assessments, thereby minimizing any potential influence on the data collection and analysis processes. Nonetheless, I acknowledge the possibility that my professional background and institutional affiliation may still shape my perspective, and I remain committed to maintaining transparency and rigor throughout the research process.

Chapter 4 RESULTS

This study examined the impact of course modality on attitudes and interests toward science. In addition, this study explored whether scientific skills and knowledge differ as a function of course modality for precollege research programs. Within this overarching research focus, there were two areas of inquiry: (1) Did the delivery method of the life science research immersion program have an impact on research scholars' perceptions, interests, and attitudes towards science following participation in either the in-person, online, or hybrid research program? (2) Did the delivery method of the life science research immersion program have an impact on research scholars’ changes in scientific skills and knowledge? This chapter addresses these research questions through a synthesis of quantitative data.

Participants

As mentioned in Chapter 3, only San Diego County students who completed the pre-and post-TOSRA and the pre-and post-assessments were included in this study. Table 2 below is a summary of the number of students per modality that are included in the analysis of this study.

Table 2.

Participants in the Study

	In-person	Online	Hybrid
Number of Cohorts	3	7	6
Number of Students	55	91	40

TOSRA Analysis

The following analysis of the TOSRA pre and post-survey results was repeated for each program modality. This TOSRA analysis section will conclude with a comparative analysis of all three modalities. For each modality, the mean differences were determined from the average scores of all San Diego County students participating in the program. The TOSRA contains 70 questions over seven categories: Social Implications of Science (S), Normality of Scientists (N), Attitudes to Scientific Inquiry (I), Adoption of Scientific Attitudes (A), Enjoyment of Science Lessons (E), Leisure Interest in Science (L), and Career Interest in Science (C). Each category is composed of ten questions (Fraser, 1978; 1981).

A one-tailed Wilcoxon t-test was conducted to determine if the pre-and post-TOSRA differences were statistically different from one another within each of the seven categories of the TOSRA, as shown in Tables 3, 4, and 5 below. A one-tailed test was chosen assuming a positive impact of the program on students' results, thereby focusing the analysis on detecting improvements in the surveyed categories. A one-tailed Wilcoxon t-test was also conducted for each question to determine if pre- and post-TOSRA differences were statistically different, as shown in Tables 6, 7, and 8 below.

Table 3.

Wilcoxon Test for 7 TOSRA Categories for In-Person Cohorts

Category	Differences, post-pre program			Significance	
	Mean	SD	SE	P value summary	P value
Social Implications of Science (S)	0.0296	0.1256	0.03971	ns	0.1475
Normality of Scientists (N)	0.1171	0.1739	0.05498	*	0.041
Attitude to Scientific Inquiry (I)	0.04963	0.08728	0.0276	ns	0.0781
Adoption of Scientific Attitudes (A)	0.04848	0.1631	0.05158	ns	0.1953
Enjoyment of Science Lessons (E)	0.02084	0.09234	0.0292	ns	0.3262
Leisure Interest in Science (L)	0.1114	0.06486	0.02051	***	0.001
Career Interest in Science (C)	0.02239	0.1296	0.04097	ns	0.4688

*p < 0.05; **p < 0.01; ***p < 0.001; ns = not significant

The results of the Wilcoxon test on the seven TOSRA categories for the in-person cohorts are highlighted in Table 3 above. A Wilcoxon test revealed a statistically significant increase in the Normality of Scientists (N) category following participation in the in-person program, $z = 1.74$, $p = 0.041$, with a small effect size ($r = 0.23$). The Wilcoxon test also revealed a statistically significant increase in the Leisure Interest in Science (L) category following participation in the in-person program, $z = 3.09$, $p = 0.001$, with a moderate effect size ($r = 0.42$).

Table 4.

Wilcoxon Test for 7 TOSRA Categories for Online Cohorts

Category	Differences, post-pre program			Significance	
	Mean	SD	SE	value summar	P value
Social Implications of Science (S)	0.08681	0.7637	0.02532	***	0.0006
Normality of Scientists (N)	0.08022	0.7927	0.02628	**	0.0023
Attitude to Scientific Inquiry (I)	0.06264	0.8797	0.02916	*	0.032
Adoption of Scientific Attitudes (A)	0.006593	0.7707	0.02555	ns	0.7964
Enjoyment of Science Lessons (E)	-0.05714	0.6232	0.02066	**	0.0058
Leisure Interest in Science (L)	0.01099	0.8351	0.02768	ns	0.6915
Career Interest in Science (C)	-0.08022	0.738	0.02447	**	0.0011

*p < 0.05; **p < 0.01; ***p < 0.001; ns = not significant

The results of the Wilcoxon test on the seven TOSRA categories for the online cohorts are highlighted in Table 4 above. A Wilcoxon test revealed a statistically significant increase in the Social Implications of Science (S) category following participation in the online program, $z = 3.24$, $p = 0.0006$, with a moderate effect size ($r = 0.34$). The Wilcoxon test also revealed a statistically significant increase in the Normality of Scientists (N) category following participation in the online program, $z = 2.83$, $p = 0.0023$, with a moderate effect size ($r = 0.30$).

The Wilcoxon test also revealed a statistically significant decrease in the Enjoyment of Science Lessons (E) category following participation in the online program, $z = 2.52$, $p = 0.0058$, with a low effect size ($r = 0.26$). There was also a statistically significant decrease in the Career Interest in Science (C) category following participation in the online program, $z = 3.06$, $p = 0.0011$, with a moderate effect size ($r = 0.32$).

Table 5.

Wilcoxon Test for 7 TOSRA Categories for Hybrid Cohorts

Category	Differences, post-pre program			Significance	
	Mean	SD	SE	P value summary	P value
Social Implications of Science (S)	0.0541	0.7842	0.0392	ns	0.2880
Normality of Scientists (N)	0.1568	0.9412	0.0471	***	0.0004
Attitude to Scientific Inquiry (I)	0.0892	0.8166	0.0408	ns	0.8591
Adoption of Scientific Attitudes (A)	-0.0297	1.0184	0.0509	ns	0.6205
Enjoyment of Science Lessons (E)	-0.0432	0.7423	0.0371	ns	0.1607
Leisure Interest in Science (L)	0.0643	0.7976	0.0399	ns	0.3881
Career Interest in Science (C)	0.0429	0.7284	0.0364	ns	0.3164

*p < 0.05; **p < 0.01; ***p < 0.001; ns = not significant

The results of the Wilcoxon test on the seven TOSRA categories for the hybrid cohorts are highlighted in Table 5 above. A Wilcoxon test revealed a statistically significant increase in the Normality of Scientists (N) category following participation in the hybrid program, $z = 3.35$, $p = 0.0004$, with a large effect size ($r = 0.53$).

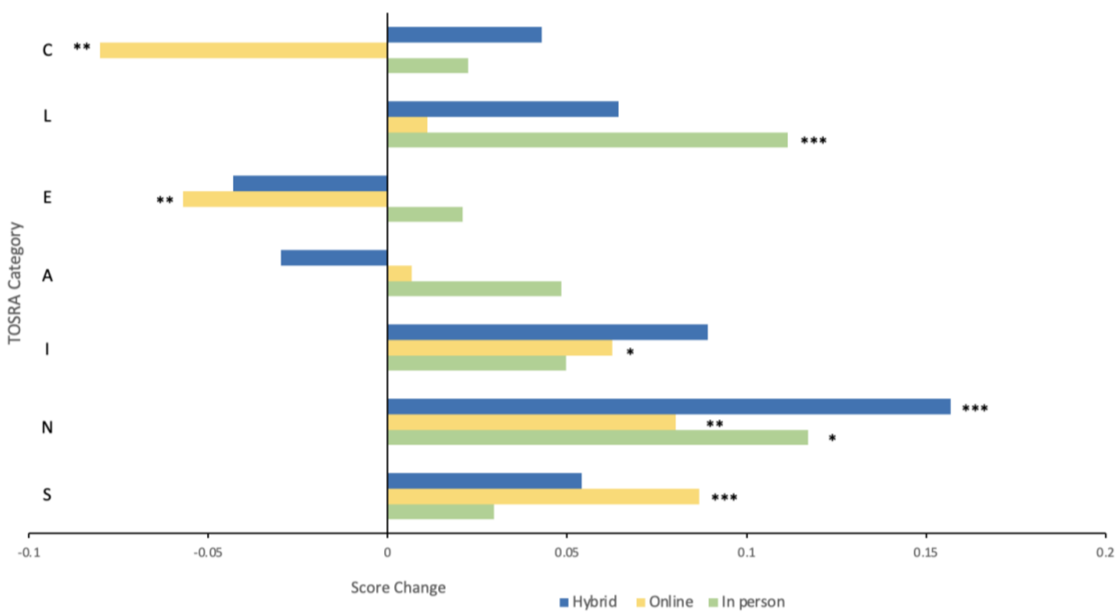


Figure 1.

Change by TOSRA Category per Course Modality

It is interesting to note that the Leisure Interest in Science (L) category was statistically significant for in-person programs but not for online and hybrid programs. Furthermore, the Normality of Scientists (N) category was the only statistically significant category across all modalities, as highlighted in Figure 1 above. In comparing the means across the categories and different modalities in Figure 1, The Career Interest in Science (C) displayed a negative trend only for the online courses, whereas the Enjoyment of Science Lessons (E) was negative in both the online and hybrid courses. The Adoption of Scientific Attitudes (A) displayed a negative trend only for the hybrid courses. The hybrid courses also have a smaller sample size, contributing to increased response variation in comparison to the other two modalities. To further this analysis of the TOSRA, Tables 6, 7, and 8 below highlight the individual questions that were found to be statistically significant within each course modality.

Table 6.

Wilcoxon Test Results on Individual TOSRA Questions for In-person Cohorts

Question #, Question (category)	Mean	SD	SE	Significance	P value	Effect Size r
Q9, Scientists are about as fit and healthy as other people. (N)	0.4909	0.1294	0.0038	**	0.0011	0.4129

**p < 0.01

A Wilcoxon test revealed a statistically significant increase in Q9 of the TOSRA following participation in the in-person program, $z = 3.06$, $p = 0.0011$, with a moderate effect size ($r = 0.41$). Q9 belongs to the Normality of Scientists (N) category, which was found to be statistically significant as a category for the in-person cohorts, $z = 1.74$, $p = 0.041$, with a small effect size ($r = 0.23$) (Table 3).

Table 7.

Wilcoxon Test Results on Individual TOSRA Questions for Online Cohorts

Question #, Question (category)	Mean	SD	SE	Significance	P value	Effect Size r
Q15, Public money spent on science in the last few years has been used wisely. (S)	0.2088	0.9252	0.097	*	0.034	0.1913
Q36, Too many laboratories are being built at the expense of the rest of education. (S)	0.1648	0.764	0.0801	*	0.0425	0.1806
Q9, Scientists are about as fit and healthy as other people. (N)	0.2418	0.7355	0.0771	**	0.0023	0.2971
Q16, Scientists do not have enough time to spend with their families. (N)	0.1758	0.8379	0.0878	*	0.0483	0.1742
Q23, Scientists like sport as much as other people do. (N)	0.1868	0.5946	0.0623	**	0.0035	0.2827
Q37, Scientists can have a normal family life. (N)	0.1538	0.6132	0.0643	*	0.0188	0.2180
Q31, I would prefer to do my own experiments than to find out information from a teacher. (I)	0.2527	0.864	0.0906	**	0.0064	0.2609
Q52, It is better to ask the teacher the answer than to find it out by doing experiments. (I)	0.1868	0.7136	0.0748	*	0.0143	0.2295
Q39, I find it boring to hear about new ideas. (A)	-0.1538	0.6654	0.0698	*	0.03	0.1972
Q61, I look forward to science lessons. (E)	-0.1099	0.4583	0.048	*	0.0245	0.2064
Q49, A job as a scientist would be boring. (C)	-0.1209	0.5341	0.056	*	0.0335	0.1920

*p < 0.05; **p < 0.01; *** p < 0.001

The Wilcoxon test also revealed a statistically significant increase in Q9 of the TOSRA following participation in the online program, $z = 2.83$, $p = 0.0023$, with a moderate effect size ($r = 0.30$), as shown in Table 7 above. The Wilcoxon test also found a statistically significant increase in Q23 of the TOSRA following participation in the online program, $z = 2.70$, $p = 0.0035$, with a small effect size ($r = 0.28$). Both Q9 and Q23 belong to the Normality of Scientists (N) category, which was found to be statistically significant as a category, $z = 2.83$, $p = 0.0023$, with a moderate effect size ($r = 0.30$) (Table 4).

