# Teaching Science Thinking: Examining the Effect of Daily Science Thinking on Post-Secondary Students

by

Mark Brenneman

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Approved by

Christine Guy Schnittka, Chair, Professor of Science Education
Paul Fitchett, Professor, Department Head of Curriculum and Teaching
Jordan Harshman, Assistant Professor of Chemistry
Chih-hsuan Wang, Associate Professor of Educational Foundations, Leadership, and Technology

**Abstract**

This dissertation examines the effect of science journal writing on student scientific thinking skills in one private Christian university in the southeastern United States. The participants' scientific thinking skills were measured using the Lawson Classroom Test of Scientific Reasoning (LCTSR) assessment. This study was designed to encourage scientific thinking outside the classroom setting in an everyday context about scientific content. The journal assignment encouraged students to observe, ask questions, experiment, reason, collect data, and draw conclusions based on evidence. Participants were enrolled in a science course during the fall semester. The participants were identified as science or non-science majors, as well as journalers and non-journalers. There was an overall significant difference in LCTSR scores at the end of the semester; journaler participants scored higher than non-journaler participants when there was no difference between the two groups at the beginning of the semester. Finally, the participants had an overall positive view of the assignment. Completing the journal assignment may have had a positive impact on scientific thinking skills.

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## Chapter 1: The Problem

Scientific thinking and literacy are important concepts in today's educational climate. Scientific thinking can be defined as how scientists think about problems (Moore, 2019) in the various scientific disciplines. Scientific literacy is the "ability to use scientific knowledge, identify questions, and draw conclusions based on evidence in order to understand and make decisions regarding nature and its changes due to human activity" (Putra, 2023, p. 417). Scientific literacy is being able to apply scientific thinking skills to multiple types of problems and questions in science.

Today's technological society often necessitates understanding and applying mathematics and science to everyday situations. Scientific thinking, reasoning, and literacy has been a focus of the federal government for approximately 70 years. For example, the launch of Sputnik by the Russians during the Cold War spurred the federal government to increase funding for science education in America, becoming a focal point of educational reform (Beaton et al., 2011). As science and technology increased exponentially through the 1970s, 1980s, and 1990s, the need for quality science and technology education became clear. In 2001, the National Science Foundation developed the concept of STEM education: Science, Technology, Engineering, and Mathematics education (Hallinen, 2020). In 2012, the National Research Council (NRC) developed a framework for K-12 science education, which led to the creation of the Next Generation Science Standards (NGSS), and is designed to help students become scientifically informed, responsible citizens (Next Generation Science Standards, 2013).

However, science competence is lacking in the United States. According to the Pew Research Center and the Organization for Economic Co-operation and Development (OECD), in 2015, the United States ranked 24$^{th}$ out of 71 countries in science performance as measured by the Programme for International Student Assessment (PISA) (OECD, 2018; DeSilver, 2017). Current data from the Nation's Report Card from 2019 show that students in grades four experienced a decrease in science assessment scores from 2015 to 2019 while students in Grades 8 and 12 saw no difference between those years (National Assessment of Educational Progress, 2023).

There are several issues that individuals currently face that need a good understanding of science and technology. These issues are called socioscientific issues (SSI). These issues are comprised of two parts: a scientific component and a social component (Sadler & Zeigler, 2002). From a global pandemic to energy consumption and production and its relationship to changes in the climate, as well as food production, people could make more informed decisions about these issues with a better understanding of basic scientific concepts. Also, being able to think scientifically (asking questions, interpretation of data, analyzing claims for evidence and reasoning) allows individuals to be more discriminating about the information presented by the media and others related to these issues.

**The Impact of the COVID-19 Virus**

One science issue people experienced firsthand during the past three years was the effect of a global pandemic. During a global pandemic, scientific literacy and thinking are vitally important to the health and wellbeing of all citizens. The ability to analyze and critique scientific information is a valuable tool for every citizen to have. The age of social media and the rampant spread of various conspiracy theories surrounding the SARS-CoV-2 virus led citizens to question sound, scientific reasoning. The political climate in the United States during the pandemic did nothing to ease the situation. The presidential election, and politics in general, polarized the population, leading to mistrust in rational scientific reasoning by some and blind acceptance without any analysis by others. Scientific thinking and literacy are necessary tools for all citizens, no matter their political leanings. The learning that undergirds scientific literacy and the thinking skills necessary are of paramount importance in today's rapidly changing environment.

**Energy Production, Consumption, and Global Climate Change**

Another example of scientific illiteracy is the large-scale denial of global climate change, particularly in the United States of America. Approximately 36% of U.S. citizens are deeply concerned about environmental problems (Funk & Kennedy, 2016). Scientists have identified the problem, but a large part of society has dismissed their conclusions. "The science of global warming is clear – why are we not acting as a society to combat the problem? Why are they not listening? Why is no one doing anything" (Dilling & Moser, 2007, p. 3)?

One of the ways to combat the problem of climate change denial is through two educational avenues. The first way is already in motion; today's educational standards address the need for student awareness concerning the changing global climate. The second involves re-teaching adults who did not learn the science necessary to understand climate change in school (Grotzer & Lincoln, 2007). Those individuals are the ones that require more intervention because of deeply held beliefs and mental models that are challenging to change. However, Kahan et al. (2012) found in one study, problematically, that as one's science literacy increases, concerns for the risks associated with climate change decrease.

**Food Production and Consumption**

Food production is an issue that affects every single person on the planet. With an increasing population, food shortages caused by a war (as currently experienced in Ukraine), and droughts in regions around the world caused by climate change, food production issues are of grave concerns to scientists, politicians, and citizens alike. Whether the issue is food shortages, lack of productive farms, pollution from pesticides and fertilizers, water shortages, processed versus organic food sources, or some other related issue, consumers benefit from having a basic knowledge of scientific principles (Hemmings & Halsey, 2015).

Not only are there issues with food production and its impact on the environment, but there are also nutritional issues that students, specifically in America, need to know. The American lifestyle has led to an increase in the consumption of processed foods, fast food on the go, a sedentary lifestyle (at work and play), as well as overconsumption of foods that are nutritionally deficient (Mirkowsky & Ross, 2015). “Education is the key to good health” (p. 297).

Whether the issue is a global pandemic, energy consumption, production and climate change, food production, or some other scientific issue, scientific literacy and scientific thinking skills are of paramount importance for an individual to be successful in today’s ever-changing culture. The proliferation of social media outlets interjecting science into our everyday lives causes us to make decisions based on claims by companies, individuals, and media personalities that may present only part of the information necessary to make wise decisions. The problem of scientific illiteracy must be addressed in a rational, sensible method if change is going to occur.

**Statement of the Problem**

Scientific literacy in America has been studied for years. Approximately ten percent of Americans were considered scientifically literate in the late 1980s and early 1990s. According to a study at Michigan State University in 2007, that number increased to 28%. Compared with European and Japanese adults, American adults were more scientifically literate. However, “we should take no pride in a finding that 70 percent of Americans cannot read and understand the science section of the New York Times” (Michigan State University, 2007).

In 2019, the Pew Research Center conducted a survey that assessed scientific knowledge in the United States of America (Kennedy & Hefferon, 2019). The survey consisted of 11 multiple choice questions about life science, earth science, and physical science. The mean score of the survey was 6.7 out of 11. The results of this survey show that Americans still need a better understanding of scientific principles.

The media's portrayal of scientific research is often misrepresented to the public by various individuals and media outlets, whether intentionally or unintentionally. For example, a story by the USA Today recommended the consumption of four cups of coffee a day without considering any other factors that the researchers clearly omitted (Molina, 2017). Individuals often base their lives on the recommendations of individuals and media sources without further investigation. Scientifically literate people must be able to examine claims from media sources and ask tough questions about the stories they read. Politicians often use or misuse science to promote their policies and practices. Science is designed to be apolitical; without bias or agenda (Miller, 2017).

Addressing the lack of scientific thinking skills in the public must begin with teacher preparation programs. Before teachers can prepare future scientists to use scientific thinking skills, they must address their own scientific thinking skills (Krell et al., 2020). Preservice science teachers, while not the focus of this study, must be knowledgeable about scientific thinking skills before ever hoping to pass that knowledge on to their students.

**Purpose of the Study**

This study focused on college students in their first chemistry course at a small university in the southeastern region of the United States and an intervention designed to increase their scientific thinking skills. For many students, college is the final direct exposure to science and scientific thinking in the classroom setting. It is also when students, freed from most of their parents' influence, can make their own decisions. This study will add to the literature by examining methods that can be utilized to increase scientific thinking skills in college students. This study used the process of reflective journaling to increase scientific thinking skills in real-life situations rather than a writing assignment that students write following an in-class lesson. This journal assignment was designed to apply science to everyday situations that the participants experience, rather than learning scientific facts in a classroom setting.

**Importance of the Study**

This study encouraged young adults to evaluate their own understanding of science in their lives. The evaluation of the science journal process is a key step to analyze its effect on scientific thinking.

**Research Questions**

The research questions for this study were:

1. What are the topics, as well as the Science and Engineering Practices (SEPs), that natural science major participants choose to write about, as well as participants not majoring in natural science?
2. How does the use of a weekly science journal impact scientific thinking skill scores for students majoring in natural science and students not majoring in natural science?
3. Is there a significant difference in pre- and post-scientific thinking skill scores for participants based on the student's major (science versus non-science major)?
4. Is there a significant difference between the journal entry quality depending on the participants' major?
5. How do journalers describe their attitudes towards the assignment?

## Overview of the Research Design

This study was comprised of two parts. The participants completed a pre-assessment on scientific thinking skills to identify their baseline scientific thinking level. Their scientific thinking skills were measured using the Lawson Classroom Test of Scientific Reasoning (LCTSR) assessment (Lawson, 1978) using the version updated in 2000. This assessment provides scientific scenario questions to individuals that require the participants to think through them using various tools of scientific thinking: generating plausible explanations, examining evidence, and providing conclusions based on evidence.

After the pre-assessment, the participants completed the scientific journal assignment. The assignment consisted of a minimum of two journal entries per week for sixteen weeks. The assignment was open-ended; the participants were allowed to choose the science discipline that they wrote about (biology, chemistry, earth/space science, physics, etc.). They also chose how to write their journal entry. The participants were encouraged to write using a variety of scientific thinking skills. Students were encouraged to think scientifically by:

- Asking questions about the natural world around them related to science (e.g., What causes the leaves of a tree to change color in the fall?)
- Making observations about nature (e.g., The phases of the moon, storms, etc.) as they go about their day.
- Responding to scientific articles, podcasts, or other media that they encountered during their daily routine.
- Any other scientific thoughts that occur to them daily.

The students were also encouraged to write using a variety of practices such as experimenting on an observation, conducting research, or drawing diagrams to explain their observations. The journal entries were coded using the eight NGSS Scientific and Engineering Practices (SEPs) developed the National Research Council: (1) asking questions/defining problems, (2) developing and using models, (3) planning and carrying out investigations, (4) analyzing and interpreting data, (5) using mathematics and computational thinking, (6) constructing explanations/designing solutions, (7) engaging in argument from evidence, and (8) obtaining, evaluating, and communicating information (National Research Council, 2012). These are all valid ways to think about science in daily life.

At the conclusion of the journal assignment, the participants took the LCTSR assessment again to measure the change in their scientific thinking skills. The participants also completed a post-assignment questionnaire to determine how seriously they worked on the assignment. The journals were evaluated using a rubric to determine the quality and quantity of entries. The participants were also categorized as "journalers" and "non-journalers," depending on whether they turned in a journal at the end of the semester, to assess the relationship between participation in the assignment and their LCTSR scores.