Finally, the Wilcoxon test revealed a statistically significant increase in Q31 of the TOSRA following participation in the online program, $z = 2.49$, $p = 0.0064$, with a low effect size ($r = 0.26$). Q31 belongs to the Attitudes to Scientific Inquiry (I) category. The online cohorts were the only group to have a question from this category statistically significant at $p < 0.01$.

Table 8.

Wilcoxon Test Results on Individual TOSRA Questions for Hybrid Cohorts

Question #, Question (category)	Mean	SD	SE	Significance	P value	Effect Size r
Q9, Scientists are about as fit and healthy as other people.(N)	0.5	0.8165	0.1291	***	0.0004	0.5301
Q23, Scientists like sport as much as other people do. (N)	0.375	0.9524	0.1506	*	0.0238	0.3132
Q31, I would prefer to do my own experiments than to find out information from a teacher. (I)	0.275	0.7506	0.1187	*	0.0346	0.2873
Q39, I find it boring to hear about new ideas. (A)	-0.1538	0.6654	0.0698	*	0.0422	0.2729

*p < 0.05; **p < 0.01; *** p < 0.001

Similarly to the in-person and the online cohorts, the Wilcoxon test revealed a statistically significant increase in Q9 of the TOSRA following participation in the hybrid program, $z = 3.35$, $p = 0.0004$, with a large effect size ($r = 0.53$), as shown in Table 8 above.

In analyzing the Wilcoxon test results from Tables 6, 7, and 8, there are clear themes across the modalities. The Normality of Scientists (N) category, along with some of the individual questions in this category, seem to have statistical significance at each modality, with varying effect sizes. The online cohorts had more questions that were statistically significant ($p < 0.01$) than the other two modalities, although the majority of the questions were only significant at $p < 0.05$ (Table 6). The hybrid cohort was the only one to have Q9 significant at $p = 0.0004$ with a large effect size ($r = 0.53$) (Table 8).

Comparative Analysis

To complete the TOSRA analysis, a Kruskal-Wallis test with Dunn's post hoc pairwise comparison was conducted to compare the effect of the posttest results between the in-person, online, and hybrid groups for each question on the TOSRA. The questions that had statistical significance are highlighted below in Table 9.

Table 9.

Kruskal-Wallis Results for Mean Posttest Scores Across Course Modalities

Question	P-value	Comparison	Dunn's Adjusted P-value	Significance
Q10 - Doing experiments is not as good as finding out information from teachers (I)	0.028	Hybrid vs. In-person	0.185	ns
		Hybrid vs. Online	0.023	*
		In-person vs. Online	0.395	ns
Q37 - scientists can have a normal family life (N)	0.034	Hybrid vs. In-person	0.128	ns
		Hybrid vs. Online	0.031	*
		In-person vs. Online	0.598	ns
Q51 - scientists are just as interested in art and music as other people are (N)	0.009	Hybrid vs. In-person	0.264	ns
		Hybrid vs. Online	0.007	**
		In-person vs. Online	0.264	ns
Q58 - few scientists are happily married (N)	0.044	Hybrid vs. In-person	0.041	*
		Hybrid vs. Online	0.145	ns
		In-person vs. Online	0.318	ns

* $p < 0.05$; ** $p < 0.01$; ns = not significant

The Kruskal-Wallis with Dunn's post hoc multiple pairwise comparisons test for the mean posttest scores of the TOSRA yielded four statistically significant questions, three of them came from the Normality of Scientists category (Table 9). The Kruskal-Wallis test showed there was a significant difference of means for Q10 ($p = 0.028$), Q37 ($p = 0.034$), Q51 ($p = 0.009$), and Q58 ($p = 0.044$). In Dunn's post hoc pairwise comparison test, Q10 (doing experiments is not as good as finding out information from teachers) demonstrated statistical significance in the hybrid vs. online comparison ($p = 0.023$), but not in the hybrid vs. in-person or in-person vs. online comparisons. Q37 (scientists can have a normal family life) also demonstrated statistical significance for the hybrid vs. online comparison ($p = 0.031$) but not the hybrid vs. in-person or in-person vs. online comparisons. Q51 (scientists are just as interested in art and music as other people) also demonstrated statistical significance for the hybrid vs. online comparison ($p = 0.009$) but not the hybrid vs. in-person or in-person vs. online comparisons. Q58 (few scientists are happily married) demonstrated statistical significance for the hybrid vs. in-person comparison ($p = 0.041$) but not the hybrid vs online or in-person vs. online comparisons.

The observed significance in questions such as Q10 (doing experiments is not as good as finding out information from teachers) and Q37 (scientists have a normal family life) for the hybrid versus online comparison underscores the potential influence of instructional methods on students' perceptions of science-related activities and career prospects. This finding suggests that the hybrid modality may offer unique advantages or challenges compared to purely online instruction in shaping student attitudes towards science.

Similarly, the significant differences observed in Q51 (scientists are just as interested in art and music as other people) and Q58 (few scientists are happily married) highlight the importance of considering both course format and content in understanding student perceptions of the scientific profession. These findings may inform curriculum design and teaching strategies aimed at fostering a more inclusive and holistic view of science among students. The post hoc results in Table 9 emphasize the nuanced impact of instructional methods on various aspects of sustaining interest in STEM fields. These findings underscore the importance of examining individual questions to uncover subtle variations in student outcomes across course modalities. These insights contribute to a more refined understanding of how the instructional format may influence specific aspects of student interest in STEM.

Scientific Reasoning Assessment Analysis

As mentioned in Chapter 3, the scientific reasoning assessment data analysis differed for the course modalities. The students in the in-person courses were all administered one version of the test, while those in the online and hybrid courses were exposed to two different versions of equal difficulty. In all versions of the assessments, the question's subject matter remained consistent. The questions tested hypothesis formulation (Q1), experimental design (Q2), analytical skills through fluorescence (Q3), Western blotting gel image interpretation (Q4), and data interpretation through bar graphs with complex experimental conditions (Q5). The assessments can be found in Appendix C. Students who chose not to submit either the pre- or post-assessment were excluded from the assessment score analyses. The analysis for each modality is below.

In-Person Courses

Student's scientific reasoning scores per question were normalized to percentages of total possible points for that question. Student improvement on each question was calculated by subtracting the normalized pre-assessment score from the normalized post-assessment score. To compare pre- and post-assessment student performance on each question for individual quarters, a one-way analysis of variance (ANOVA) was performed, followed by multiple pairwise comparisons with Bonferroni correction (Table 10). The normality conditions required for conducting an ANOVA were confirmed to be met, allowing for the application of this parametric test.

Table 10.

One-Way ANOVA for In-Person Assessments

Session and question no.	Difference			Significance	Adjusted P Value	df	Eta Squared η^2
	Mean	SE	95.00% CI				
Summer 2019							
Q1	-2.083	4.234	- 14.58 to 10.42	ns	>0.9999	23	0.0111
Q2	9.896	4.188	- 2.469 to 22.26	ns	0.1887	23	0.0092
Q3	4.167	3.557	- 6.335 to 14.67	ns	>0.9999	23	0.0033
Q4	6.667	2.225	0.09672 to 13.24	*	0.0452	23	0.0506
Q5	4.861	3.817	- 6.410 to 16.13	ns	>0.9999	23	0.0076
Fall 2019							
Q1	4.167	9.146	-25.97 to 34.30	ns	>0.9999	11	0.0048
Q2	29.17	6.765	6.876 to 51.46	**	0.0086	11	0.0648
Q3	5.000	5.708	- 13.81 to 23.81	ns	>0.9999	11	0.0047
Q4	11.67	9.679	- 20.22 to 43.56	ns	>0.9999	11	0.0104
Q5	-2.778	4.51	- 17.64 to 12.08	ns	>0.9999	11	0.0135
Winter 2020							
Q1	-6.41	3.931	- 17.67 to 4.851	ns	0.6928	25	0.0017
Q2	-8.974	6.354	- 27.18 to 9.228	ns	>0.9999	25	0.0006
Q3	5.000	5.152	- 9.759 to 19.76	ns	>0.9999	25	0.0032
Q4	8.013	6.738	- 11.29 to 27.32	ns	>0.9999	25	0.0198
Q5	7.212	5.511	- 8.577 to 23.00	ns	>0.9999	25	0.0035

Note. Statistical values from one-way ANOVA for average scores per question (Q), by quarter. P values were adjusted through Bonferroni's multiple comparison test. *, P<0.05; **, P<0.01; ns, not significant

A one-way ANOVA revealed a statistically significant difference between the pre- and post-assessment for Question 4 in the summer 2019 cohort ($p < 0.05$) but with a fairly low effect size and Question 2 in the fall 2019 cohort ($p < 0.01$), with a moderate effect size. Q4 is a Western blotting gel image interpretation question and Q2 is about experimental design. There were no statistically significant differences between the pre and posttest assessments for the winter 2020 class (Table 10).

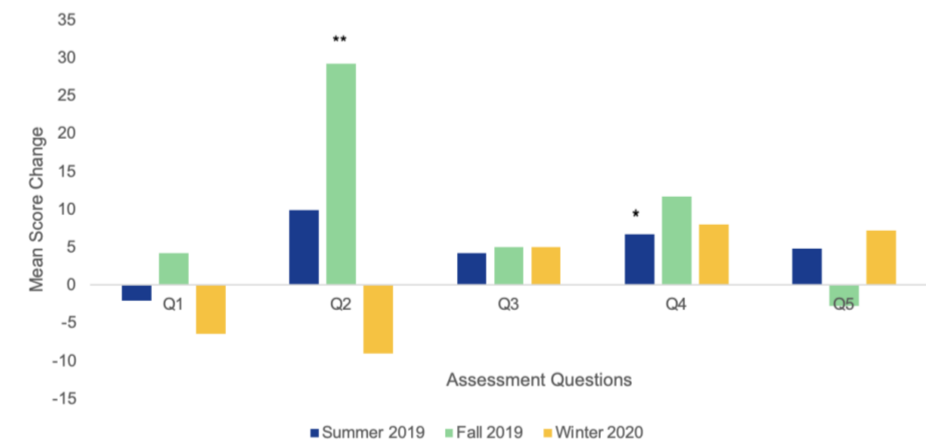


Figure 2.

Mean Score Differences in Assessments for In-Person Cohorts

Despite the lack of statistically significant changes in the other questions, students did show improvements on four out of the five questions in the summer 2019 and fall 2019 cohorts. Three questions showed overall improvements in the winter 2020 cohort indicating students improved scientific reasoning capabilities as a result of the research program (Figure 2).

Online Courses

A distinct difference between the online and in-person courses was that they used two different pre- and post-scientific assessments. Different questions were used to test the same five concepts in both versions of the test and were deemed equally difficult by the research staff. As a result of having two different versions of the test, the scores were no longer on the same scale. For example, Q1 in version 1 may have been worth three points, while it was worth five points in version 2. Thus, the scientific reasoning assessments for the online courses were normalized using the Circle-arc method (Livingston & Kim, 2008; 2010). Each of the scores in version 2 was equated to the corresponding question scores in version 1. The equated version 2 and version 1 scores were found to be non-normal via the Shapiro-Wilk test for all questions. An analysis using the Friedman test with Dunn's correction for multiple comparisons was conducted to compare pre- and post-assessment student performance on each of the five questions.

Table 11.

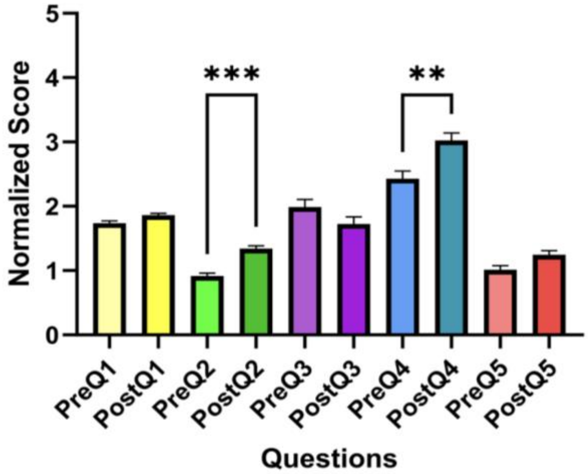
Friedman Test Results for Online Course Assessments

Total N	159
Kendall's W	0.2816
Test Statistic	403
Degrees of Freedom	9
Asymptotic Sig. (1-sided test)	<0.0001

Dunn's multiple comparisons test	Rank sum diff.	Significant?	Summary	Adjusted P Value
PreQ1 vs. PostQ1	-45.5	No	ns	>0.9999
PreQ2 vs. PostQ2	-212	Yes	***	0.0004
PreQ3 vs. PostQ3	125.5	No	ns	0.1005
PreQ4 vs. PostQ4	-189	Yes	**	0.0023
PreQ5 vs. PostQ5	-97	No	ns	0.362

**, P<0.01; *** P<0.00; ns = not significant

As highlighted in Table 11 above, there was a statistically significant difference between pre-and post-assessment performance on the five questions for the online courses, $\chi(9)^2 = 403$, $p < 0.0001$. Kendall's W indicates a small effect size. Dunn's post hoc tests were carried out, and there were significant differences between performance on the pre-and post-assessment for Q2 ($p < 0.001$) and for Q4 ($p < 0.01$).



Note. From pre- to post-assessment, student scores significantly increased on Q2 and Q4, while decreased on Q3. Error bars represent standard error of means. Statistical significance: $^{**}p < 0.01$, $^{***}p < 0.001$

Figure 3.

Friedman Test Results for Online Course Assessments

Despite only seeing statistical significance in Q2 (experimental design) and Q4 (Western blotting gel image interpretation) in the post hoc summary, student scores improved for four out of the five questions in the scientific reasoning assessment (Figure 3). Q1 (hypothesis formulation) and Q5 (data interpretation through bar graphs with complex experimental conditions) also saw increases. Q3, a question about analytical skills through fluorescence, saw a decrease but not significantly.

Hybrid Courses

Two versions of the pre-and post-scientific assessments were also used for the hybrid courses, just as in the online courses. As a result, the scientific reasoning assessments for the hybrid courses were also normalized using the Circle-arc method (Livingston & Kim, 2008; 2010). Each of the scores in version 2 was equated to the corresponding question in version 1. The equated version 2 and version 1 scores were found to be non-normal via the Shapiro-Wilk test for all questions. An analysis using the Friedman test with Dunn's correction for multiple comparisons was conducted to compare pre- and post-assessment student performance on each of the five questions.

Table 12.

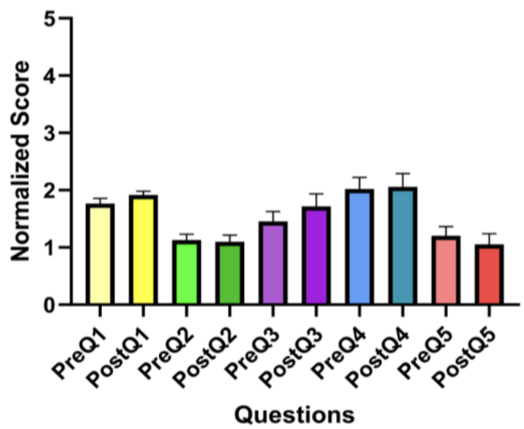
Friedman Test Results for Hybrid Course Assessments

Total N	32
Kendall's W	0.1763
Test Statistic	50.78
Degrees of Freedom	9
Asymptotic Sig. (1-sided test)	<0.0001

Dunn's multiple comparisons test	Rank sum diff.	Significant?	Summary	Adjusted P Value
PreQ1 vs. PostQ1	-21	No	ns	>0.9999
PreQ2 vs. PostQ2	5	No	ns	>0.9999
PreQ3 vs. PostQ3	-37	No	ns	0.6331
PreQ4 vs. PostQ4	5	No	ns	>0.9999
PreQ5 vs. PostQ5	25	No	ns	>0.9999

Note. ns= not significant

As highlighted in Table 12 above, there was a statistically significant difference between pre-and post-assessment performance on the five questions, $\chi (9)^2 = 50.78$, $p < 0.0001$. Kendall's W indicates a small effect size. Dunn's post hoc tests were carried out, and there was found to be no statistically significant difference between the pre- and post-assessment performance on each of the five questions.



Note. Friedman's test with Post hoc analysis using Dunn's correction showed no significant positive difference between the pre- and post assessment questions

Figure 4.

Friedman Test Results for Hybrid Course Assessments

Despite the lack of statistical significance in the Friedman test for the hybrid courses, there were minor improvements in the posttest performance, as indicated in Figure 4 above. Q1, hypothesis formulation, and Q3, analytical skills through fluorescence, showed subtle yet noteworthy shifts. For Q1, students demonstrated a slight increase in their ability to articulate clear and testable hypotheses, which may suggest a qualitative refinement in their understanding of scientific inquiry. In Q3, although quantitative scores did not exhibit significant improvement, students' performance metrics hinted at potential progress in fluorescence analysis skills. These improvements could be attributed to various factors such as increased exposure to relevant content, enhanced practice opportunities, or the cumulative effect of instruction across multiple skill domains. Conversely, Q5, focused on data interpretation through bar graphs with complex experimental conditions, saw a decline in performance. While this decrease was not statistically significant, it raises the question about the effectiveness of instructional approaches or the complexity of the material presented. The observed trend in Q5 may prompt further investigation into instructional design strategies aimed at supporting students' comprehension of complex experimental data formats.

Interestingly, Q2 and Q4, pertaining to experimental design and Western blotting gel image interpretation respectively, showed no discernible differences between pre- and posttest scores. This consistency suggests a potential plateau in students' proficiency in these areas or the need for more targeted interventions to stimulate growth.

Comparative Analysis

Phase 3 of the quantitative analysis of the scientific reasoning assessment results included comparing results across all modalities. Raw online and hybrid scientific assessment scores were graded using different scales between questions and versions. As a result, all scores for all three modalities were normalized to the maximum possible score for each question.

Pretest Comparative Analysis

A Kruskal-Wallis test with Dunn's post hoc pairwise comparison was performed to assess the overall differences in the five scientific reasoning assessment questions (pretest) among the students who took the courses in-person, online, and in the hybrid course modalities. For the pretest pairwise comparisons, only Q3 (analytical skills through fluorescence) and Q4 (Western blotting gel image interpretation) were statistically significant, as shown in Table 13 and Table 14 below.

Table 13.

Kruskal-Wallis Results for Pretest Q3 Across all Course Modalities

Total N	358
Test Statistic	9.053
Degrees of Freedom	2
Asymptotic Sig. (1-sided test)	0.0108

Dunn's multiple comparisons test	Mean rank diff.	Significant?	Summary	p-value
In Person PreQ3 vs. Online PreQ3	-42.66	Yes	**	0.0099
In Person PreQ3 vs. Hybrid PreQ3	-23.62	No	ns	0.7161
Online PreQ3 vs. Hybrid PreQ3	19.04	No	ns	0.7521

** $p < 0.01$

Q3 in the pretest exhibited a statistically significant difference between in-person and online courses (adjusted $p = 0.0099$). However, no significant differences were observed in Q3 between the in-person and hybrid courses or online and hybrid courses ($p > 0.05$) (Table 13).

Table 14.

Kruskal-Wallis Results for Pretest Q4 Across all Course Modalities

Total N	358
Test Statistic	18.47
Degrees of Freedom	2
Asymptotic Sig. (1-sided test)	<0.0001

Dunn's multiple comparisons test	Mean rank diff.	Significant?	Summary	p-value
In Person PreQ4 vs. Online PreQ4	-58.01	Yes	***	0.0002
In Person PreQ4 vs. Hybrid PreQ4	-19.18	No	ns	>0.9999
Online PreQ4 vs. Hybrid PreQ4	38.83	No	ns	0.0604

*** $p < 0.001$

Similarly, Q4 in the pretest exhibited a statistically significant difference between in-person and online courses ($p = 0.0002$). However, no significant differences were observed in Q4 between the in-person and hybrid courses or online and hybrid courses (adjusted $p > 0.05$) (Table 14).

Posttest Comparative Analysis

A Kruskal-Wallis test with Dunn's post hoc pairwise comparison was also performed to assess the overall differences in the five scientific reasoning assessment questions (posttest) among the students who took the courses in-person, online, and in the hybrid course modalities. The results are highlighted in table 15 below.

Table 15.

Kruskal-Wallis Results for Posttest Q4 Across all Course Modalities

Total N	358
Test Statistic	12.29
Degrees of Freedom	2
Asymptotic Sig. (1-sided	<0.0021

Dunn's multiple comparisons test	Mean rank diff.	Significant?	Summary	p-value
In Person PostQ4 vs. Online PostQ4	-42.96	Yes	**	0.01
In Person PostQ4 vs. Hybrid PostQ4	-2.959	No	ns	>0.9999
Online PostQ4 vs. Hybrid PostQ4	40	Yes	*	0.0498

* $p < 0.05$; ** $p < 0.01$

As shown in Table 15 above, Q4 in the posttest exhibited a statistically significant difference between in-person and online courses ($p = 0.01$) and between the online and hybrid courses ($p = 0.0498$). However, no significant differences were observed in Q4 between the in-person and hybrid courses ($p > 0.05$). The online format outperformed the other two modalities.

Chapter 5 DISCUSSION

Overview of the Problem

Addressing the central problem of declining interest among high school students in pursuing STEM at post-secondary institutions will require a holistic approach. The solution requires repeated and targeted efforts to engage students in STEM activities to address the cracks in the STEM education pipeline. Precollege programs should consider the advantages of research immersion courses or similar applied active learning models to cultivate analytical and practical STEM skills and increase students' interest in science in and beyond the classroom. Research immersion courses, such as the ones discussed in this study, have the potential to be realistic and practical within a university research system infrastructure, and many such programs are available to students. Considering the importance of students' early engagement in research for their success in STEM, a collaborative program with universities or research entities seems a more practical solution for improving STEM education (Baran et al., 2019; Bischoff et al., 2008; Heise et al., 2020; Kong et al., 2014; Winkleby, 2007). Development of practical and applied STEM skills should assure more retention in STEM majors during schooling and in STEM careers beyond academic experience.