**Assumptions, Delimitations, and Limitations**

There are several assumptions that I make in this study. I assume that the journaling process is taken seriously by the participants. Since this process is done outside the guise of the classroom, it is more challenging to motivate students to participate authentically in this assignment. To help motivate students to take the assignment seriously, it is centered around the MUSIC Model of Motivation (Jones, 2009). The MUSIC Model describes what motivates students in completing an assignment in the educational setting. The assignment is considered motivating if it is empowering to the student, useful, the students experience some sort of success completing the assignment, it is interesting, and the instructor expresses caring about the participants. Another assumption that is made is that the participants are not taking part in any course that encourages scientific thinking; the participants may be taking a science course that might focus on the nature of science and scientific thinking. Taking other courses focused on science and scientific thinking could cause unforeseen effects on a participant's science thinking by adding more opportunities for thinking about science. That could affect the scientific thinking skills of the participants who are enrolled in such a course.

**Summary**

Scientific reasoning and thinking skills are essential for all individuals. Everyone makes decisions based on stated claims, evidence presented, and reasoning they consider consistent with their ideas. Many times, individuals do not consider sound, vetted sources for their information. The goal of any educational program in science should be to educate individuals to recognize solid, scientific evidence and reasoning without prejudice to personal thoughts and beliefs. There is a time and place for an individual's thoughts and beliefs about answers that cannot be achieved through scientific reasoning, but many of the other times, individuals should be capable of deciding what is the best course of action based on claims, evidence, and reasoning. Through this study, I hope to decide if the process of journaling about daily scientific experiences affects scientific thinking skills in a positive way.

# Chapter 2: Literature Review

Scientific thinking is important in a myriad of ways. There are a variety of decisions that individuals must make every day that have a scientific component. For example, what kind of car should a person purchase? What improvements need to be made to the home to make it more energy efficient? Individuals must weigh several different options such as cost, ease of implementation, as well as environmental issues. Critical, scientific thinking must be used to make a decision that is most beneficial to the individual. Teaching students this skill when they are young helps them in their future to consider all the facts as they make decisions. Teaching them about scientific thinking also helps them keep their natural wonder and curiosity about science. Today's educational climate tends to drown students with facts and algorithms designed to make them scientific dictionaries and calculating machines (Moore, 2018). This method is destroying their natural wonder and curiosity about science. This study tries to analyze a tool that might help students keep that desire to learn about science.

## Scientific Thinking in Society

Scientific thinking is using the skills and knowledge gained and applying that to a completely different scenario in a scientific discipline (Moore, 2019). Scientific thinking and reasoning skills are vitally important, not just for scientists, but for every individual in today's science rich environment (Engelmann et al., 2016). A student who knows all the names of the elements on the periodic table has a good knowledge of the periodic table. However, could that individual think like Dmitri Mendeleev did in the 1860s and find the relationship between atomic mass and the elemental properties to create the periodic table? Scientific thinking has been defined "as the way expert scientists think about problems in their field" (Moore, 2019, p. 17). Knowing and thinking are two parts of a complete understanding of a subject. The third part of true understanding is doing. “The learner may know facts, but without the underlying context of how these facts came to be known, and the thinking required to link actions to knowing, the learner does not understand the content that they know” (p. 20).

Moore (2019) found seven patterns that scientists use in their research: “pattern recognition, causation, determining relative variables and isolating them, hypothetical-deductive thinking, metacognition and relative value of evidence, and proportional thinking” (p. 26). There is a need to teach science thinking deliberately. He taught a physical science course filled primarily with prospective teachers. The course used inquiry as the primary pedagogical method of instruction. He did not lecture once during the entire course; the course was designed so that students would experience firsthand what scientists do every day. He found his course worked very well teaching the content. He also wanted to know if the course increased student scientific thinking skills. He “found *zero* improvements in science thinking. None. Not even a little, tiny, itsy-bitsy gain in science thinking ability” (p. 5). However, over the next 10 years he used the same process, and found that his program resulted in “significant gains in science thinking when implementing the ideas” (p. 5) that he used in that first course.

The origin of scientific thinking in individuals is an important thing to consider when taking part in the education of individuals in science. When does scientific thinking and reasoning develop? This question “centers on whether the early childhood years are characterized by any cognitive achievements specific and central to the development of scientific thinking” (Kuhn & Pearsall, 2000, p. 114). Defining the concept of scientific thinking is key to figuring out when and how children develop these skills.

When children can link the evidence presented with a thought-out explanation (theory), then they can think scientifically (Kuhn & Pearsall, 2000). The key piece in scientific thinking is the idea of connecting theory and evidence in a “consciously controlled manner” (p. 114). Young children are constantly changing their thinking as they grow and learn; they, however, are not often aware of how and why they change their thinking. A young child may react to outside stimulation to change their thoughts. For example, a child may place their hand on a hot surface and burn their fingers. As they experience the pain of a burnt hand, they have learned that some surfaces in their environment heat up and transfer heat easily. But they may not make the conscious explanation of heat transfer and material type.

Another factor in understanding scientific thinking is metacognition and epistemological awareness (Kuhn & Pearsall, 2000). Metacognition is the process where we focus on our thinking process. Epistemology is understanding how we know things. These are key factors in understanding the scientific thought process. Much of our learning is experiential; however, there is learning that occurs that is based on the experiences of others. Recognizing how we know something based on the theories and evidence of others is vitally important in our own knowledge construction.

Scientific reasoning and thinking skills, however, are complex; there are several characteristics that must develop for an individual to grasp deep, scientific thought. It is not as simple as being able to conduct an experiment where independent, dependent, and controlled variables interact with one another. Scientific thinking encompasses multiple variables; it is not a straightforward process where students learn information and apply that information to new scenarios to develop their understanding. Scientific thinking skills must develop in three ways: multivariable reasoning, argumentation, and a deeper understanding about the nature of science (Kuhn et al., 2008).

Recognition that science involves relationships between multiple variables is key to understanding how students develop their scientific thinking skills. Students must have the ability to connect multiple variables into their scientific thinking skills; science requires the analysis of multiple variables to understand nature. However, students often do not identify all the variables that they need to when they examine data to develop a complete prediction (Kuhn et al., 2008). The challenge is not necessarily the understanding of the variables that is difficult for students. The challenge is that students cannot keep a consistent connection between variables based on changing conditions (Kuhn et al., 2008).

Another key factor in developing scientific thinking skills is the concept of understanding the nature of science and scientific knowledge (Kuhn et al., 2008). “Science students must come to understand that scientific knowledge is constructed by humans, not simply discovered in the world” (p. 440). This requires individuals to be able to draw rational, evidence-based conclusions about the scientific information they experience daily.

**Scientific Literacy and Socioscientific Issues**

Scientific literacy and the ability to think scientifically has decreased in the current educational climate (National Assessment of Educational Progress, 2023). The emergence of socioscientific issues (SSI) as a topic in science education has revealed the lack of scientific literacy in society. SSIs are those that have a moral and ethical component (Sadler & Zeidler, 2002). Some examples of SSIs are global climate change, energy production, genetic engineering, cloning, farming, foods, vaccines, and other similar issues. Individuals may have the necessary scientific knowledge about an issue but have ignored the ethical and moral issues that are raised. Likewise, individuals may understand ethical and moral principles, but lack the necessary scientific knowledge needed to make an informed decision. Individuals need to have both scientific reasoning skills and the ability to understand the moral implications involved to make their decision based on evidence, not merely personal beliefs alone (Sadler & Zeidler, 2002). Scientific reasoning skills such as observing/measuring, interpreting, predicting/concluding, investigating, and reasoning/problem solving have been identified as key skills for students to use in their daily life (Hicks et al., 2017). These should be the focus of improving scientific literacy.

The ability to make decisions about socioscientific issues begins with the ability of individuals to construct an argument, analyze the evidence provided to support the argument, and satisfactorily provide evidence to counter such claims if necessary. Individuals must have the skills to examine evidence to make a claim, construct an argument from that evidence, and be ready to examine peer critiques based on the argument (Ford, 2012). These skills do not develop without intervention. Wallon et al. (2018) used a game-based activity to increase student argumentation in a high school biology course. Instructors used the activity along with direct instruction about argumentation. The students' scores on the argumentation assignment increased significantly by using the game-based activity.

Psycharis (2016) studied the use of inquiry-based computational scenarios on student argumentation levels. He found that student argumentation levels increased through these inquiry scenarios. Short et al. (2020) designed an intervention around Talk Science, where students utilized productive class discussions before engaging in a written argumentation exercise. They found that the discussions prior to the exercise can be used to increase argumentation skills. Dawson & Venville (2022) studied the development of a socioscientific issue activity in three phases around water use and its impact on student argumentation skills. They found that student could generate claims, construct arguments based on evidence, but could not backup their claim with sufficient reasoning.

Previous studies have examined various interventions to increase scientific thinking and scientific literacy. One study focused on increasing scientific literacy by examining scientific texts, observational skills, and reading and interpreting data (Hicks et al., 2017). Focusing on these key areas allowed students to develop better scientific thinking and literacy skills. “By encouraging higher order thinking in students, the benefits of focusing on specific key skill areas was evident” (Hicks et al., 2017, p. 32). Larison (2022) utilized a non-fiction science text to demonstrate how scientists generate arguments. This method provides the students and instructors with an exemplary method to showcase scientific argumentation.

Godfrey & Erduran (2023) used a card sorting activity to study student engagement in argumentation in the context of sensitive topics. The activity was designed to focus the students on the scientific content of the topic, not personal feelings or opinions. They found that the students could use the card sorting activity without incorporating their personal feelings about the topic. In the context of these studies, it is necessary to provide “support for a principled, practiced-based way to simulate scientific discourse in classrooms to support sense-making” (Ford, 2012, p. 207). Students who learned how to develop and critique scientific arguments are “better able to make their own results and conclusions more rigorous but also developed an awareness that results and conclusions are constructed generally through careful attention to ruling out errors and alternative possibilities” (Ford, 2012, p. 235).

Current political ideologies expressed in the media stress the need for students to have strong scientific reasoning skills, particularly around socioscientific issues (Chan, 2020). Even though many people have a career that is outside the scientific community, “they still encounter and must make decisions about scientific problems in their communities" (p. 1503). They must decide what changes they may need to make to their daily lives to reduce their energy consumption, what improvements to make to their house to make it more energy efficient, and what type of vehicle is the best option based on price and impact on the environment. Individuals in a community face those choices alone, but they affect the entire world. Using socioscientific issues in the learning process is vital to develop scientific reasoning skills for that very purpose.

Socioscientific issues require the students to develop the ability to think scientifically to answer the questions raised by the SSIs. Another topic of concern that must be examined through the lens of student scientific thinking skills is scientific content. Students must have sufficient content knowledge to engage in the scientific thinking process, especially in today's politically charged climate.

Chan (2020) studied how students approached socioscientific issues based on content. The study focused on the differences seen between environmental topics and topics related to genetics. She studied the difference between these two topics and four levels of socioscientific reasoning skills: complexity, perspectives, inquiry, and skepticism. She studied the differences in these four characteristics and the type of socioscientific issue the participants encountered: environmental versus genetics. She found significant differences between the topic and the characteristics of skepticism and perspective. She found "that students were more prone to consider alternative perspectives with the environmental topic, yet the Skepticism results showed more sophistication for the genetics issue" (p. 1513). Students were more likely to consider alternative views about environmental issues, while they questioned views about genetic issues.

Socioscientific issues will continue to dominate the media for years to come (Sadler et al., 2004). Science programs continue to focus on educating students about SSIs to improve their scientific thinking abilities (Dawson & Venville, 2022). Students must learn how to navigate these issues so they can make informed, logical decisions, the current goal of the NGSS (National Research Council, 2012). The next section will examine how the Nature of Science plays an important role in developing scientific thinking skills.

**The Role of Nature of Science in Scientific Thinking**

The focus of science education today is moving away from the knowledge based, memorization of facts form of teaching to integrating more societal issues surrounding science and the Nature of Science (NOS) (Sadler et al., 2004). There is a multitude of works describing the nature of science. Folino (2001) lists the following as the key features of the Nature of Science:

- Scientific knowledge demands empirical evidence.
- Scientific claims are testable/falsifiable.
- Scientific tests or observations are repeatable.
- Scientific knowledge is tentative and developmental, and hence fallible.
- Science is self-correcting.
- Scientific progress is characterized by the invention of, and competition among, hypotheses/theories.
- Different scientists can observe the same things, and interpret the same experimental data, differently.
- Science cannot provide complete answers to all questions/problems.
- Science is a social activity, both influencing society and being influenced by people's values and opinions.