Review of the Theoretical Framework

This dissertation posits that cognitive, behavioral, and environmental factors influence students' learning, following Bandura's insights from 1991. Bandura's framework, outlined in 1977 and 1986, identifies three interacting constructs—personal factors (age, previous education, expectations, attitudes), environmental factors (family, peer influence, teacher guidance), and behavioral elements (skills, self-efficacy). Consequently, the evolution of career aspirations, interests, and perseverance in STEM is an outcome of the interplay among the three principal constructs. Elements such as family, socioeconomic status, school atmosphere, and individual traits can function as catalysts or impediments in shaping students' academic perspectives on STEM disciplines and careers. Insight into the dynamics of these factors can impact the growth of academic proficiency in STEM and the selection of future professions.

Summary of Key Findings

The goal of this study was to answer two questions through the lens of social cognitive theory: (1) Did the delivery method of the life science research immersion program have an impact on research scholars' perceptions, interests, and attitudes towards science following participation in either the in-person, online, or hybrid research program? (2) Did the delivery method of the life science research immersion program have an impact on research scholars' changes in scientific skills and knowledge? To answer these questions, the study encompassed three phases of data collection and analysis: Phase I involved gathering data from three instruments for in-person, online, and hybrid courses, while Phase II focused on analyzing this data for each modality separately. The final phase conducted a comparative analysis across all three learning modalities to explore potential relationships between changes in student achievement or interest in STEM and the course modality. The Wilcoxon signed-rank test assessed significant changes in attitudes within each modality, considering the non-normally distributed TOSRA data. The analysis was repeated for each of the 70 questions in the TOSRA and included one composite analysis for each of the seven categories. Additionally, the Kruskal-Wallis test was utilized to examine overall differences in mean pooled TOSRA posttest scores across the three modalities. Complementing this, the ANOVA and Friedman tests were employed to analyze pre and post-scientific reasoning assessment scores, assessing mean score differences for in-person courses and median score differences for online and hybrid courses, respectively. Pooling all pre-assessment and post-assessment scores for a final Kruskal-wallis test provided a broader understanding of how different course modalities may impact scientific reasoning abilities, capturing trends and distinctions across all modalities. This dual approach enhances the study's reliability and offers practical insights for educators and curriculum designers. The key findings for each research question are below.

Research Question 1 Key Findings

Finding One In-person modality supported increases in student perceptions and attitudes towards the leisure interest of science.

Finding one suggests that the in-person modality of the life science research immersion program played a pivotal role in fostering positive changes in research scholars' perceptions and attitudes toward the leisure interest in science. To delve deeper into this, we can draw on SCT, which posits that individuals learn not only from direct experiences but also by observing and modeling others' behaviors, attitudes, and outcomes (Bandura, 1977; 1986). In the context of the in-person research immersion programs, the physical presence of the instructional team, peers, and the lab environment likely provided research scholars with rich observational experiences.

According to SCT, individuals engage in observational learning, acquiring new knowledge and skills by observing the actions and outcomes of those around them (Bandura, 1977; 1986). In the in-person setting, research scholars directly witnessed their instructors' and peers' enthusiasm, passion, and expertise. This interactive and interpersonal nature of the in-person interactions created a social environment that facilitated the modeling of scientific curiosity and engagement, aligning with the principles of SCT. Furthermore, the in-person modality provided more immediate and personalized feedback, allowing the research scholar's to experience the tangible impact of their scientific curiosity and efforts. This real-time feedback loop, consistent with SCT, reinforced attitudes and perceptions by connecting scholars' actions with favorable outcomes.

In summary, finding one not only highlights the positive impact of the in-person modality on research scholars' perceptions and attitudes towards the leisure interest of science but also suggests that SCT provides a valuable framework for understanding the underlying mechanisms at play. The in-person setting, with its emphasis on observational learning, interactive experiences, and immediate feedback, aligns with the principles of SCT and offers insights into how educational programs can effectively shape individuals' attitudes and interests in the fields of science.

Finding Two Online modality had broad gains in fostering awareness of the societal implications of science.

Drawing on SCT, which emphasizes the role of observational learning and modeling in acquiring knowledge and attitudes, the observed changes in the TOSRA categories suggest that the online modality facilitated a unique set of observational experiences and social interactions. In an online learning environment, scholars engaged with diverse perspectives, fostering an awareness of the social implications of scientific endeavors. Through virtual discussions, collaborative projects, and exposure to online resources, research scholars witnessed and absorbed varying viewpoints on the societal relevance of science.

Moreover, findings related to the normality of scientists and science lessons may be linked to the online modality's capacity to provide flexibility and personalization. Online platforms allow for self-paced learning, enabling scholars to explore scientific concepts at their own pace and in ways that align with their individual learning styles. While some lectures were live on Zoom, other activities and assignments were more self-paced, allowing for greater flexibility. This autonomy and adaptability may contribute to a sense of normality in approaching scientific studies, enhancing the overall enjoyment of science lessons for some, while others may have preferred a more traditional learning environment.

Additionally, the statistically significant decrease on career interest in science within the online modality (as seen in Figure 4) may be associated with exposure to diverse virtual networks, professional resources, and online collaborations. Research scholars participating in online courses had the opportunity to connect with professionals and experts from various geographical locations, broadening their understanding of potential career paths within the scientific field. This broad exposure enabled students to make better decisions about whether the field of life sciences was a right fit for their career aspirations. Students may have come to the realization that a career in science may not be the best fit for their aspirations due to the broad exposure to what the field entails.

In conclusion, finding two suggests that SCT can offer insights into the mechanisms underlying these changes. The online modality, through its emphasis on diverse virtual interactions, flexibility, and personalized learning experiences, aligns with the principles of SCT and provides a nuanced understanding of how online educational environments can shape research scholars' attitudes toward science.

Finding Three Hybrid modality had a notable positive impact on perceptions of science as a normative and integral part of life.

The Wilcoxon test results in Table 3 reveal the statistical significance for the Normality of Scientists (N) category was the strongest in the hybrid group of students. This suggests the hybrid modality had a robust influence on shaping perceptions of science as a normative aspect of education. Furthermore, a closer examination of the TOSRA pooled mean score differences for the hybrid modality further corroborates the positive impacts on perceptions related to the Normality of Scientists (N) category. This consistent pattern of positive gains aligns closely with the pooled mean score differences for the in-person students in the Normality of Scientists (N) category, reinforcing the claim that the hybrid modality contributes significantly to shaping positive attitudes toward the normality of scientific studies.

The hybrid modality, by offering a unique blend of in-person and online elements, likely provided diverse observational opportunities and social interactions for students. This aligns with the principles of SCT, emphasizing that individuals learn not only through direct experiences but also by observing and modeling behaviors and outcomes (Bandura, 1977; 1986). In the in-person component, students engaged in direct interactions with instructors, peers, and hands-on activities, providing tangible and immediate experiences. Simultaneously, the online components exposed students to a diverse array of virtual interactions, discussions, and collaboration projects. This multifaceted approach aligns seamlessly with SCT, offering students a spectrum of observational opportunities (Bandura, 1977; 1986).

Finding Four Instructional methods have a nuanced impact on specific aspects of student perceptions and interests in STEM fields within the life science research immersion program.

As presented in Table 9, the Kruskal-Wallis test results revealed statistically significant differences in TOSRA posttest scores for Questions 10, 37, 51, and 58 across the in-person, online, and hybrid modalities. Subsequent post hoc tests delved deeper into these findings, revealing the specific influence of instructional methods on student outcomes, aligning with the principles of SCT.

The significance of Q10 (doing experiments is not as good as finding out information from teachers), Q37 (scientists have a normal family life), and Q51 (scientists are just as interested in art and music as other people) for the hybrid versus online comparison underscores the potential influence of instructional methods on students' perceptions of science-related activities, career prospects, and ability to pursue other interests. SCT emphasizes the importance of observational learning, and in this context, the hybrid modality provides a unique vantage point for students. They not only engaged in traditional in-person interactions but also navigated the virtual realm during a time when global events, such as the pandemic, significantly impacted the world view on science and scientists. The diverse social interactions and modeling experiences inherent in the hybrid approach may have enabled students to witness, in real-time, the dynamic interplay between public perception, scientific research, and societal implications of being a scientist.

In a parallel manner, the significance of Question 58 (few scientists are happily married) in the hybrid versus in-person comparison takes on relevance when viewed through the lens of SCT. The distinctive environment of hybrid learning provides students with a vast array of resources and perspectives, fostering observational opportunities related to the normality of scientists and the enjoyment of science and scientists' ability to live "normal" lives. The autonomy and flexibility inherent in hybrid instruction may contribute to the cultivation of positive attitudes towards seeing scientists build happy relationships, as observed through the lens of SCT. This finding highlights the significance of utilizing online platforms in conjunction with in-person lessons in shaping attitudes and behaviors related to informal science interactions among peers.

In summary, this analysis viewed through the lens of SCT, emphasizes the importance of recognizing the specific and nuances influence of instructional methods on various facets of student interest in STEM fields. The findings suggest that instructional formats play a crucial role in shaping observational learning experiences, providing valuable insights for educators seeking to optimize STEM programs through tailored instructional designs grounded in SCT principles.

Research Question 2 Key Findings

Finding Five Students across in-person, online, and hybrid modalities demonstrated improvements in scientific reasoning skills, suggesting the effectiveness of diverse instructional approaches in fostering enhanced scientific reasoning abilities.

The life science research immersion programs were designed to provide an alternative STEM learning experience to the traditional high school classroom-based format, by engaging students in a comprehensive research experience focused on promoting STEM success beyond their academic experience. The questions in the scientific reasoning assessment tested hypothesis formulation (Q1), experimental design (Q2), analytical skills through fluorescence (Q3), Western blotting gel image interpretation (Q4), and data interpretation through bar graphs with complex experimental conditions (Q5).

In-person Modality. Despite the absence of statistically significant changes in certain assessment questions, the observed improvements on four out of five questions in the three in-person cohorts suggest a positive trend in skill development among research scholars. While statistically significant differences were noted for two specific questions on the scientific reasoning assessments, the overall trend of positive improvements across multiple questions for in-person students suggests a consistent and substantial influence of the in-person modality. This aligns with SCT, emphasizing the importance of direct experiences and interactions in the learning process (Bandura, 1977; 1986). The in-person courses likely provided unique and tailored opportunities for observation, modeling, and hands-on experiences that contributed to an active learning environment.

Students in the in-person programs performed well in the pre-assessment on hypothesis formulation (Q1), leaving little room for improvement, but scored relatively low on the pre-assessment technical questions (Q3 and Q4) with modest improvements in all quarters at the end of the program. These results are not entirely unexpected. Students typically learn about hypothesis formulation in their traditional high school curriculum, while interpretation of molecular biology assays are more advanced technical concepts (CA Dept of Education, 2021). Furthermore, required course reading assignments and detailed discussions of relevant peer-reviewed research manuscripts were implemented through journal clubs. Both the practical and discussion-based learning approaches likely enhanced students' scientific reasoning capacity, thus improving post-assessment performance.

As expected, experimental design question (Q2) scores improved, as students actively discussed their experimental design with their peers and instructor's multiple times throughout the course. The students also revised their experimental designs multiple times from the initial experiment planning to the poster session through collaborations with their peers and the instructional team. An increase in Q2 scores was consistent for two out of the three quarters but inconsistent with a decrease in the WI20 cohort. A potential explanation for the decreased performance was the beginning of the Covid-19 pandemic during the last two weeks of the program, resulting in no formal presentations of students' science posters. A combination of an incomplete experience, coupled with pandemic-induced stress may have affected the student's post-assessment scores (Chung & Kim, 2022; Gehrke et al., 2023; Krause et al., 2022).

This is in line with SCT, which clearly suggests that observational learning and modeling play crucial roles in the acquisition and refinement of skills (Bandura, 1977; 1986). In the context of the improved scores for the experimental design question (Q2), SCT posits that students learn not only through direct experiences but also by observing others and engaging in collaborative activities. The active discussions, multiple revisions, and collaborative efforts observed during the course provide students with opportunities to witness effective experimental design strategies modeled by their peers and instructors. SCT contends that individuals can enhance their skills by observing and incorporating successful practices demonstrated by others. However, the deviation in performance during the Winter 2020 cohort emphasizes the theory's acknowledgment of external factors influencing learning outcomes (Bandura, 1977; 1986). The onset of the Covid-19 pandemic disrupted the regular collaborative and presentation components, introducing stress and incomplete experiences that align with SCT’s recognition of environmental and situational impacts on skill development (Gehrke et al., 2022; Krause et al., 2023).

Online Modality. Online students exhibited improvements in two out of the five scientific reasoning assessment questions. Similar to the in-person cohorts, students in the online programs performed well in the pre-assessment on hypothesis formulation (Q1), again leaving little room for improvement. Experimental design question (Q2) scores improved, as students actively discussed their experimental designs with their peers and instructor’s multiple times throughout the course, just as the students did in the in-person cohorts. The mode of communication, primarily through Zoom and Canvas, did not hinder improvements, highlighting the effectiveness of online engagement in key components of the curriculum. Improvements in Q4 and Q5 (Western blotting gel image interpretation and data interpretation through bar graphs with complex experimental conditions) suggest the successful integration of online platforms for technical skill development. This underscores SCT, demonstrating that collaborative activities and online observational learning contribute to skill enhancement, even in the absence of in-person interactions (Bandura, 1977; 1986).

Hybrid Modality. Despite the lack of statistical significance, the hybrid courses displayed minor improvements in posttest performance, paralleling the trends observed in other modalities. The slight increase in Q1 (hypothesis formulation) and Q3 (analytical skills through fluorescence), coupled with a decrease in Q5 (data interpretation through bar graphs with complex experimental conditions), highlights the nuanced impact of the hybrid approach. The absence of significant differences in Q2 (experimental design) and Q4 (Western blotting gel image interpretation) deviates from the patterns seen in the in-person and online cohorts. This may indicate a unique challenge associated with the hybrid learning environment.

These findings collectively emphasize the importance and efficacy of diverse instructional approaches in enhancing students' scientific reasoning skills. Whether through direct experiences, online collaborations, or a blend of in-person and online elements, the positive trends across all modalities underscore the adaptability of different instructional methods in promoting skill development. The varied approaches provide students with opportunities for observation, modeling, and collaborative learning, contributing to the enhancement of scientific reasoning abilities in different learning environments.

The life science research immersion programs, designed to offer an alternative STEM learning experience, proved successful in engaging students and fostering their scientific reasoning abilities beyond traditional classroom settings. By focusing on comprehensive research experiences and promoting STEM success through active learning, these programs equipped students with valuable skills applicable beyond their academic endeavors.

Moreover, the assessment questions targeting hypothesis formulation, experimental design, analytical skills, and data interpretation provided insights into students' proficiency levels and areas of improvement. While certain modalities showed more pronounced enhancements in specific skill areas, the overall trend of progress across all formats highlights the benefit of tailored instructional methods.

The observed trends align with SCT, emphasizing the importance of direct experiences, observational learning, and collaborative activities in skill development. Despite challenges such as the onset of the Covid-19 pandemic impacting learning environments, the study's results affirm SCT's recognition of external factors influencing learning outcomes.

Overall, this study contributes to the growing body of research on STEM education by demonstrating the effectiveness of diverse instructional approaches in nurturing students' scientific reasoning skills. As education continues to evolve, understanding the nuances of different modalities and their impacts on learning outcomes remains essential for designing effective educational interventions and promoting student success in STEM fields.

Limitations

The first limitation of this study is that students self-select by way of applying and paying a fee to attend the research immersion courses. Students are likely to already have an interest in STEM, which may impact the results of the TOSRA and technical assessments. Furthermore, there were geographical limitations for the in-person and hybrid courses. Students must live or attend school within San Diego County to go to the lab for the in-person components to be included in the study. However, San Diego County is a large county, and not all students have transportation to attend lab classes in person. Furthermore, demographic data on the student application, such as GPA, family income, race, and family household size, are self-reported but not verified by the partnering university or the non-profit. This could have an impact on statistical analyses. Finally, the Covid-19 pandemic posed many challenges for teaching online courses that may impact the analytical results. For example, the university policy was that instructors could not force students to keep their cameras on during online instruction. As a result, there is no way to determine if students attended the full lecture or received outside assistance on assignments or exams. This may impact the results of the technical assessments as well as subsequent statistical analyses.

The second limitation involves the SCT theoretical framework. To critically assess the application of SCT in the context of this study on changes in attitudes, perceptions, and scientific knowledge, it is imperative to recognize several inherent limitations in the theory's conceptualization. Environmental factors are cited as one of the key constructs of the framework (Bandura, 1977; 1986). However, SCT oversimplifies these factors to an extent. Environmental factors are dynamic and can be influenced by many complex elements not fully captured in the model. For example, cultural factors can impact the student environment at home and school but aren't captured in the current model. The environment also includes peer interactions (Bandura 1977; 1986). However, the model doesn't comprehensively address the complexity of peer interactions and social dynamics within a classroom and across different age groups. Behavioral elements are also cited as one of the key constructs of the framework (Bandura, 1977: 19986). This model considers Self-efficacy static, but it can change over time based on students' experiences, feedback, and external influences. Students' confidence and beliefs in their own abilities will change as their classroom experiences change. These dynamic changes are not fully accounted for in this mainly static model.

The third limitation of this study is the lack of a control group. It is unethical to withhold educational experiences from a group of students. Depriving young students of a potentially beneficial research class or educational program could be seen as ethically questionable. Furthermore, withholding an educational experience from one group of students while providing it to another can exacerbate educational inequalities and negatively affect students' overall learning experiences. While not having a control group limits the ability to make causal claims about the impact of the research courses, it is essential to acknowledge this limitation and adopt alternative research designs or analytical approaches that allow for meaningful interpretation of the study's findings without hurting the student experience.

Validity

The life science research immersion programs were delivered via in-person (precovid) and hybrid modalities (postcovid), each incorporating a lab component that was not available to participants taking the courses online during Covid-19. The lab component serves as a pivotal experience of the immersion experience, providing participants with hands-on opportunities to apply theoretical concepts, develop practical skills, and deepen their understanding of the subject matter. Consequently, the comparison of the data across all three modalities should acknowledge the absence of the lab component for the online participants. While efforts were made to compensate for this disparity through alternative learning activities and virtual resources, the inherent limitations of online delivery may impact the acquisition of practical skills and engagement with the course material among online participants. Despite these challenges, the presence of the lab component appears to play a role in influencing the TOSRA results and technical assessments assigned to students, emphasizing the importance of recognizing this difference when interpreting and generalizing the study findings. For example, there were statistically significant decreases for the Career Interest in Science ($p = 0.0011$) category and the Enjoyment of Science Lessons ($p = 0.0058$) category in the TOSRA for the online group (Table 4). This was not the case for the in-person or the hybrid category. Furthermore, at the individual question level for the online cohorts, there were statistically significant decreases for questions that could be linked to a lack of online component. For example, Q61 (I look forward to science lessons) saw a statistically significant decrease ($p = 0.0245$) and Q49 (A job as a scientist would be boring) saw a statistically significant decrease ($p = 0.0335$) (Table 7). These insights have implications for the future design and delivery of life science research immersion programs, emphasizing the need to carefully consider the integration of hands-on components in online learning environments and explore innovative strategies to enhance the virtual learning experience.

Implications for Leadership

Education leaders are essential in retaining students' interest in STEM subjects. High school principals, counselors, and teachers encourage, engage, and provide students with opportunities to explore the breadth and depth of STEM that can directly impact future workforce demands (Kim et al., 2020; Mau et al., 2016; Woods & Domina, 2014). While STEM subjects are typically more challenging to master and teach, schools can provide professional development opportunities for their teachers, enabling them to stay up to date on the latest scientific and technological changes (Han & Hur, 2021; Merrill & Daughtry, 2010; Wright et al., 2019). Working with research immersion programs, such as the one proposed in this study, can help supplement science instruction in the classroom. Furthermore, principals should encourage their teachers to create multi-disciplinary projects highlighting the interplay between science, math, and engineering subjects (Han & Hur, 2021). The school administration should adequately monitor the implementation of new STEM education efforts and students' learning outcomes to determine the appropriate investment of resources (Han & Hur, 2021; Wright et al., 2019).

Due to the projected growth of jobs in the STEM fields, this research presents an opportunity for policymakers to ensure funding for STEM education is a priority. President Biden proposes allocating $1.6 Billion for public school teachers to receive additional training and certifications at no cost in subjects such as STEM (White House, 2021). Increasing funding for post-secondary institution programs supporting the K-12 STEM pipeline is essential.

Overall, the findings of this study carry significant implications for leadership in STEM education. Leaders and educators should recognize the positive impact of in-person and hybrid modalities on students' scientific reasoning skills and attitudes toward STEM subjects. The active learning environments, collaborative opportunities, and hands-on experiences provided in these modalities contribute to enhanced skill development and positive shifts in students' perceptions. To maximize these benefits, educational leaders should consider the incorporation of experiential learning components, fostering active engagement, and creating opportunities for collaborative interactions within STEM programs. Additionally, leaders may explore ways to adapt and integrate successful instructional practices observed in in-person and hybrid modalities into online courses to enhance the online learning experience.

Implications for Social Justice

As our world and the issues we face increase in complexity, the STEM field and the jobs considered STEM are also adapting and evolving. The number of STEM jobs and career paths available has diversified in many ways, except for the people who participate in those jobs and career paths (Fouad & Santana, 2017). The lack of diversity in STEM fields can be tied to certain barriers (socioeconomic factors, systems of oppression, stereotypes, and entitlement) that those in the non-dominant culture don't face (Tai et al., 2017; Lindsey et al., 2018; Welborn, 2019). If the dominant culture is the only one represented in STEM, only the issues affecting the dominant culture will be addressed. Society needs to continuously innovate and develop unique solutions to future problems, as sometimes those problems disproportionately affect historically underrepresented students and low-income families and communities (Lindsey et al., 2018).

The study's results underscore the importance of ensuring equitable access to diverse instructional modalities in STEM education. While in-person and hybrid modalities have demonstrated positive effects on students' scientific reasoning skills, it is crucial to address potential disparities in access. Educational institutions and policymakers should consider strategies to provide inclusive access to hands-on experiences, collaborative learning, and active engagement for all students, regardless of their learning environment. This is particularly important for promoting social justice in STEM education, as students from different backgrounds and educational settings should have equal opportunities to benefit from effective instructional approaches. Addressing these disparities aligns with the principles of social justice, fostering an inclusive and accessible STEM education for all.

Implications for Future Research

While there are many comprehensive studies on the effectiveness of various enrichment and out-of-school STEM programs on STEM retention, key elements are missing due to the nature of out-of-school or summer programs (Baran et al., 2014; Gayles & Ampaw, 2011; Markowitz, 2004; Young et al., 2017). Most students self-select to participate in STEM programs (Kong et al., 2013; Markowitz, 2004). They will do their research, reach out to local universities, and apply for programs. Students who attend STEM programs are typically already high-achieving and interested in STEM subjects, creating a bias in any educational study (Kong et al., 2013; Markowitz, 2004). Many studies have shown positive impacts on students' perceptions of STEM subjects and retention in STEM majors when they attend college (Kong et al., 2013). However, future studies are needed to determine the effects of similar programs on students who were not already interested in STEM subjects and perhaps less academically prepared.