- Logic, imagination, curiosity, and serendipity contribute to scientific exploration (Folino, 2001, p. 44-45).

Sadler et al. (2004) studied how biology students used the Nature of Science when analyzing socioscientific issues involving climate change and how they deal with conflicting information presented by scientific experts. Participants were expected to examine articles written by experts expressing positions that reached differing conclusions from similar data. They wanted to figure out how students were using the concepts learned about the nature of science (data driven, tentative, and the social/scientific interaction). They found that approximately 50% of the participants confused the concept of data and could not identify what data authors used to support their positions or they had a very rudimentary view of what data were presented but could not understand what the data were telling them in the articles they analyzed.

It is also important to understand how students assess scientific information. It has been a major goal for many science education programs (Kolstø et al., 2006). How does an individual recognize scientific claims, arguments, data, and reasoning in a discipline fraught with political opinions, ethical considerations, individual opinions, and distrust? “We need more knowledge of the nonexpert’s criteria for critical examination in real situations, and we need to understand the knowledge base that these criteria presuppose” (Kolstø et al., 2006, p. 633).

We can see from this research that students use a variety of techniques to evaluate scientific claims (Kolstø et al., 2006). Students used their own prior knowledge about science, their understanding of the peer review process when accepting and trusting the conclusions by scientists, their awareness of proper references to the work of others, and the need to present evidence in developing an argument in science. When we think about the inclusion of socioscientific issues in science pedagogy, scientific literacy is a vitally important piece to completing the scientific knowledge puzzle.

Another important piece of scientific reasoning related to socioscientific issues is the increase in web-based content that is deliberately misleading its readers (Tseng, 2018). In today's information saturated culture, being able to identify accurate scientific claims is vitally important in daily decision-making. In an era of misinformation and a climate of "fake news" claims from a variety of individuals, it is important to educate the public on how to recognize unreliable scientific claims.

Students took part in a study to analyze information by reading a blatantly false blog post about vaccinations. During the process, students read the article and took part in a think aloud activity. The students were asked to verbalize their thinking process about the articles that they read. After the think aloud activity, the students were asked to critique the article during the interview part of the data collection. The participants were categorized into three groups: accepting students, critical students, and changers (Tseng, 2018).

Accepting students chose to agree with the author's point of view about the dangers of vaccines. These students had difficulty in identifying the misconceptions and logical fallacies the author used to construct their argument. They felt that the author cited several sources to confirm the truthfulness of their argument. Critical students developed a stronger argument against the scientific validity of the author and the claims they made. They identified fallacies in the author's reasoning; however, these fallacies were not from a scientific viewpoint. Participants who were classified as "changer" students initially agreed with the author's conclusions in the think aloud activity. During the critiquing phase, the students developed a more critical eye and noticed inconsistencies in the arguments presented in the article (Tseng, 2018). These participants are passive readers at first, but when given the opportunity or direction to critique an argument, there is more engagement in critical analysis of the arguments presented.

This research is important, because it shows that "students need opportunities to evaluate arguments about science" (Tseng, 2018, p. 26). Because students learn to identify and evaluate logic used in other areas, science educators need to take the opportunity to teach the skills to recognize scientific inaccuracies used in argument development. "Scarce attention has been given in formal curriculum to the identification of errors in scientific reasoning, even though evaluation of scientific information is a crucial scientific practice" (p. 263). This lack of attention has recently taken center stage. Events in recent history have highlighted the need for strong scientific thinking skills, as evidenced by the COVID-19 pandemic, highlighted in the next section.

**The Role of COVID-19 in Scientific Thinking**

The biggest socioscientific issue of the past three years has been the COVID-19 pandemic. One reason that residents of the United States of America struggled with the COVID-19 virus is the pervasive lack of scientific literacy. "It's not new that the United States has an uneasy relationship with science" (Salisbury, 2020, para. 1). Salisbury reasoned that there are two main causes of this; "Americans give themselves permission to disregard scientific findings…[and] better general education" (Salisbury, 2020, para.6 and 7), specifically science education.

The COVID-19 pandemic was a confusing time experienced by doctors, scientists, politicians, media personalities, and others. It exposed the gaps in scientific and mathematical knowledge of the citizens of the United States (Bloom & Fuentes, 2020). Cultural forces such as skepticism, politics, and distrust of science came from "a lack of understanding, among the general public, of several important characteristics of science and the scientific process" (p. 2). The pandemic highlighted the need for better education of students in science and mathematics.

The pandemic also highlighted the inability of the public to identify fraudulent scientific claims, products, or scientific conclusions, specifically about the coronavirus (Allchin, 2020). One category of fraudulent claims involved the products that were claimed useful for protecting oneself from COVID-19. Claims made by doctors, politicians, scientists, and others flooded social media; conflicting reports arose and confounded the problem. Citizens need to be able to analyze claims, evidence, and reasoning from new reports, articles, and social media posts critically to make informed decisions about these things.

During the pandemic, the study of other diseases that kill millions of people (tuberculosis) or past pandemic responses (the Spanish influenza of 1918-1919) could shape the understanding of the current pandemic. Comparisons were made to the COVID-19 pandemic that were important for individuals to understand. Individuals need to be aware of past historical events in science to advance their understanding of what is happening in their everyday lives. The "aim here is not to look at the specifics of how biology education might respond to COVID-19 but rather to examine what history, philosophy and sociology of science might contribute and the implications of this for school science" (Reiss, 2020, p. 1080).

Another important study that came out from the COVID-19 pandemic studied the correlations between scientific reasoning and beliefs about health during the COVID-19 pandemic (Čavojová et al., 2020). One important claim came out from this study: "Scientific reasoning is therefore crucial – not only for understanding the causes and consequences of natural hazards…but also for sifting through the large amount of conflicting (and often false) information in the media and social networks" (Čavojová et al., 2020 p. 1).

Overall, there was found a negative correlation between scientific reasoning skills and the various coronavirus conspiracies, the general health beliefs, and negative vaccination attitudes (Čavojová et al., 2020). They also found a negative correlation between those high in scientific reasoning and their acceptance false information about the coronavirus as true. One conclusion that can be drawn from this work is that strong scientific reasoning skills “can prove useful in a crisis like the COVID-19 one, as it enables people to evaluate new evidence and not fall prey to conspiracy theories and beliefs” (p. 11). Another important conclusion that can be drawn is that during a crisis is not the proper time to develop these skills. Citizens should be actively engaging with science daily.

Another critical issue that came up during the pandemic was one of ethics. Is it ethical to require someone to do something even though they may personally be against it? This kind of question shows the need for teaching ethics in the science classroom (Reiss, 2020). “It is easier for science teachers to teach about ethics than it is for specialist ethics teachers to teach about science” (p. 1088). The ethical implications of the pandemic should be considered, especially when the discussion comes to access to healthcare and the development and use of vaccinations. This discussion can also lead into the study of the sociology of science, the study of human behavior. “Students can be introduced, in the context of COVID-19, to sociological ways of thinking and ways of examining data and questioning human practices” (p. 1089). This can be done by studying how governments responded to the crisis, how individuals reacted to governmental mandates, and the personal response to the vaccination development process. One fact remains: that science instruction needs to keep pace with current scientific issues.

Even though most citizens will not examine scientific information directly (through research and medical journals), they need to be aware of what information they glean from social media, close associations, and the national news media. The ability to detect suspicious claims brought by individuals on social media or traditional news sources must include some form of scientific thinking skills, which must be addressed in the educational setting.

## Scientific Thinking in the Educational Setting

### *The National Research Council (NRC) Framework*

Scientific literacy and scientific thinking are important characteristics for people to develop as they mature. The NRC (2012) developed a framework to address scientific literacy and thinking in the United States. The goal in developing this framework was to:

> Ensure that by the end of 12$^{th}$ grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (p. 1)

The NRC (2012) said that the need for scientific knowledge "now, more than ever, is essential for every American citizen" (p. 7). They said that science is necessary for every individual to know because of its impact on everyday life. The current pandemic is a prime example of this fact. With the framework, the NRC tried to combat scientific illiteracy by focusing on three dimensions: scientific and engineering practices, crosscutting concepts, and disciplinary core ideas in the physical sciences, life sciences, earth and space sciences, and engineering, technology, and applications of science.

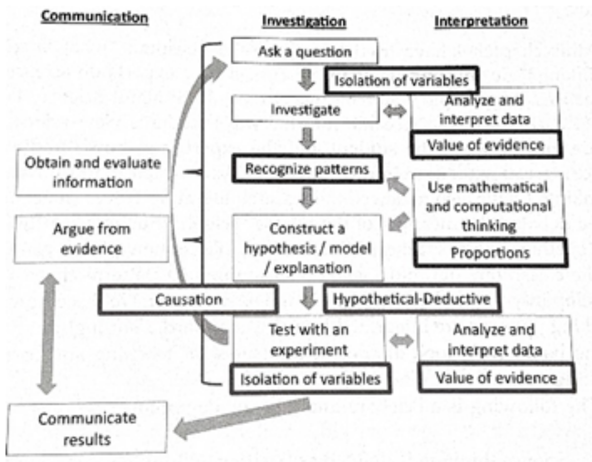
## The Next Generation Science Standards

The conceptual framework from the NRC (2012) led to the creation of the Next Generation Science Standards (NGSS). The NGSS are designed to be a comprehensive guide to K-12 science education because “never before has our world been so complex and science knowledge so critical to making sense of it all” (p. 1) They involve planning and conducting investigations, analyze data, the concepts that transcend all sciences (crosscutting concepts), and the core disciplinary concepts that students need to master at the end of the grade level in question. Some states adopted the NGSS as written; other states adapted their state standards in science to mimic the NGSS.

The standards created were designed to represent the work that scientists perform in their research activities. They were designed to incorporate data analysis, scientific thinking, developing scientific questions, providing evidence for claims, and reasoning from that evidence to draw conclusions. The idea behind the NGSS was to provide a model for what scientists do during the entire process of science. The current scientific method that is often presented in textbooks no longer serves as a practical model to explain the everyday work of scientists. Moore (2019) moved beyond the standard scientific method model often presented in science textbooks and created a new, “messy” model for scientific investigation that included the seven patterns in scientific thinking. His model can be seen in Figure 1.

**Figure 1**

*How the Scientist Practices Science*




Note. Reprinted from Moore, C. (2019). *Teaching science thinking: Using scientific reasoning in the classroom*. Routledge.

**Science and Engineering Practices in Scientific Thinking**

One of the most important components of the K12 Framework by the NRC is the Science and Engineering Practices (SEPs). Assessing the use of the SEPs by students can be challenging in the classroom. Often, the SEPs can be measured by students completing independent research projects, like a science fair (Koomen et al., 2021). They studied the use of individual student science fair projects and their attainment of rigor with the SEPs. They found that there was "strong evidence that as students completed SF [science fair] projects, attainment of the SEPs…and developing explanations…was appropriate and sufficient" (p. 320). They also found that students with help from science professionals designed projects that were more rigorous than students who worked alone. The students can gain insight and input from professionals in the field, those who use the SEPs on a daily basis.

While the independent science fair project is useful in assessing SEPs use, not every student participates in a school science fair. Another way an instructor can introduce students to the SEPs is by using classroom science projects (Stuart et al., 2021). These projects introduce designing, planning, modeling, and testing their final products. These are all key components of the NRC Framework and the SEPs.

While projects naturally incorporate the SEPs, teachers can incorporate the SEPs in their everyday classroom discussions. Malkawi & Rababah (2018) studied how instructors used the SEPs in Jordanian classrooms. They found that the teachers incorporated only two out of the eight practices with any high degree: use charts, tables, or diagrams during instruction and how to interpret quantitative data from an experiment or investigation. They found that teachers used all the SEPs, but only used them a few times a month. They concluded that the use of the SEPs certainly needs to increase. Exposure to the SEPs during this assignment can provide students with exposure during class that they can put into practice through the journal assignment.