Furthermore, very few programs have conducted long-term follow-up with program participants to track whether participants maintained their interest in STEM by majoring in a STEM subject, graduating with a STEM degree, and working in a STEM field (Gibson & Chase, 2002; Markowitz, 2004; Winkleby, 2007). As a student advances through the STEM education pipeline, there are likely to be other positive factors contributing to retention rates in STEM (Gayles & Ampaw, 2011; Young et al., 2017). Attributing long-term success to any particular middle school or high school STEM program becomes more challenging. Long-term tracking can help determine other success factors critical to K-12 and post-secondary institutions. Educational institutions can then design more relevant and successful programs using the data surrounding the essential success indicators from long-term tracking endeavors.

Significance of the Study

This study significantly contributes to the understanding and enhancement of STEM education, particularly focusing on life science research immersion programs. By addressing the central problem of the apparent decline of high school students' interest in pursuing STEM at post-secondary institutions, this research provides valuable insights into effective strategies for engaging students in science-related activities. The adoption of Bandura's STC framework enriches the study's conceptual foundation, offering a lens through which to explore the interplay of personal, environmental, and behavioral factors influencing students' perceptions, attitudes, and skills in STEM.

The study's multifaceted approach, encompassing in-person, online, and hybrid modalities, ensures a comprehensive analysis of the impact of diverse instructional methods. The findings shed light on nuanced differences in student perceptions and interests, emphasizing the importance of tailored instructional designs grounded in SCT principles.

The findings from this study offer valuable insights that can be leveraged to optimize hybrid learning modalities, which have a unique blend of in-person and online elements. Educators should consider employing a hybrid approach that combines the strengths of both the in-person and online modalities. The hybrid modality also has the potential to allow for increasing capacity with limited funds. Based on the data collected, several strategies can be implemented to enhance the effectiveness and engagement of hybrid courses. One significant finding from the study is the importance of hands-on lab experience for student comprehension and retention. To optimize the hybrid modality, the in-person lab sessions can be designed to maximize hands-on activities and minimize passive learning. This could involve reducing group size and increasing the number of hours in the lab to ensure each group has ample opportunity to participate in experiments. The study also highlighted the role of synchronous online lectures in supporting theoretical learning. For more effective sessions, more interactive elements can be incorporated to encourage student participation and engagement. Furthermore, students can be required to review lecture materials and complete readings before the live session, allowing online lectures to focus on discussion and application of concepts.

Moreover, the study's implications for leadership underscore the role of educational leaders in fostering positive changes in STEM education. The call for collaboration, professional development, and a focus on experiential learning offers practical guidance for educational institutions and policymakers. The study aligns with the broader societal need for a diverse and well-prepared workforce in STEM fields, making it relevant for educational leaders, policymakers, and practitioners.

Conclusion

In conclusion, this dissertation provides a thorough investigation into the effectiveness of life science research immersion programs and their impact on students' perceptions, interests, attitudes, and scientific reasoning skills. The research has successfully addressed two key questions through a robust theoretical framework and a meticulous three-phase analysis across different instructional modalities.

The findings highlight the pivotal role of in-person experiences in fostering positive changes in student perceptions and attitudes, while online and hybrid modalities contribute unique advantages, emphasizing societal implications and normalizing science in students' lives. The nuanced impact of instructional methods on specific aspects of student interest underscores the need for tailored approaches grounded in social cognitive theory.

Acknowledging limitations, such as self-selection bias and geographical constraints, this study remains a valuable contribution to STEM education literature. The recognition of these limitations prompts a call for future research designs that address these challenges and provide a deeper understanding of the long-term effects of research immersion programs on diverse student populations.

In summary, this dissertation serves as a roadmap for educators, policymakers, and researchers seeking to optimize STEM programs through evidence-based instructional designs. By embracing the significance of in-person experiences, recognizing the impact of online flexibility, and leveraging the strengths of hybrid modalities, educators can foster positive changes in students' perceptions, interests, and scientific reasoning abilities. This research advances our knowledge in STEM education and sets the stage for continued exploration and refinement of instructional practices that inspire the next generation of STEM professionals.

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Appendices

Appendix A: Student Application

Program Information

In partnership with [redacted], we will offer a unique science research learning experience. Our programs will involve field work, fundamental molecular biology topics, modern laboratory techniques, and relevant bioinformatics and statistical applications. Learn to synthesize life science fundamentals, review literature, formulate hypotheses and design experiments, collect and process samples, execute experiments, and analyze data.

Application Deadline: Space is limited and students will be accepted on a rolling basis

**Demographic information may be used in future research studies. All unique identifiers (such as names) will be removed.*

Legal Name*

First Name

Middle Name (optional)

Last Name

Preferred Name (Optional)

First Name

Middle Name (optional)

Last Name

Email*

Confirm Email*

Address 1 *

Address Line 1

Address Line 2

City

State/Province

ZIP / Postal

Country

Preferred Phone Number *

Alternative Phone Number

Date of Birth *

Citizenship: *

- U.S. citizen
- Decline to state
- Other:

Gender *

- Male
- Female
- Transgender - Female
- Transgender - Male
- Non-binary
- Decline to state

Pronouns

Ethnicity *

- ☐ U.S./African American
- ☐ African (from African continent)
- ☐ Caribbean (African/Black ancestry)
- ☐ Central or South American
- ☐ Other Black or African ancestry
- ☐ American Indian/Alaskan Native
- ☐ Chinese/Chinese American (including Taiwanese)
- ☐ Filipino/Filipino American
- ☐ Japanese/Japanese American
- ☐ Korean/Korean American
- ☐ South Asian (e.g., from India, Pakistan, Sri Lanka, Bangladesh)
- ☐ Vietnamese/Vietnamese American
- ☐ Other South East Asian (e.g., from Cambodia, Laos, Thailand)
- ☐ Other Asian/Asian American ancestry
- ☐ Central American
- ☐ Chicano/Mexican American
- ☐ Cuban/Cuban American
- ☐ Puerto Rican
- ☐ South American
- ☐ Other Latino/Hispanic American (including Latin Caribbean) ancestry

- [ ] Guamanian/Chamorro
- [ ] Native Hawaiian
- [ ] Samoan
- [ ] Other Pacific Islander ancestry
- [ ] European/European American
- [ ] Middle Eastern/Middle Eastern American
- [ ] North African American
- [ ] Other White/Caucasian ancestry
- [ ] Other Ethnicity
- [ ] Decline to state

Do you require special accommodations?*

○ Yes

○ No

If you selected yes, please specify:

Educational Information

Name of School*

Current Grade Level*

○ Select Grade Level

9th

10th

11th

12th

Other:

Current Overall G.P.A. *

Expected Graduation Date From High School *

Type of School Attending *

Public

Private

Other:

Parent/Guardian I Information

Parent/Guardian Name *

First Name

Middle Name (optional)

Last Name

Relationship *

Does this parent/guardian have legal custody of the minor?*

◯ Yes

◯ No

Address*

Address Line 1

Address Line 2

City

State/Province

ZIP / Postal

Country

Email Address*

Confirm Email Address*

Preferred Phone Number*

Alternate Phone Number

Parent/Guardian I Highest Education*

Select an option

Parent/Guardian II Information

Parent/ Guardian Name

First Name

Middle Name (optional)

Last Name

Relationship

Does this parent/guardian have legal custody of the minor?

- ◯ Yes
- ◯ No

Address

Address Line 1

Address Line 2

City

State/Province

ZIP / Postal

Country

Email Address

Confirm Email Address

Preferred Phone Number

Alternate Phone Number

Parent/Guardian II Highest Education

Select an option

Additional Parent/Guardian Information

Number of Household *

Your family means all the people living in the same household who are related by birth, marriage or adoption.)

Household Income *

$0-$20,450

This means all types of income which your family is required to report on the IRS Form 1040 annual Tax Return.

Essay Question

Please explain how biodiversity influences your life. Support your answer with relevant example(s). Plagiarism is not acceptable. Should you reference a textbook, journal, website or etc, please make sure to cite your source. *

3500/3500

(maximum of 3,500 characters with spaces):

End of Application

You've reached the end of the application. Please make sure to submit the application by clicking on "Submit Form." Once that has been completed, you will receive a copy via email. Should you have any questions, please contact the [redacted] at [redacted]

Parent/Guardian Signature	Date and Time
[clear]	Oct 09 2022 09 : 32 AM

Student Signature*	Date and Time*
[clear]	Oct 09 2022 09 : 32 AM

Appendix B: TOSRA

Test of Science-Related Attitudes (TOSRA)

Thanks for completing this survey; it's not really a test, that's just the name. It will be used to help us understand the different ways this educational program is having an impact on our students. We need your name to match your answers to other information such as the courses you take, if you have a complete education plan, etc. Once we create the match your name (and any other identifiers) will be deleted.

Please answer honestly and do not skip any items.

Today's Date: ____________________ **Your Name:** __________________________________

This Class/Course: _________________________

		Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
1	Money spent on science is well worth spending........................	☐	☐	☐	☐	☐
2	Scientists usually like to go to their laboratories when they have a day off..	☐	☐	☐	☐	☐
3	I would prefer to find out why something happens by doing an experiment than by being told..	☐	☐	☐	☐	☐
4	I enjoy reading about things which disagree with my previous ideas..	☐	☐	☐	☐	☐
5	Science lessons are fun	☐	☐	☐	☐	☐
6	I would like to belong to a science club....................................	☐	☐	☐	☐	☐
7	I would dislike being a scientist after I leave school	☐	☐	☐	☐	☐
8	Science is man's worst enemy	☐	☐	☐	☐	☐
9	Scientists are about as fit and healthy as other people..............	☐	☐	☐	☐	☐
10	Doing experiments is not as good as finding out information from teachers..	☐	☐	☐	☐	☐
11	I dislike repeating experiments to check that I get the same results..	☐	☐	☐	☐	☐
12	I dislike science lessons	☐	☐	☐	☐	☐
13	I get bored when watching science programs on TV at home...	☐	☐	☐	☐	☐

		Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
14	When I leave school, I would like to work with people who make discoveries in science	☐	☐	☐	☐	☐
15	Public money spent on science in the last few years has been used wisely	☐	☐	☐	☐	☐
16	Scientists do not have enough time to spend with their families	☐	☐	☐	☐	☐
17	I would prefer to do experiments than to read about them	☐	☐	☐	☐	☐
18	I am curious about the world in which we live	☐	☐	☐	☐	☐
19	School should have more science lessons each week	☐	☐	☐	☐	☐
20	I would like to be given a science book or a piece of scientific equipment as a present	☐	☐	☐	☐	☐
21	I would dislike a job in a science laboratory after I leave school	☐	☐	☐	☐	☐
22	Scientific discoveries are doing more harm than good	☐	☐	☐	☐	☐
23	Scientist like sports as much as other people	☐	☐	☐	☐	☐
24	I would rather agree with other people than do an experiment to find out for myself	☐	☐	☐	☐	☐
25	Finding out about new things is unimportant	☐	☐	☐	☐	☐
26	Science lessons bore me	☐	☐	☐	☐	☐
27	I dislike reading books about science during my vacations	☐	☐	☐	☐	☐
28	Working in a science laboratory would be an interesting way to earn a living	☐	☐	☐	☐	☐
29	The government should spend more money on scientific research	☐	☐	☐	☐	☐
30	Scientists are less friendly than other people	☐	☐	☐	☐	☐
31	I would prefer to do my own experiments than to find out information from a teacher	☐	☐	☐	☐	☐
32	I like to listen to people whose opinions are different from mine	☐	☐	☐	☐	☐
33	Science is one of the most interesting school subjects	☐	☐	☐	☐	☐
34	I would like to do science experiments at home	☐	☐	☐	☐	☐
35	A career in science would be dull and boring	☐	☐	☐	☐	☐
36	Too many laboratories are being built at the expense of the rest of education	☐	☐	☐	☐	☐

	Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
37	Scientists can have a normal family life	☐	☐	☐	☐	☐
38	I would rather find out about things by asking an expert than by doing an experiment	☐	☐	☐	☐	☐
39	I find it boring to hear about new ideas	☐	☐	☐	☐	☐
40	Science lessons are a waste of time	☐	☐	☐	☐	☐
41	Talking to friends about science after school would be boring	☐	☐	☐	☐	☐
42	I would like to teach science when I leave school	☐	☐	☐	☐	☐
43	Science helps to make life better	☐	☐	☐	☐	☐
44	Scientists do not care about their working conditions	☐	☐	☐	☐	☐
45	I would rather solve a problem by doing an experiment than be told the answer	☐	☐	☐	☐	☐
46	In science experiments, I like to use new methods which I have not used before	☐	☐	☐	☐	☐
47	I really enjoy going to science classes	☐	☐	☐	☐	☐
48	I would enjoy having a job in a science laboratory during my school holidays	☐	☐	☐	☐	☐
49	A job as a scientist would be boring	☐	☐	☐	☐	☐
50	This country is spending too much money on science	☐	☐	☐	☐	☐
51	Scientists are just as interested in art and music as other people are	☐	☐	☐	☐	☐
52	It is better to ask the teacher the answer than to find out by doing experiments	☐	☐	☐	☐	☐
53	I am unwilling to change my ideas when evidence shows that the ideas are poor	☐	☐	☐	☐	☐
54	The material covered in science lessons is uninteresting	☐	☐	☐	☐	☐
55	Listening to talk about science on the radio would be boring	☐	☐	☐	☐	☐
56	A job as a scientist would be interesting	☐	☐	☐	☐	☐
57	Science can help to make the world a better place in the future	☐	☐	☐	☐	☐
58	Few scientists are happily married	☐	☐	☐	☐	☐
59	I would prefer to do an experiment on a topic that to read about it in science magazines	☐	☐	☐	☐	☐

	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
60 In science experiments, I report unexpected results as well as expected ones	☐	☐	☐	☐	☐
61 I look forward to science lessons	☐	☐	☐	☐	☐
62 I would enjoy visiting a science museum on the weekend	☐	☐	☐	☐	☐
63 I would dislike becoming a scientist because it needs too much education	☐	☐	☐	☐	☐
64 Money used on scientific projects is wasted	☐	☐	☐	☐	☐
65 If you met a scientist they would probably look like anyone else you might meet	☐	☐	☐	☐	☐
66 It is better to be told scientific facts than to find them out from experiments	☐	☐	☐	☐	☐
67 I dislike listening to other people's opinions	☐	☐	☐	☐	☐
68 I would enjoy school more if there were no science lessons	☐	☐	☐	☐	☐
69 I dislike reading newspaper articles about science	☐	☐	☐	☐	☐
70 I would like to be a scientist when I leave school	☐	☐	☐	☐	☐

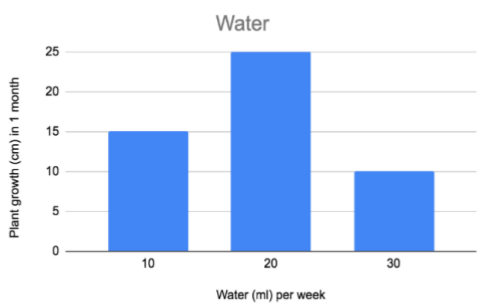
You're done. Congratulations and thanks again!

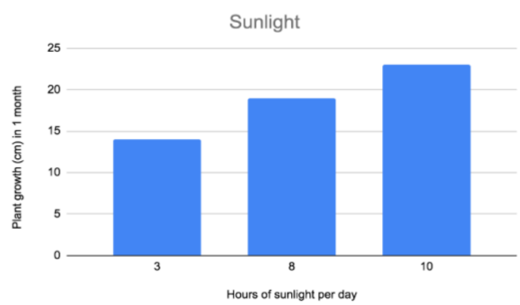
Appendix C: Scientific Reasoning Assessment Version A

(1) You want to start growing plants and purchase 10 to start out. At the end of one month, you notice that there are differences in their growth. After some investigation, it was discovered that the automated watering system you use has a leak and two out of ten plants have been watered a different amount. You plot the differences on a chart (provided below) using averaged growth data.

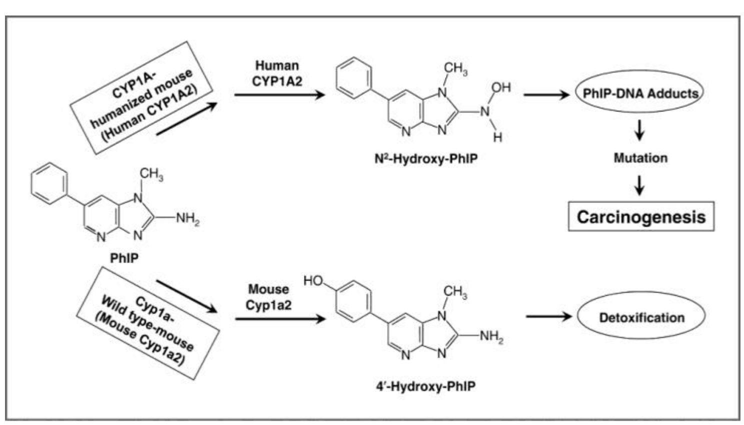
You also notice that another two of your plants are shorter. After observing for a day, it becomes obvious that those two are getting a different amount of sunlight. You estimate the amount of sunlight your plants get per day and graph the results (chart provided below) using averaged growth data.

You decide to use this preliminary data to frame an experiment in order to discover the ideal conditions to grow your plants. **Write a single-sentence testable hypothesis based on the provided information. (3pts)** (hint: you don't have to use all the information provided; you can choose to focus one factor / don't worry about using specific numbers).



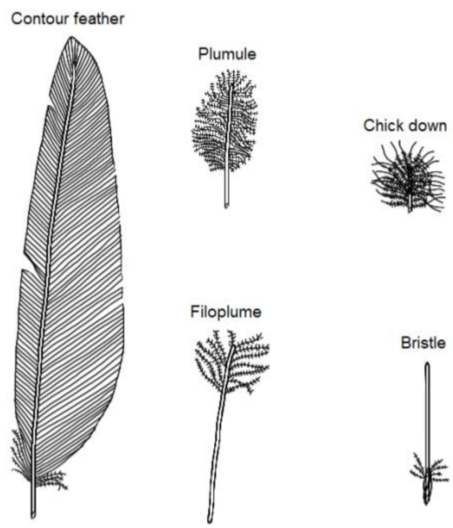


(2) Consider the Figure below. Based on the information flow, state the NULL hypothesis and interpret the results of the study. Cytochrome P4501A is Phase I detoxification enzyme that is activated upon toxicant exposure. Provide the reasonable mechanistic explanation as to why there are two different physiological outcomes upon carcinogen exposure. (10 pts)

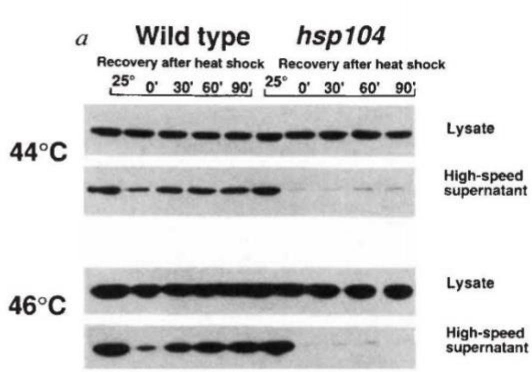


(3) You have been collecting feathers from birds in your backyard and now have a collection of about 20 feathers of different shapes, sizes, colors, and textures. You want to find out how many different species are present and the age of the birds. Keeping in mind that every bird has at least 5 different feather types. How would you design an experiment to do so? What factors would you have to consider? What resources would you utilize to do your research?

Example of different feather types:



(4) Heat shock proteins (*hsp*) are a family of proteins often involved in helping organisms survive stress responses. Although many heat shock proteins have been found, not all have been matched with a function. Some researchers wanted to test the function of Hsp104. Hsp104 was suspected of helping misfolded proteins reform properly. The researchers tested this by causing proteins to misfold in cells that had Hsp104 (Wild type) and cells that did not (*hsp104)*. They then centrifuged the cell solutions twice – once to remove cell debris and once to remove all still misfolded proteins. The researchers used western blot (a molecular biology technique to qualitatively assess protein presence) the solutions without cell debris (lysate) and without all misfolded proteins (high-speed supernatant) to obtain the following figure.



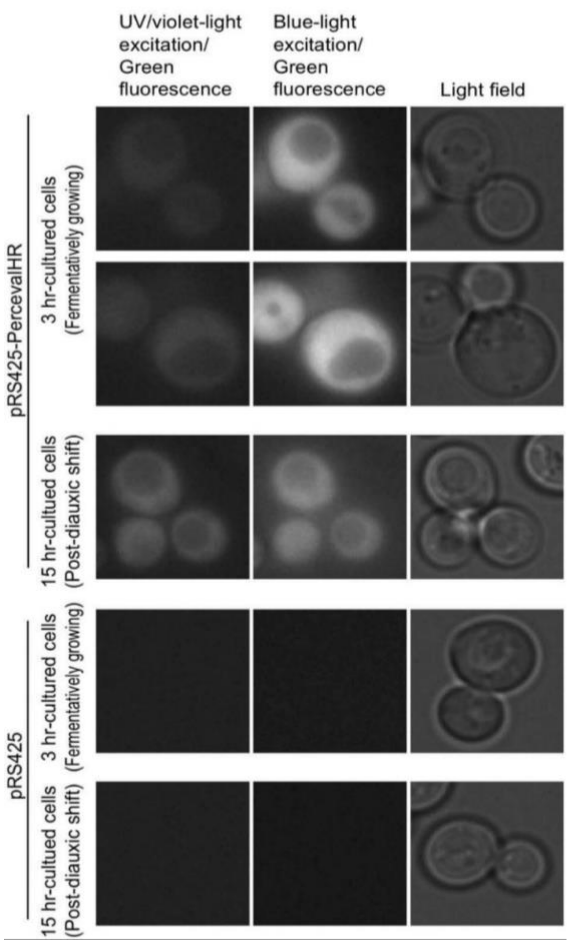
The lanes labeled 25° contain samples from cells incubated at 25℃ without experiencing heat shock. Cells containing Hsp104 (labeled wild type) and without Hsp104 (labeled hsp104) were treated with heat at two different temperatures, allowed to recover at 25℃ for 120 minutes (samples collected at 0, 30 60, 90 minutes during recovery as labelled) then centrifuged twice per sample. The products of each centrifugation were western blotted and shown here (lysate and high-speed supernatant).

4a. What is the relationship between the recovering time and the amount of misfolded proteins remaining in the cell? Regarding this relationship, is there a difference between wild type and *hsp104* cells? If so, what is the difference?

4b. What is the purpose for the lanes labeled 25°?

4c. According to figure 1, did cells lacking *hsp104* demonstrate an inability to refold proteins? Why?