SEPs often are second nature to science practitioners. Some of these practitioners change careers to become teachers, bringing skills and content knowledge to the profession. Antink-Meyer & Brown (2017) studied these second career teachers and how their previous experience in the scientific world translated to the educational world. They found that second career educators were more adept to incorporate the practices because they were "informed by explorations of their experiences and beliefs in their STEM-related careers and their science education careers" (p. 1525).

**Argumentation in Scientific Thinking**

One method of science instruction is to use the concept of argumentation. Argumentation is the practice of stating a claim, providing evidence to support that claim, and providing sound reasoning that connects the claim to the evidence (Murphy et al., 2018, Engelmann et al., 2016). One method to increase the use of argumentation in the classroom is the use of the Quality Talk

Science program. Quality Talk was designed to provide teachers with professional development in implementing more discussion opportunities into their science courses.

Murphy et al. (2018) found that using the Quality Talk Science program increased student and teacher discourse, teacher questioning skills, as well as an increase in student written argumentation skills. They did not find, however, any statistical significance in student conceptual understanding by using the Quality Talk Science program. Utilizing such a program would be an acceptable addition to a science educators toolkit to promote student argumentation skills.

**Wonder and Curiosity in Scientific Thinking**

True scientific thinking does not occur randomly in the life of a student. There is a natural wonder and curiosity that we have from birth. Before continuing, however, it is important to distinguish between these two concepts. According to Merriam-Webster, wonder is defined as the state of amazement and awe at the natural world. Another interesting definition that I will focus on is the “rapt attention or astonishment at something awesomely mysterious or new to one’s experience” (Merriam-Webster, n.d.). Wonder captures our human minds; it comes from the natural observation of the world around us.

Wonder, specifically in science, is necessary because “the wonder of science may be one reason why science still holds sway in the imagination of ordinary people” (Deane-Drummond, 2007, p. 587). People are amazed at the world around them. Our natural wonder is described as filling in the gaps of our knowledge (Opdal, 2001). It is part of our development. The knowledge of a child is incomplete; they wonder about so many things to complete their knowledge. As we mature, we do not have as many gaps in our knowledge. Our sense of wonder seems to wane and fade away. To address the issue of the fading of natural wonder, the importance of what is called "deep wonder" needs to be stressed in education (Schinkel, 2017). "There is surely something paradoxical, for example, about the suggestion that the experience of mystery – not ignorance, but *mystery* – is fundamental to education or to scientific inquiry" (Schinkel, 2017, p. 539-540).

The current educational climate is not necessarily designed this way. Currently, the amount of scientific knowledge available is staggering. Anyone can conduct an internet search about any scientific principle and find a multitude of results in seconds. Teaching students about the facts of science is not, and should not, be the focus of education today. The NRC and the NGSS are designed to encourage investigation and analysis. Developing Schinkel's idea of deep wonder seems to fit right into these ideas.

Wonder often progresses to a state of curiosity. Curiosity is the "desire to know; [an] interest leading to inquiry" (Merriam-Webster, n.d.). Curiosity can drive an individual to search for the answers, to experiment, research, or inquire of experts what is happening in the observed phenomenon. Curiosity has also been defined this way:

> Curiosity is seen to be the catalyst that creates knowledge. Because we are curious, we think. Because we are dissatisfied with the answers we get, we come up with new ways of thinking. Because we are curious, we discover new methods. We discover science… Experimental science is based so much on the character of curiosity… (Sarukkai, 2009, p. 760).

There are two very distinct types of curiosity, aimless and scientific (Whitesides, 2018). Individuals often have aimless curiosity. They do things to see what happens. They experiment, not necessarily to understand, but to see what happens. This type of curiosity has the potential to lead to scientific curiosity, the why something happens. "Curiosity is not a quiz, and there is no right answer" (Whitesides, 2018, p. 4127). It does not matter if aimless curiosity leads to scientific curiosity or not. The important piece is to keep that curiosity throughout life. That has the potential to lead to scientific curiosity in the future.

Another intervention that has been studied in the past is Creative Inquiry-based Science Teaching (CIST) and its impact on scientific thinking skills (Yang et al., 2016). Creativity and scientific study complement each other nicely. “Creative thinking such as divergent or convergent thinking is one of the critical essentials when scientists, engineers, or students are engaged in constructing explanations or developing solutions” (p. 2135). They found that utilizing CIST increased students’ scientific thinking skills and understanding in scientific inquiry.

**Scientific Inquiry in Scientific Thinking**

One method to encourage scientific curiosity and wonder is to use research style inquiry in the science classroom. It is also one proven method to encourage the development of scientific thinking and reasoning skills (Yuksel, 2019, Lawson, 2004, Russ et al., 2008, Dolan & Grady, 2010, Thoron & Myers, 2012). Scientific inquiry can be defined as “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (National Research Council, 2000, p. 1). Another definition to scientific inquiry is when “students answer research questions through data analysis” (Bell et al., 2005, p. 30). It is helpful to think of scientific inquiry as the application of scientific knowledge to real-world problems and questions. Teaching science in a more authentic way that applies to an individual’s daily life provides students with the opportunity to see how science connects to their world.

The connection between scientific thinking and inquiry is important for several reasons. How are students thinking during an activity where they are generating questions, hypotheses, procedures to test their hypotheses, and recording and analyzing data to answer their questions?

Does inquiry-based teaching impact a student's scientific reasoning skills? How can we measure student scientific reasoning skills using inquiry-based teaching methods?

Thoron and Myers (2012) studied the effects of inquiry-based instruction in agricultural science on student scientific reasoning. They studied 437 students at ten high schools in the United States. These students were enrolled in an agricultural science program at their school. The instructors that were selected for this study taught similar content to two different classes. One class was taught using inquiry-based instruction while the other class was taught using a subject matter approach. They found that the group of students taught using the inquiry-based instruction method had a statistically significant difference in scientific reasoning than students taught using the subject matter approach. The students in the inquiry-based instruction group had an average score on the LCTSR that was ten points higher than the subject matter instruction group. This shows one of the many benefits of using inquiry-based instruction in science courses.

Dolan and Grady (2010) developed a matrix that allows teachers to examine the complexity of student scientific reasoning. They postulated that "teachers need support in recognizing gaps in student reasoning during teaching by inquiry as a first step to mitigating them" (p. 32). Their matrix analyzes common items related to scientific inquiry: asking questions, making predictions, generating a hypothesis, creating and doing an experiment, examining variables (independent, dependent, control), analyzing data, generating explanations, identifying any limits to their experiment, and drawing conclusions to answer their questions. The matrix provides science educators with an additional tool to use in teaching scientific inquiry.

Another study involved the Thinking Doing and Talking Science (TDTS) intervention (McGregor et al., 2022). This program utilizes professional development to train teachers on "the development of creative and challenging science activities that encourage pupils to develop their thinking" (p. 365). The students use practical problem-solving techniques to complete the scientific process by thinking, doing, and talking about a specific scientific concept. The study found that there was a significant impact on student achievement.

Similar to the TDTS intervention, Dresner et al. (2014) studied the effect of classroom reform on introductory environmental science classes. The class was modified to include "more field experiences, data analysis and synthesis" (p. 40) rather than the traditional lecture presentations to students. They found that they students who participated in the modified classroom experience had higher scores on the Retention of Knowledge Test (RKT).

Scientific thinking is an important part of a person's life, whether they would like to admit it or not. With today's ever-changing technological landscape, the need for critical, scientific thinking is key to making decisions, analyzing media content, and assessing what is best for their personal lives. Scientific thinking does not fully develop on its own. There is an innate curiosity and wonder about the world, but people must be encouraged and taught how to develop their scientific thinking skills. Teaching these skills early to children will help them as adults navigate the world.

**Teaching Scientific Thinking in the Classroom**

The question then becomes, "How does a science educator teach their students scientific thinking and reasoning skills in the classroom"? Science educators spend years developing their content knowledge in their chosen field of science. They engage in coursework designed to learn about how students learn, methods that science educators have developed to teach concepts in science, and classroom management practices that are helpful to use in the classroom. Where do science educators "learn" how to teach scientific thinking? For that matter, how do they best teach the concept of scientific thinking and reasoning skills?

Science educators must display good scientific reasoning skills themselves before they try to educate their students. Krell et al. (2020) studied pre-service teachers' scientific reasoning competencies (SRC). "Science teachers need to not only possess conceptual knowledge of their subject, but also procedural and epistemic knowledge about the process of science and scientific reasoning" (p. 34). They surveyed the participants at the beginning of the first year of their program and students at the end of the first year of the program. They found no statistical difference between the two groups. The conclusion can be drawn that this process is a long-term process, not a quick fix.

One method that has shown promise is incorporating scientific thinking and reasoning into science, technology, engineering, and mathematics (STEM) instruction. Scientific reasoning skills "are characterized as the inquiry processes of students to reexamine and reproduce their hypothesis about the world involved in experimentation, assessment, and induction, deriving logical understanding therefrom" (Hasanah, 2020, p. 273). Students benefit from the study of STEM subjects by including a variety of disciplines in a course. STEM instruction encompasses "the acts of scientific inquiry, technology and engineering design, arithmetical study, and 21st century skills" (p. 274).

Students must have the ability to analyze their thought processes, brainstorm innovative ideas, assess, and evaluate during the learning process (Hasanah, 2020). STEM instruction allows for this naturally. Hasanah (2020) studied the effect of STEM instruction on high school students in Indonesia and found that students who were instructed with STEM principles experienced a statistically significant improvement in reasoning skills versus students who were instructed using traditional methods. In fact, the traditional students on the post-test assessment experienced “a loss of 36% in the reasoning skills value” (p. 277). The incorporation of STEM instruction is one way to improve scientific reasoning skills.

Scientific knowledge alone is not enough to increase students’ scientific thinking skills. Scientific knowledge and reasoning strategies are both important pieces to a complete understanding in science (Linn et al., 1989). Knowledge without context is more likely “memorized for a test and then forgotten because it was never understood” (Linn et al., 1989, p. 172). Scientific reasoning instruction along with scientific knowledge instruction will allow students to make deeper connections for learning.

In their study, Linn et al. (1989) focused on “the joint contribution of science topic knowledge instruction and strategy instruction” (p. 174). All students were provided instruction on blood pressure; the experimental group received additional instruction about reasoning strategies before the instruction on blood pressure. They found that the “combination of science topic knowledge instruction and strategy instruction produced more generalized reasoning performance than science topic knowledge instruction alone” (p. 183). Their results show that teaching science content along with scientific reasoning skills is more likely to increase retention of information, rather than simply teaching science content in isolation.

Ding et al. (2016) asked a vitally important question to consider about scientific reasoning skills: does higher education improve them? Conventional wisdom suggests that “students with more years of higher education are expected to have a greater level of scientific reasoning” (p. 619). They studied 1,637 Chinese students studying physics, chemistry, engineering, and science education in tier one (ranked in the top 30 institutions) and tier two (ranked between 100 and 150) institutions in China. They assessed students in years one through four at each university using the Lawson Classroom Test of Scientific Reasoning (LCTSR). Their results were unexpected; they found that over the four years there was no significant difference in scientific reasoning skills.

The LCTSR has been used to examine scientific reasoning skills in a variety of studies. Fabby & Koenig (2015) used the LCTSR to study the relationship of scientific reasoning and its relationship to problem solving in physics. They found that students with higher reasoning skills had less difficulty solving problems than students with lower reasoning skills. Marušić & Dragojević (2020) studied the impact of an active learning setting in a physics class for pharmacy students on their scientific reasoning skills, measured by the LCTSR. The students who participated in the active learning group achieved higher scores on the LCTSR, also scoring better in the course overall. Carmel & Yezierski (2013) also used the LCTSR to study the growth of students' scientific reasoning ability after taking part in a nonscience majors chemistry course. They found that the change in scientific reasoning was significant, but much lower than where the students should have been. The LCTSR has been used in a variety of ways to measure scientific reasoning and thinking skills.