(5) Adenosine diphosphate (ADP) and adenosine triphosphate (ATP) are important chemicals in metabolism processes. A group of researchers are trying to monitor the relative amount of ADP and ATP in *Saccharomyces cerevisiae*, a species of yeast commonly used as a model organism. Perceval High Resolution (PercevalHR) is a fluorescent protein and emits various intensities of green light when excited by light at different wavelengths based on the ADP/ATP ratio of the environment: under UV/violet light, PercevalHR emits light of higher intensity when the concentration of ADP is relatively high; under blue light, PercevalHR emits light of higher intensity when the concentration of ADP is relatively low. Yeast does not have the coding sequence of PercevalHR, so PercevalHR is not naturally expressed in yeast. By combining a vector called pRS425 and the coding sequence of PercevalHR to create the plasmid pRS425-PercevalHR, the researchers were able to express PercevalHR in yeast cells with pRS425-PercevalHR inserted. Below are photos taken by the researchers during one of their experiments. As labelled on the figure, there were two groups of yeast cells: one group was inserted the plasmid pRS425-PercevalHR, while the other group was inserted the vector pRS425. As the labels indicate, some of the photos were taken when the yeast cells were fermentatively growing, while others were taken after an event called diauxic shift has happened. Light field (3rd column) photos were taken under white light, without selecting for any particular fluorescence signal. Answer the following questions based on the information given.



5a. Assume the properties of PercevalHR are solely dependent on ADP/ATP ratio. Comparing the two observed stages (fermentation and post-diauxic shift) of yeast cells with pRS425-PercevalHR, when is ADP concentration higher relative to ATP concentration, and when is ATP concentration higher relative to ADP concentration? (2pts)

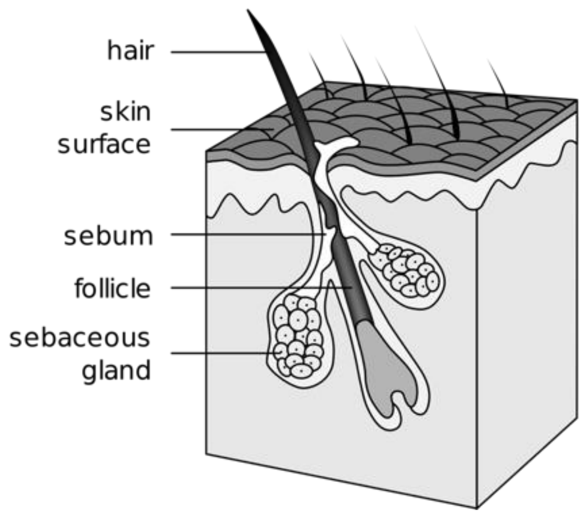
5b. Why did the researchers have a group of yeast cells inserted pRS425 (without PercevalHR sequence)? What are they trying to prove? (2pts)

5c. What is the purpose of having light field microscopy in addition to fluorescence microscopy? (1pt)

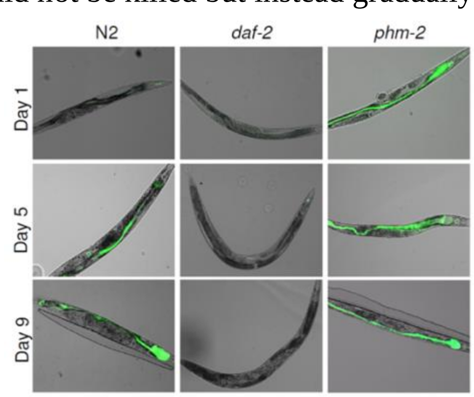
Appendix D: Scientific Reasoning Version B

(1) Piper goes into her pantry and finds a package of sliced bread that is covered in grey, fuzzy mould. She is curious about the conditions that contribute to the growth of that mould. To conduct her experiment, Piper decides that she can alter the temperature, exposure to light, and oxygen contact (aerobic vs. anaerobic conditions) by using individual slices of bread. She measures growth of the mould by the change in diameter size. Write a single sentence testable hypothesis that Piper could use to frame her experiment.

(2) You have collected hair from all of your pets and want to determine which one of them is the healthiest. You decide to do so by looking at the follicles at the end of each individual hair which should be small and barely visible. You have two dogs and three cats. Can you design an experiment using just a microscope and a measurement device? Keep in mind some of your pets naturally shed and others do not. What factors would you have to consider and what would you use as controls for this experiment? Is it ok to compare two different organisms in this way? Explain why/why not.



(3) *Caenorhabditis elegans* (*C. elegans*) is a species of roundworms that is used in research labs as a model organism. The worms feed on bacteria, and *Escherichia coli* (*E. coli*) is often used as the worms' food source in labs. A group of researchers are studying the digestive system of *C. elegans*. The researchers are able to induce two mutations in the worms: *daf-2* and *phm-2*. *daf-2* is associated with the worm's immune system, while *phm-2* is associated with the worm's grinder, which functions like our teeth and helps the worms to break the cells of the bacteria they eat. If the worms' digestive system is defective in some way, the bacteria they eat would not be killed but instead gradually accumulate and proliferate in the intestines of the worms. The researchers fed the *C. elegans* with *E. coli* expressing the green fluorescent protein (GFP) so that the existence of *E. coli* could be observed. In their experiments, the researchers used 3 strains of *C. elegans*: *daf-2*, *phm-2* and N2, which is a wild-type strain with no mutations. The results of their experiment are shown in the figure. Based on the figure below, please answer the following questions.



a. Is the *daf-2* mutation positively or negatively affecting the immune system? Is the *phm-2* mutation positively or negatively affecting the grinder?

b. What further experiment would you suggest in order to investigate the interaction between the two mutations? What are the possible results? What conclusions can be drawn from the possible results? Please list all possibilities.

(4) Apoptosis, or programmed cell death, is a highly conserved process multicellular organisms use to remove cells. The IAP (inhibitor of apoptosis) protein family can regulate apoptosis induced through UV radiation. These IAPs are regulated by proapoptotic signaling molecules in insects and other vertebrates, however, a proapoptotic signaling molecule has not yet been identified in mammals. It is observed that MIHA, a mammalian IAP, is gradually removed from a cell after UV radiation, allowing the cell to undergo apoptosis. DIABLO is a small molecule being considered as a candidate in regulation of MIHA. These are results from western blots of the two proteins (western blot is a method of qualitatively evaluating protein presence in molecular biology).

Figure 1: Time following UV radiation

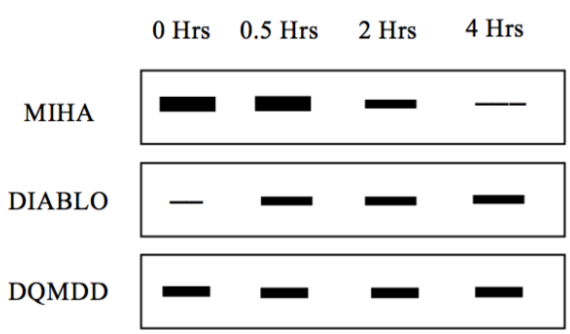


Figure 2: Blot for presence

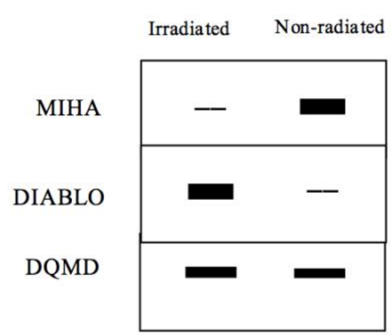


Figure 1: Neuronal cells constantly expressing MIHA at low levels were incubated for 0, 2, 4, or 6 hours following UV radiation. Cells were then lysed and prepped for Western Blot (a small portion of total protein in each lane, separated by SDS-PAGE and blotted to nitrocellulose membranes). Antibodies were made against MIHA and non-modified DIABLO. DQMD, a protein involved in apoptosis, was used as control.

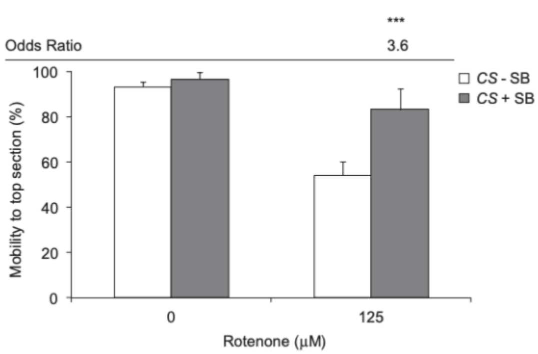
Figure 2: Neuronal cells constantly expressing MIHA at low levels were irradiated. Cells were lysed and prepped for Western Blot. Irradiated versus non-radiated cells are compared here.

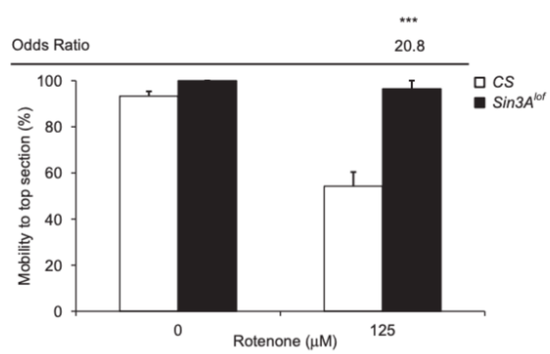
a) Based on the gel, do DIABLO levels seem to correlate with MIHA levels? Explain why or why not.
b) If you wanted to ascertain DIABLO's relationship to MIHA, what would be the next experiment you would perform to check interactions between the two?

(5) Parkinson's disease is a neurodegenerative movement disorder caused by the loss of dopamine-producing neurons in the substantia nigra, resulting in debilitating motor impairments such as tremor, rigidity, and slowness of movements. Neurodegenerative disorders such as Parkinson's disease have been associated with disruption of balanced activity between histone deacetylase (HDAC) and histone transferase (HAT), with an overall HDAC:HAT ratio > 1 (global decrease in acetylation). HDACs silence gene expression while HDAC inhibitors, such as sodium butyrate (SB), can result in enhanced gene expression.

In this study, wild type (CS) fruit flies were used in comparison to mutant flies ($Sin3A^{lof}$) who have a genetic knockdown of HDAC activity. Additionally, *Drosophila* (fruit flies) were experimentally exposed to rotenone (Rot), an insecticide used as a Parkinson's disease inducing agent at 125 M, and to sodium butyrate, an HDAC inhibitor.

Based on the information in the figures and legend below, answer the following questions.





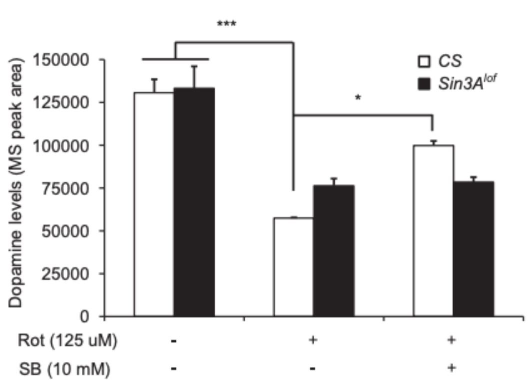


Figure A: Wild type (CS) fruit flies were used to compare the effects of exposure to SB. Locomotor impairment was assessed by quantifying climbing ability. Fruit flies were placed in a clear plastic column that was divided into a top and bottom half by a line. Flies were shaken to the bottom of the column and after 1 minute, the number of flies at the top and bottom of the column were counted separately. Flies were exposed to rotenone for 3 days at 125 M.

Figure B: Wild type (CS) fruit flies were used in comparison to mutant flies ($Sin3A^{lof}$) for exposures and non-exposures to 125 M of rotenone. Locomotor impairment was assessed by quantifying climbing ability as described above.

Figure C: Wild type (CS) fruit flies were used in comparison to mutant flies ($Sin3A^{lof}$) for exposures and non-exposures to rotenone (125 M) and sodium butyrate. Five fruit fly heads were used per genotype and treatment to extract dopamine content. Dopamine levels were determined using high-performance liquid chromatography (HPLC) - mass spectrometry (MS).

Based on the data in this experiment, does sodium butyrate likely improve locomotor impairment in *Drosophila*? Explain.