The LCTSR itself can also be an important intervention for instructors to use. Deming et al. (2012) pointed out that "science teachers should consider utilizing a thinking skills measure that can provide comparisons in the United States" (p. 13). When instructors know the specific scientific thinking skills students struggle in grasping, the instructor can better adapt their teaching to better assist students in developing those skills.

**Writing in Academic Achievement**

Writing in general is an important part of the education process, but is an under-used tool, especially in high schools (Kohnen, 2013). In a 2002 study, Applebee and Langer (2006, as cited in Kohnen, 2013) found that “40% of twelfth graders report never or hardly ever being asked to write a paper of 3 pages or more” (p. ii). Teachers often fear using writing in their classrooms; their past experience has been one of difficulty (Kohnen, 2013). Teachers, however, are expected to incorporate writing into their daily teaching, along with the SEPs and NGSS standards.

With the focus on writing at the secondary level, students are still entering post-secondary education lacking the necessary skills to be successful at the college level. Students coming to post-secondary education that lack the necessary writing skills to succeed will not succeed without some intervention (Crews & Aragon, 2004). In their study, Preiss et al. (2013) found that writing skills was a significant predictor of success at the college level. They also found that over time, writing and the skills needed to write, are vital, even more than mathematical skills.

Sampson et al. (2013) studied the use of writing in the science classroom, specifically the skills necessary to creating an argument from data collected through the inquiry process. This is a necessary skill that students need in the pursuit of science (SEP 7: engaging in argument from evidence, SEP 8: obtaining, evaluating, and communicating information). Even though it is an important skill for students to learn, most science teachers avoid this type of writing. Through their study, Sampson found that not only did the participants improve their writing skills, but the complexity of their writing also improved.

**Reflective Journaling in Scientific Thinking**

One instructional strategy that teachers can use to increase the amount of writing in science is having the students write in a reflective journal. Al-Rawahi & Al-Balushi (2015) studied the effect of reflective journal writing in science class on student self-regulated learning strategies. Reflective writing “encourages learners to be involved in cognitive processing, which facilitates the interaction between data (the content space) and reasoning (the discourse space)" (p. 368). Using an experimental/control group design, they studied the use of reflective journals in a tenth-grade science class in Oman. They found that "journal writing can improve self-regulation strategies if it is structured around self-reflection in terms of learning goals, learning strategies, observations, understanding, feeling, and dialogues with oneself and others" (p. 377).

The journaling process has been used in a variety of educational settings. Teachers can use reflective journals in the analysis of their practice. Teachers can use the reflective journal in the classroom with the students to allow them to reflect on content and their learning experience. They can be used to "promote student learning, develop writing skills, assess students' reflection level, promote teachers' professional development, and gather research data" (Ahmed, 2019, p. 483). Reflective journals also give the opportunity for students to express their thoughts in a safe environment when they may feel a hesitation to converse in the typical classroom setting.

Reflective journals can be useful to assess student understanding and their thought processes following an assessment (Scheidegger, 2020). It allows the students to reflect on their preparation for the assessment, analyze their attendance patterns, and where changes need to be made. While the reflective journal process is directly related to an increase in skills or knowledge, the writing process for a reflective journal can transfer to other types of writing.

Reflective writing should not only focus on the negative aspects of a situation, but positive aspects as well. The reflective journal process can be used for any reason in the classroom setting; it does not have to be totally educational in nature. Students can write about life experiences, whether that would be positive, negative, or neutral life events. It is interesting to see how writing about these experiences can impact a variety of educational measures.

Generally, writing about positive life experiences leads to an increase in academic success (Jones & Destin, 2021).

Reflective journaling has been used in the classroom to formatively assess student learning in a science classroom (Trauth-Nare & Buck, 2011). Reflective journaling allowed teachers to alter their instruction in real-time. They can be used as “a relational tool for engaging both teachers and students in the learning process” (p. 386). The important concept educators must realize is that the students must be free to express their thoughts in the reflective journal that is used to help students with their learning. This allows the students to be active participants in the learning process, not a passive audience. It also gives the instructor a tool to adjust their teaching practice to fit more with the needs of the students.

Dianovsky & Wink (2011) studied journal writing as an avenue at exploring student understanding for science concepts, particularly in chemistry classes. They are a great formative assessment idea where instructors can correct misconceptions, focus on topics the students did not understand the first time, and personalize instruction and group work to help students better understand concepts. In their study, they found that reflections on a “classroom event” (p. 556) had a positive correlation to overall class performance while a reflection on “the textbook, handouts, and worksheets” had a negative correlation with course performance.

Reflective journaling is rarely seen, however, in education (Stephens & Winterbottom, 2010). Instruction in secondary science education is often self-directed; instructors present information and it is up to the students to apply the knowledge independently. The students may not find this type of learning motivational or beneficial because it is dependent on their own interests and abilities to conduct self-evaluation in their learning. When students complete a reflective journal, it provides them with the opportunity to reflect on what they learned during a lesson. In their study, Stephens and Winterbottom (2010) found in the study of reflective journaling in biology that “the learning log was effective at stimulating student awareness and critical analysist of learning” (p. 79).

Seeharaj & Samiphak (2019) studied the reflective journal process in a tenth-grade chemistry class with underprivileged students in Bangkok, Thailand. The study was designed to increase “students’ inquiring minds through science reflective journal writing and active learning” (p. 1). They found that “students paid more attention in class after the journal writing had been introduced, asked more questions, and overall had a more pleasant classroom experiences” (p. 1). The journaling process provides the students with the ability to analyze the content after the teacher’s introduction to the material in class. It gives them time to reflect on what they learned about the topic, as well as develop “the characteristics of [an] inquiring mind” (p. 5). Finally, it allows the students the opportunity to develop their innate curiosity about a topic, giving them the opportunity to explore it on their own time. The reflective journal also provides the teacher with the opportunity to provide feedback tailored to each individual student, making the learning more individualized.

Kawalkar & Vijapurkar (2015) studied the use of reflective journals in the science classroom; they used the journals to analyze student learning in an active, hands-on classroom experience versus the traditional teaching mode often employed in the typical science classroom. In the comparison of traditional modes of teaching versus active, hands-on inquiry teaching, the classes involved in inquiry activities developed “higher level cognitive demands…contingent upon observations and discussions in class” (p. 2130). This allowed the teachers to adjust their teaching in real time; it allowed them to provide scaffolding for the students to meet their cognitive needs.

Kawalkar & Vijapurkar (2015) also found that the students in the inquiry classroom wrote more entries in their journal as well as having longer journal entries than the students in the traditional classroom setting. The students in the inquiry group were more engaged in the process, with several students taking notes in their journal about questions that came to them during the course of the lesson. The combination of inquiry-based learning and reflective journals provides the teacher with better student engagement, deeper learning, and a formative assessment opportunity to adjust their teaching in real time.

Mohr et al. (2014) tasked preservice teacher candidates to observe nature, ask higher level questions, use their senses, represent knowledge in a variety of ways, and how they can teach observation to young children. The participants were given the freedom to organize their thoughts in a logical way using constructivist methodology. They found that the participants fell into three categories: reflectors, wonderers, and planners (p. 389). The participants either reflected on previous experience, ask questions about observations, or plan for future lessons. This design is similar to the present assignment.

**Conclusion**

Scientific journals have been used to analyze student learning (Ahmed, 2019; Scheidegger, 2020; Jones & Destin, 2021; Trauth-Nare & Buck, 2011), to identify student content knowledge (Dianovsky & Wink, 2011), and to have students and teachers reflect on the learning process (Stephens & Winterbottom, 2010; Seeharaj & Samiphak, 2019; Kawalkar & Vijapurkar, 2015). They have also been used to analyze preservice teachers' use of some of the SEPs (Mohr et al., 2014). However, no studies have investigated the role of reflective journaling as an intervention in developing scientific thinking and reasoning skills. Therefore, this study will investigate how the reflective journal assignment impacts students' scientific thinking skills.

It will place the development of scientific thinking skills in a real-life context. It will fill the gap in the literature to determine whether or not reflective science journal writing can impact scientific thinking skills.

## Chapter 3: Methodology

### Purpose

The purpose of this study is to determine if the scientific journal writing assignment increases participants' scientific reasoning skills.

The research questions for this study are:

1. What are the topics, as well as the Science and Engineering Practices (SEPs), that natural science major participants choose to write about, as well as participants not majoring in natural science?
2. How does the use of a weekly science journal impact scientific thinking skill scores for participants majoring in natural science and participants not majoring in natural science?

Null Hypothesis 2: The LCTSR scores will not be different for both science and non-science major participants.

Alternative Hypothesis 2: The LCTSR scores will be different for both science and non-science major participants.

3. Is there a significant difference in pre- and post-scientific thinking skill scores based on the participant's major (science versus non-science major)?

Null Hypothesis 3: There is no significant difference in scientific thinking skill scores based on major of the participant.

Alternative Hypothesis 3: There is a significant difference in scientific thinking skill scores based on the major of the participant.

4. Is there a significant difference between the journal entry quality depending on the participants' major?

Null Hypothesis 4: There is no significant difference between journal entry quality and the participants' major.

Alternative Hypothesis 4: There is a significant difference between the journal entry quality and the participants' major.

5. How do journalers describe their attitudes towards the assignment?

**Data Collection**

Data collection occurred during the fall semester, beginning in August 2023 and continued until December 2023. Data was collected from several sources. Participants' scientific reasons skills were assessed using the Lawson Classroom Test of Scientific Reasoning (LCTSR). The participants took the LCTSR as a pretest to establish a baseline of their scientific reasoning skills. The students were given the details about the scientific journal assignment and encouraged to focus on scientific thinking and reasoning at least two times per week for the semester. At the completion of the study, the participants were given the same LCTSR as a posttest to ascertain the effect of the journal assignment on their scientific thinking and reasoning skills.

**Instrument**

This research study used qualitative methodology to answer the first and last research question; it used quantitative methodology to answer questions 2, 3, and 4. This study involved collecting the participants' pretest and posttest scores from the LCTSR as well as computing a score on the journals with a rubric. The participants' major also factored into the data analysis. To answer the second research question, the pre and posttest scores on the LCTSR for each participant were compared to determine if there was a statistical difference between the two groups. To answer the second research question, the pre and posttest scores were compared based on science versus nonscience majors using a mixed ANOVA design. The journal assignment was scored using the Journal Entry Rubric. Participants who completed the assignment were compared to those who did not complete the assignment using their LCTSR pretest and posttest scores, as well as the participant's major.

**The Lawson Classroom Test of Scientific Reasoning**

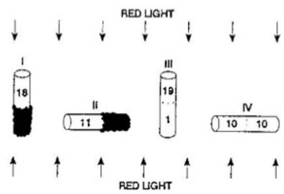
The LCTSR was originally developed by Lawson (1978). The current version has 24 multiple choice questions and requires 30 minutes to complete. The first 22 questions are paired; the first question poses a question about scenario. The second question asks about the reasoning behind the answer to the first question. It focuses on scientific reasoning by examining the participant's ability to think proportionally, think about probability, how things correlate, and to perform deductive, hypothetical reasoning.

The Cronbach's alpha reliability coefficient for the LCTSR was reported as 0.86, as well as a KR-20 reliability score of 0.78 (Lawson, 1978). Lawson also measured validity in three ways. He consulted with six experts in Piagetian research who identified that the questions needed "concrete and/or formal reasoning" (p. 17). Lawson also measured convergent validity by finding the correlation of the total test score to the subject scores of bending rods and balance beam tasks. The correlation between the two tasks and the overall score was 0.76, indicative of the assessment having convergent validity. The third form of validity was measured using principal component analysis. Lawson found that the tasks loaded onto his three main factors: formal reasoning, early formal reasoning, and concrete reasoning. The assessment met the requirements for factorial validity. Figure 2 shows an example of a question cluster.

**Figure 2**

*A Question Pair from the CTSR*

Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.




*This experiment shows that flies respond to* (respond means move to or away from):

a. red light but not gravity
b. gravity but not red light
c. both red light and gravity
d. neither red light nor gravity

*because*

a. most flies are in the upper end of Tube III but spread about evenly in Tube II.
b. most flies did not go to the bottom of Tubes I and III.
c. the flies need light to see and must fly against gravity.
d. the majority of flies are in the upper ends and in the lighted ends of the tubes.
e. some flies are in both ends of each tube.

Note: Reprinted from Lawson, A. E. (2000). *Classroom Test of Scientific Reasoning (CTSR)*. PhysPort. https://www.physport.org/assessments/assessment.cfm?A=CTSR&S=4

The LCTSR assesses several different scientific reasoning skills. The example question in Figure 2 represents questions about identification and control of variables and probabilistic thinking (ICV+PBT). The question requires the participant to identify the variable(s) that the flies respond to and the reason for their selection, based on the probability distribution of flies in the tubes. In this question pair, the participants identify that gravity is responsible for the distribution of flies, but not the exposure to red light. This occurs because of the distribution of flies in tubes II and III. In tube II, the flies are about evenly distributed instead of located in the uncovered end of the tube. Table 1 shows the eleven scientific reasoning skills that are assessed and the questions that they correspond to on the LCTSR.

**Table 1**

*LCTSR Reasoning Patterns*

| Category | Question Numbers |
|---|---|
| Conservation of weight (CW) | 1 and 2 |
| Conservation of displaced volume (CDV) | 3 and 4 |
| Proportional thinking (PT) | 5 and 6 |
| Advanced proportional thinking (APT) | 7 and 8 |
| Identification and control of variables (ICV) | 9 and 10 |
| Identification and control of variables and probabilistic thinking (ICV+PBT) | 11 – 14 |
| Probabilistic thinking (PBT) | 15 and 16 |
| Advanced probabilistic thinking (APBT) | 17 and 18 |
| Correlational thinking (CT) | 19 and 20 |
| Hypothetico-deductive thinking (HDT) | 21 and 22 |
| Hypothetico-deductive reasoning (HDR) | 23 and 24 |

The LCTSR does not directly measure all eight of the SEPs. It does not directly measure the ability of the participant to ask a question (SEP 1) or conduct research and communicate the results of an experiment (SEP 8). The other practices align very well with the LCTSR, focusing on control of variables (SEP 3, planning an investigation); proportional, advanced proportional, probabilistic, and advanced probabilistic thinking (SEP 5 mathematical and computational thinking and SEP 4 analyzing and interpreting data); correlational thinking (SEP 6 constructing explanations); hypothetico-deductive thinking and reasoning (SEP 7 engaging in argument from evidence and SEP 2 developing and using models).

**The Scientific Journal Assignment**

The original idea for the scientific journal idea came from Dr. Christine Schnittka (Schnittka et al., 2022); it was used to encourage pre-service science educators to think scientifically in a real-life setting. In this study, the scientific journal assignment was designed to have the students focus on science and scientific practices at least two times during a week. The journal assignment was presented to students at the beginning of the semester. The students' grade for the assignment was determined by the number of entries completed at midterm (16 entries) and final (32 entries). The assignment was designed to be open-ended; students were allowed to write about any scientific discipline they chose. The students were required to write at least 100 words in their journal to make it a meaningful, thought-provoking exercise. The journal handout can be found in the Appendix A. The participants received a grade based on the completion of the assignment, receiving 20 points if they completed all 32 entries. If the participants completed less than 32, they received the number of points equal to the percentage of entries completed. The assignment was 2% of the participants final grade in the course.

The scientific journals were collected during the study to analyze what topics the participants choose to write about, the major types of entries (e.g., observations, questions, scientific literature, etc.), and how the participant's journal entries evolve over the course of the semester. The quality and quantity of the journal entries were assessed using the Journal Scoring Rubric. The rubric includes the SEPs found in the NRC Framework. So, the journal entries were also coded to identify the SEPs used by the participant. The rubric can be seen in Figure 3.

**Figure 3**

*Journal Scoring Rubric*

| Criteria | Level 1 | Level 2 | Level 3 | Score |
|---|---|---|---|---|
| 2 entries per week for 16 weeks (minimum 32 entries) | 0-10 entries written | 11-22 entries written | 23-32 entries written | |
| Word count (minimum 100 words) per entry | 0-50 words | 51-99 words | 100+ words | |
| Total SEPs used | 0-32 (up to 1 per entry) | 33-64 (up to 2 per entry) | More than 65 (more than 2 per entry) | |
| Unique SEPs used | 1-3 | 4-6 | 7-8 | |
| SEPs likelihood | SEPs 1 and 8 | Level 1 + SEPs 4, 5, 6 | Level 2 + 2, 3, 7 | |
| **Total** | | | | **/15** |

The journal rubric was constructed for use in analyzing journal entry quality. Criteria 1 and 2 were based on the requirements for the journal entries. Criterion 3 was based on the number of practices the participants used in their journal entries. Participants who used more than one practice during the process looked at the content from multiple viewpoints. Criterion 4 examined the number of unique practices used. Participants who used a variety of practices looked at science from multiple perspectives instead of using one or two practices repeatedly. The final criterion was the likelihood that the participants used the practices.

Using previous research in a similar study (Schnittka et al., 2022) for an initial starting point, the SEPs were ranked by the likelihood of them appearing in the journal entries. The most likely practices were asking questions (SEP 1) and obtaining, evaluating, and communicating information (SEP 8). Level 2 practices included the Level 1 practices plus analyzing and interpreting data (SEP 4), using mathematics and computational thinking (SEP 5), and constructing explanations (SEP 6). Level 3 practices included the Level 2 practices plus developing and using models (SEP 2), planning and carrying out investigations (SEP 3), and engaging in argument from evidence (SEP 7).

This assignment was designed using the MUSIC Model of Motivation (Jones, 2009) to help motivate the students to complete the assignment. The MUSIC Model emphasized the design of instruction using the following five components: empowerment (control), usefulness (practical), success (results), interest (relevant), and caring (well-being). These five components promote student motivation; students who are motivated generally have a greater understanding of the material they are learning. Even with this, I expected that there would be students who did not complete the assignment. However, this proved helpful as a comparison group when I questioned whether the journal assignment affected scientific thinking skills.

**Participants and Study Setting**

The participants were selected from Woods University (a pseudonym), a small, private liberal arts university in the Southeastern part of the United States. Woods University is a Christian University, devoted to providing an education that not only incorporates knowledge and skills, but character and service. The university serves a student population of approximately 3,000 students, with approximately half of those students classified as underrepresented students. The average class size is approximately 15 students.

**Participants**

The participants in this study consisted of 35 science majors and 21 non-science majors enrolled in General Chemistry I (science majors) and Physical Science I (non-science majors) at Woods University (a pseudonym), a private religious university located in the Southeastern United States. The non-science major group included participants majoring in elementary education, marketing, legal studies, Bible, and counseling psychology. The average age for the non-science major participants was 20.86 years. The participants' ethnicities were 76.19% Caucasian, 14.29% African American, and 9.5% Hispanic. Overall, 81% of the non-science major participants took both the pretest and posttest LCTSR (two participants were absent from the last class and two dropped the class before the end of the semester) and 67% of the non-science major participants turned in the journal for analysis. This subgroup is referred to as "non-science major journalers". The remaining 33% of non-science major participants who did not complete the journal assignment are classified as "non-science major non-journalers."

The science major group included participants majoring in health sciences, physical therapy, biochemistry, exercise sports science, and biology. The average age for the non-science major participants was 20.40 years. The participants' ethnicities were 72.73% Caucasian, 15.15% African American, 9.09% Hispanic, and 3.03% Asian. Overall, 89% of the science major participants took both the pretest and posttest LCTSR (four participants were absent from the final class session). However, only 60% of the science major participants turned in the journal assignment for analysis, classifying them as "science major journalers" and the remaining 40% were classified as "science major non-journalers." Because this study was designed to examine the impact of the journal assignment on the participants' LCTSR score, it was important to create this distinction. The LCTSR scores were compared using this classification.

Participants in this study were attending a four-year Christian University where they experienced a science curriculum framed within a religious context. The participants may have held a viewpoint contrary to current scientific consensus about origins of humanity, age of the universe, and other contentious topics where science and religion may clash. Science and religion in the past 100 to 200 years have been viewed as incompatible; the historical nature of science has been ignored. Rather than viewing the interdisciplinary nature of science and religion, the battle lines have been drawn by individuals on both sides. Individuals often cite "religious reasons" for their reluctance to vaccines. Christians are mocked by some in the scientific community as slow, lacking the intelligence to grasp even basic concepts of science because of their religious beliefs. McLiesh (2018) framed the debate between science and religion this way:

> Maintaining the view that science and religion are in conflict does no one any favors and is hurting science. The damage comes not only through a warped transmission of history but also because it suggests to religious communities that science is a threat a threat to them rather than an enterprise they can celebrate and support (p. 12).

Individuals eventually come to a point in their life as scientists that they must confront the dissonance that may be created by their religious beliefs, specifically around their views on evolution and the age of the universe. Is there a complete answer that science or religion can offer to those individuals? Research suggests that an interdisciplinary approach to teaching science and religion is beneficial to both disciplines (Eisen & Huang, 2014; Stolberg, 2009; Davison, 2022). When students are exposed to the viewpoints with an interdisciplinary lens rather than in isolation, the benefits are visible seen. "Yet it is many of our science students who will be running the emergency rooms and laboratories of tomorrow, immersed daily in ethical situations, treating and engaging religious and non-religious people–people who have strong religious beliefs and are not experts in science" (Eisen & Huang, 2014, p. 30-31).

McLeish (2018) noted that science and religion have been related for some time:

> Newton himself is testimony to the deep, formative role of Christian theology in the rise of experimental and mathematical sciences…Small wonder that Nicolaus Copernicus saw

his astronomical work as a form of worship and that Galileo Galilei viewed his as reading God's second book (p. 12).

In this study, the participants focused on developing their scientific thinking skills, something they may not have had in their previous academic experience. The participants came from a variety of backgrounds; they were home schooled, attended religious private schools, or went to various public schools. Their past experiences with science varied widely. The opportunity to develop their scientific thinking skills during this study was analyzed. Their identification as Christians aside, allowing the opportunity to develop scientific thinking skills carries great weight today.

**Theoretical Framework**

To better understand participants' scientific thinking skills, the journal assignment was situated in a scientific context. The participants studied science content in their respective courses, but also going about their daily routine in a world full of socioscientific issues and scientific phenomena. The assignment was situated within those courses and the students' lives as an extension of the concepts learned in the classroom. Situated cognition is the concept that knowledge, learning, and understanding are situated in context. It is believed that the development and use of knowledge cannot be separated from or subordinated to how students learn and think (Brown et al, 1989).

Situated cognition has been described as "a learning theory that emphasizes and promotes real and authentic learning…learning of skills and knowledge occur in contexts that reflect how that knowledge is gained and applied in everyday situations" (Altalib, 2002, p. 2). Learners must be included in the experience, rather than learning independently from the experience (Altalib, 2002). Learning cannot be simply an understanding of the concepts that students are exposed to in the classroom. The concepts need context, meaning, and culture to be valid to the learner (Kim & Hannafin, 2008).

"Situated cognition emphasizes the importance of context in establishing meaningful linkages with learner experience and in promoting connections among knowledge, skill, and experience" (Choi & Hannafin, 1995, p. 54). Situated cognition places learning in a real-world context, a more authentic experience than the formal education setting. In the model of teacher as expert, the teacher that disseminates knowledge to the students cannot compare with the experience of learning (Choi & Hannafin, 1995). These formal educational contexts are designed to develop problem solving skills. The problem is the skills developed in the classroom do not transfer to the everyday lives of students because they are not learned and used in the context of the students' lives (Herrington & Oliver, 2000).

There are nine qualities that are essential in situated learning: authentic contexts, authentic activities, access to experts, a variety of perspectives, collaboration, reflection, articulation of knowledge, coaching and scaffolding, and authentic assessment (Herrington & Oliver, 2000). They suggested "that useable knowledge is best gained in learning environments that feature" these characteristics (p. 25). Hedegaard (1998) argued that "to contribute to the student's general cognitive and motivational development, the content of teaching should be anchored in three areas: the everyday knowledge of the student, the subject-matter area important for a society, and a theory of personality development that includes the social practice traditions of a society" (p. 115).

Current educational practices teach concepts, curriculum, and methods in isolation; the contexts where the subject matter fits are often ignored. Students learn the how-to method; they learn tricks, formulas, definitions isolated from context, algorithms, and other independent concepts that are remembered for the test, but easily discarded once assessed (Brown et al., 1989). Students can learn facts, dates, and other academic information (the tools of education) in a classroom but do not have the skills necessary to implement that knowledge in authentic situations. Standardized assessments and teacher created exams are often constructed to assess rote memorization, or the use of algorithms developed in class rather than solving real-world problems in context (Altalib, 2002).

Situated cognition compliments the journal assignment very well. Participants observed, questioned, and studied science in their everyday lives. The assignment was situated in a real-life context, not isolated in an artificial context like the classroom. Participants transferred the knowledge that they learned in the classroom and experience in their lives, and used these experiences to frame their journal entries about science in their everyday life. Finally, the participants thought scientifically, using scientific practices such as making observations, asking questions, developing and using models, obtaining, evaluating, and communicating evidence, and other scientific thinking practices seen in the NGSS.

**Timeline for Research**

The following timeline was developed to keep the research project on a manageable timeline:

- April 1, 2023: Submission of IRB approval form
- Week of August 14, 2023: Scientific journal activity introduced, participant recruitment and consent obtained
- Week of August 14, 2023: LCTSR pretest administered
- October 6, 2023: Journals collected, graded
- Week of November 27, 2023: Journals collected, LCTSR posttest administered

- December 8, 2023: Data analysis

**Data Analysis**

The quantitative data was analyzed using a mixed model ANOVA (Murrar & Brauer, 2018). The participants were categorized as either science majors or non-science majors, as well as "journalers" and "non-journalers". Their pre and post-test scores were analyzed independently to see if the assignment increased the overall score on the LCTSR. The scores were also analyzed to see if the participant's major impacts their LCTSR score. The participant's journal was scored with the journal rubric; that score was analyzed against the participants' major. Finally, the completion of the journal assignment was examined against the LCTSR score to decide if the journal assignment affected the participants' LCTSR score.

The mixed model ANOVA was used to determine the difference between the LCTSR scores and rubric scores for science majors and nonscience majors. There were six assumptions for conducting a mixed model ANOVA that were met. The dependent variables in this study (LCTSR score and rubric score) were ratio data and normally distributed. A test for normality occurred in the first phase of data analysis (skew and kurtosis were analyzed). The participants in this study were not a true random sample; the participants were purposefully selected as being science majors or nonscience majors taking part in a science course during the fall semester. The sample was also a sample of convenience. The two groups were independent of each other; the participants could not be science and nonscience majors at the same time. The sphericity of the LCTSR and rubric score was also assumed; the variances between the scores were assumed to be equal (Roberts & Russo, 1999). Mauchly's sphericity test was used for the sphericity of the data. If sphericity was not achieved, it was decided the data would be interpreted using the Greenhouse-Geisser correction (Roberts & Russo, 1999). Finally, homogeneity of variance was assumed; the error variance of each group was equal. Levene's test was used to test for homogeneity of variance.

**Researcher's Viewpoint**

A crucial factor to consider in analyzing scientific thinking and reasoning skills is the viewpoint of the researcher. As a chemistry teacher, I find it important for individuals to make well-informed decisions when it comes to how they go about their daily routine. Science generally can answer a myriad of questions that are posed every day by people who want to know more about the world they live in. Constantly asking and answering those questions makes us better individuals to understand things about the world.

As important as scientific thinking and reasoning skills are to an individual, there will be some questions that science cannot answer. Scientists try to answer these questions, but ultimately humanity must realize that scientific knowledge is constructed by the individual (Kuhn et al., 2008). There are some questions that humanity asks that cannot be directly observed. An important fact that humanity needs to learn and accept is the concept of the "unknowable"; the piece that keeps wonder and curiosity sparked in the individual.

One key piece to scientific thinking and reasoning is having an open mind to possibilities that we cannot explain, quantify, or observe with our physical senses. The concept of the supernatural goes beyond the physical world and cannot be explained using physical terms. The possibility of the existence of such things must be decided on by the individual, not a collective body such as a school or other entity. The purpose of these entities is to make the claim, provide the evidence, explain the reasoning, and allow the individual to decide for themselves what best fits for them. It is up to the individual to make the choice of how they want to see the world. It may be incorrect; that is the purpose of continued learning.

# Chapter 4: Results

This study focused on the impact of journal writing on college students' scientific thinking skills, investigating how the journal process impacted scientific thinking skills. The study also investigated whether there was a significant difference between science and non-science majors in terms of their scientific thinking skills. This study was completed in two science courses involving a variety of students, from first year to senior students, as well as science and non-science majors. The research questions in this study were:

1. What are the topics, as well as the Science and Engineering Practices (SEPs), that natural science major participants choose to write about, as well as participants not majoring in natural science?
2. How does the use of a weekly science journal impact scientific thinking skill scores for students majoring in science and students not majoring in science?
3. Is there a significant difference in pre- and post-scientific thinking skill scores for participants based on the student's major (science versus non-science major)?
4. Is there a significant difference between the journal entry quality depending on the participants' major?
5. How do journalers describe their attitudes towards the assignment?

The Lawson Classroom Test of Scientific Reasoning (LCTSR) assessment measures an individual's ability to reason scientifically. This chapter answers these five research questions by the analysis of the contents of the journal, as well as analyzing the pretest and posttest scores on the LCTSR inventory and conducting a comparison of how science and non-science major participants differed on the LCTSR and on journal entry quality. The quality of journal entries was assessed using the Journal Entry Rubric (JER).

## LCTSR Assessment

The scientific thinking skill scores were measured using the LCTSR assessment. To maintain the validity and reliability of the LCTSR, interested individuals can access a copy of the assessment here: https://www.physport.org/assessments/assessment.cfm?A=CTSR&S=4 after completing the registration. The LCTSR assessment was scored by the primary investigator. There are 24 total questions on the assessment; questions one through 22 are designed to be scored in pairs. The first question proposes a scenario; the second question asks for the correct reasoning associated with the scenario. Only participants who answer both questions correctly receive credit. Questions 23 and 24 are independent questions. The assessment is graded out of 13 total points.

## Research Question 1: Journal Entry Analysis

### *Science Disciplines*

The participants were asked to complete 32 journal entries over the course of 16 weeks (about 3 and a half months). Science majors averaged 25 entries, while non-science majors averaged 26 entries. The participants were given the freedom to choose the topics for their entries. Each entry in the journals was coded based on the science discipline of that entry (biology, chemistry, physics, etc.). The entry was coded by identifying the main scientific discipline rather than trying to combine disciplines. For example, one participant wrote about fireworks and how they work. Specifically, the wrote that they "wondered what chemicals combine and react to create the gigantic explosion in the sky." This content could be classified as either chemistry or physics, depending on the nature of the entry. However, ultimately, the entry was classified as chemistry because the entry focused on the chemical composition of the fireworks that caused the explosions in the sky rather than how the colors are produced.

Some entries genuinely mentioned two distinct disciplines; in that case, the entries were coded with both disciplines. There also were entries that were not focused on any scientific discipline. Some entries were about popular sports, the history of science, or even the nature of science. These entries were coded as “other” since they did not fall into a specific science discipline. Table 2 identifies the disciplines that non-science major and science major participants wrote about in their journals. For example, 5.5% of the entries for non-science majors were about astronomy, while 1.7% of the entries for science majors were about astronomy.

**Table 2**

*Participant Journal Entries by Discipline*

| Science Discipline | Non-science Majors | Science Majors |
|---|---|---|
| Biology | 35.1% | 38.9% |
| Physics | 27.2% | 26.4% |
| Chemistry | 11.3% | 13.5% |
| Biochemistry | 9.3% | 9.5% |
| Geology | 7.5% | 5.1% |
| Astronomy | 5.5% | 1.7% |
| Psychology | 3.5% | 3.5% |
| Other | 0.6% | 1.4% |

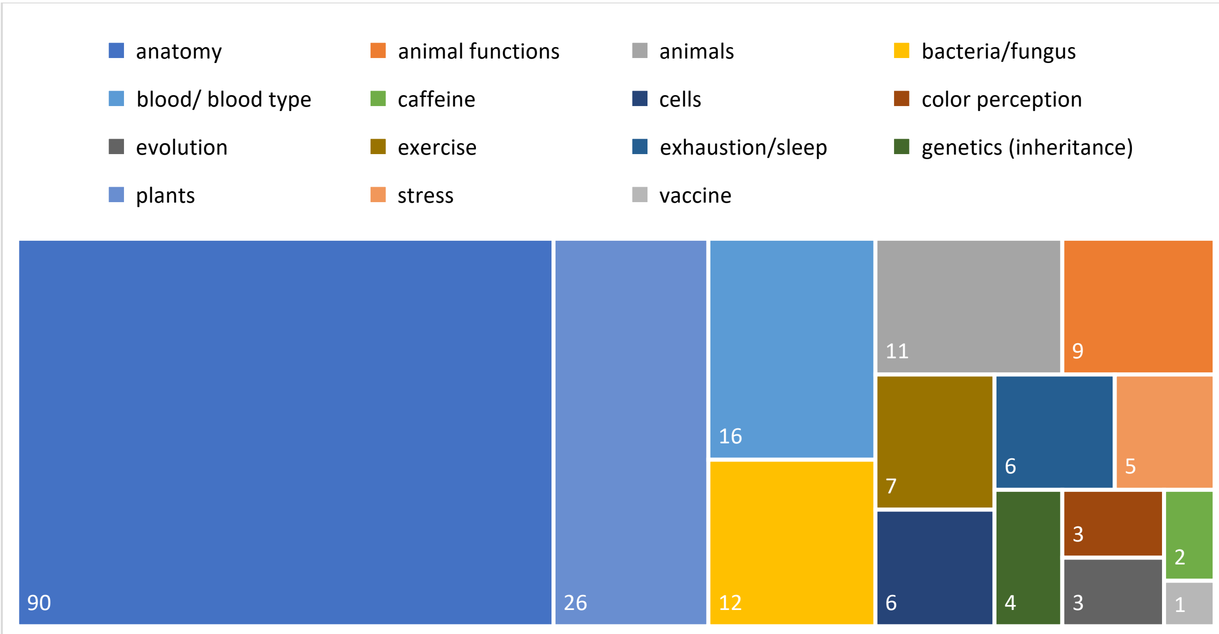
Simply for comparison, a similar study (Schnittka et al., 2022) with undergraduate and graduate preservice science teacher candidates mirrors the distribution seen here with one notable exception. The percentage of physics content for science majors (26.4%) and non-science majors (27.2%) in this study was higher than previously seen. Pre-service science teachers in that study completed the same journal assignment, but only wrote about physics content 9% of the time. One possible explanation for this difference could be that the non-science major participants were enrolled in a physical science course that focused on physics and chemistry while completing the journal assignment. The science major participants were enrolled in General Chemistry I class.

### *Biology Content*

There were several similarities between the science major and non-science major groups regarding content. The participants wrote most about biology content, with 35.1% of entries for non-science major participants and 38.9% for science major participants. Non-science and science majors focused on a variety of biology topics, some of which were anatomy, plants, animals, blood, genetics, sleep, cells (animal and plant), and the effect of stress on the body. With the science major participants, these specific biology topics were expected; many of the science major participants were either Health Science or Biology majors. A breakdown of biology topics can be seen in Figure 4 for science major participants and in Figure 5 for non-science major participants.

**Figure 4**

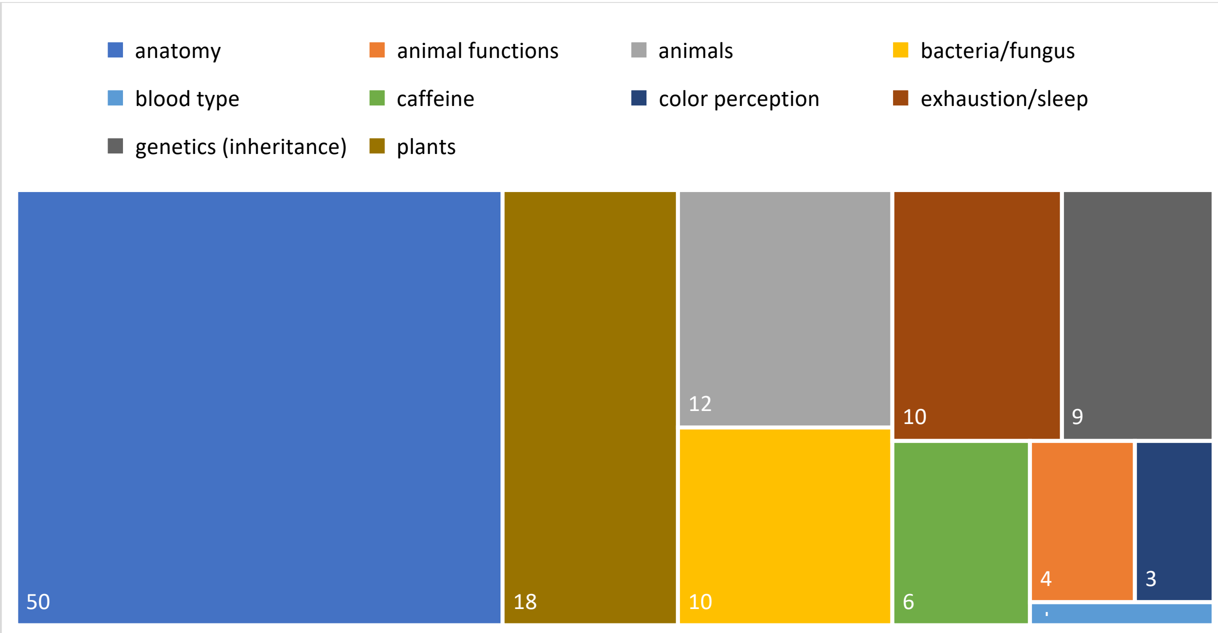
*Science Major Participant Biology Content Frequency*




*Note:* The number in the corner for these diagrams represents the total number of entries for that specific category. For example, there were 90 entries that were related to anatomy in Figure 3. The color represents the frequency, rather than the specific category.

**Figure 5**

*Non-science Major Participant Biology Content Frequency*




### *Physics Content*

The second most popular discipline that the participants wrote about was physics. The most popular physics topics were electronics, physical properties (or changes e.g., boiling, density, buoyancy, freezing), optics (light, color, rainbows), electricity, heat/temperature, gravity, airplanes, nuclear fission/fusion, and sound. The participants experienced many of these topics in the context of their everyday lives, but also experienced them in class as well.

The non-science major participants often chose topics that were discussed in the physical science class. For example, electricity was discussed in class, specifically focusing on the relationship between voltage, resistance, and current (V=IR), as well as series and parallel circuits. Many of the journal entries simply mentioned electricity, specifically when it went out in their dorm rooms or apartments. A breakdown of physics topics can be seen in Figure 6 for science major participants and in Figure 7 for non-science major participants.

**Figure 6**

*Science Major Participant Physics Content Frequency*

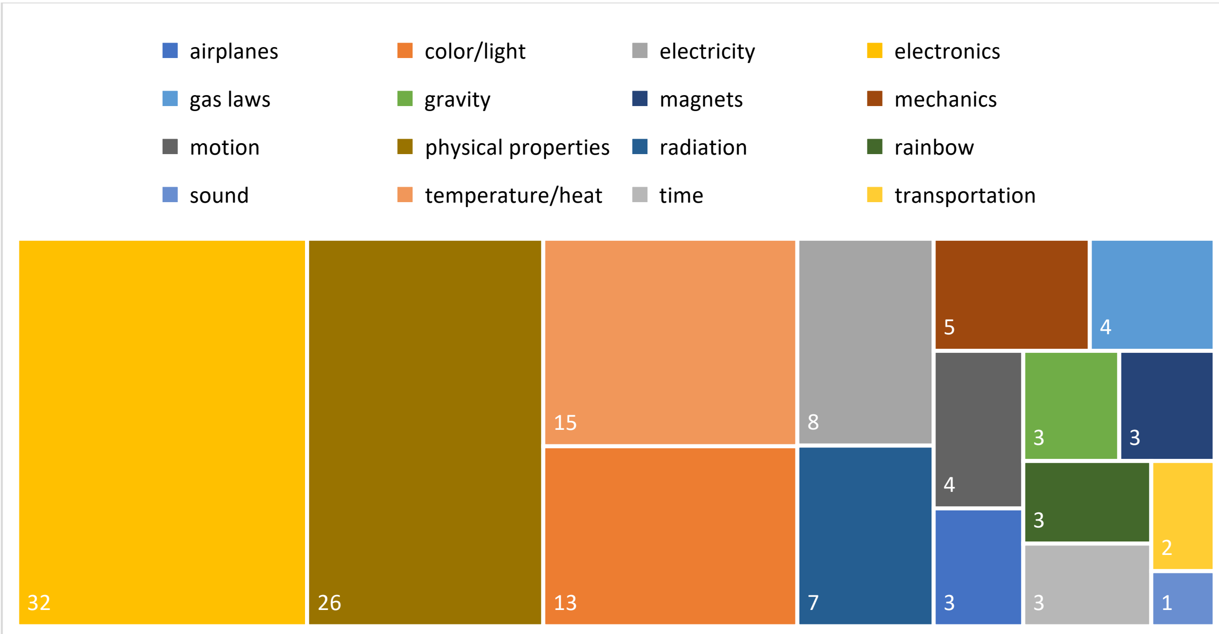
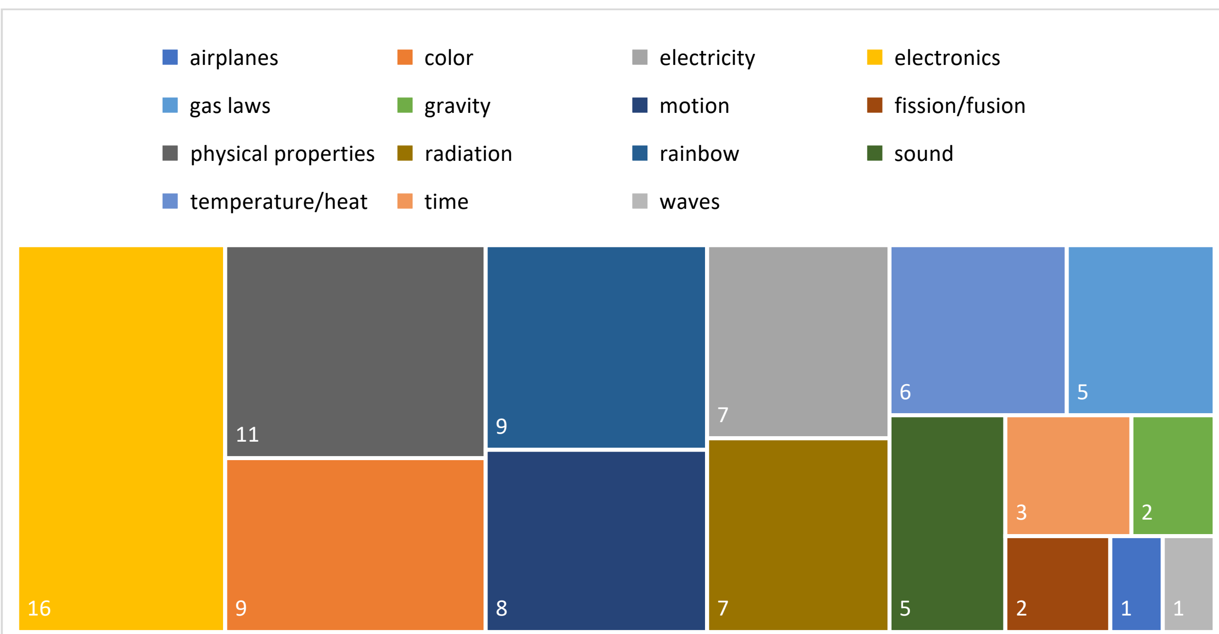



**Figure 7**

*Non-science Major Participant Physics Content Frequency*



### *Chemistry Content*

The third most popular discipline was chemistry. The most common topics mentioned were chemicals/materials (metals, bleach, gasoline, etc.), water, acids/bases, chemical reactions, chemical composition, carbon dioxide, and the periodic table. Again, both groups were studying chemistry in class; it was not uncommon for the participants to mention topics that they were studying at the time or labs they completed. It is interesting to note that the participants focused mainly on "academic" topics rather than daily life experiences. Many of the journal entries included, "today in class (or lab) we did XYZ". A breakdown of chemistry topics can be seen in Figure 8 for science major participants and in Figure 9 for non-science major participants.

**Figure 8**

*Science Major Participant Chemistry Content Frequency*

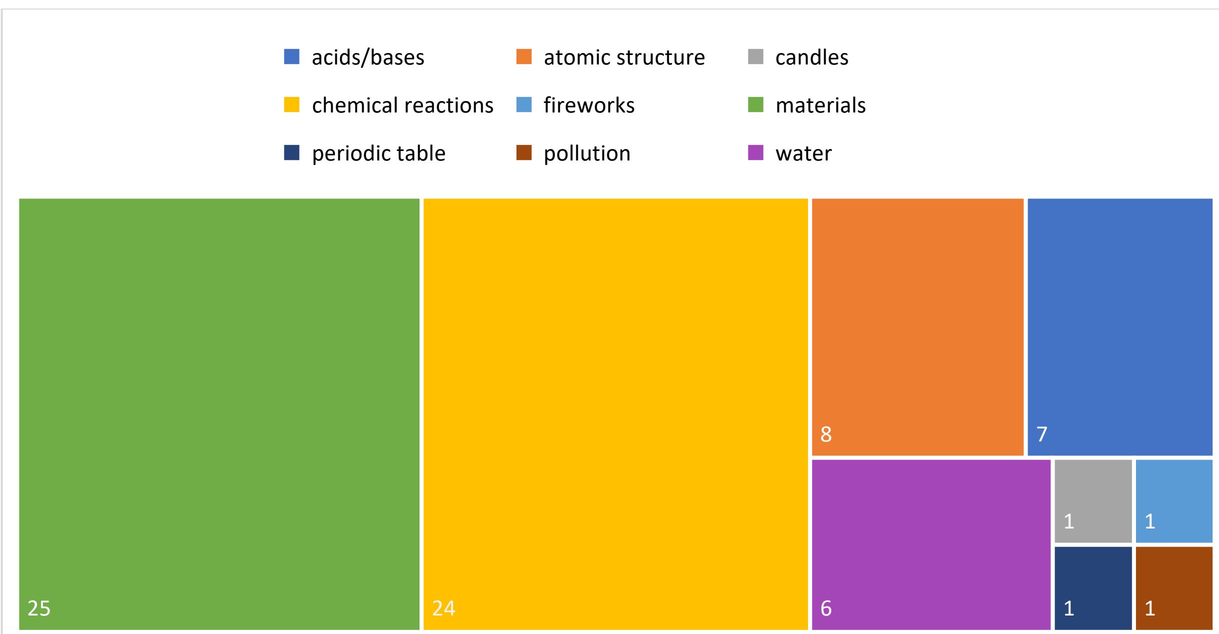
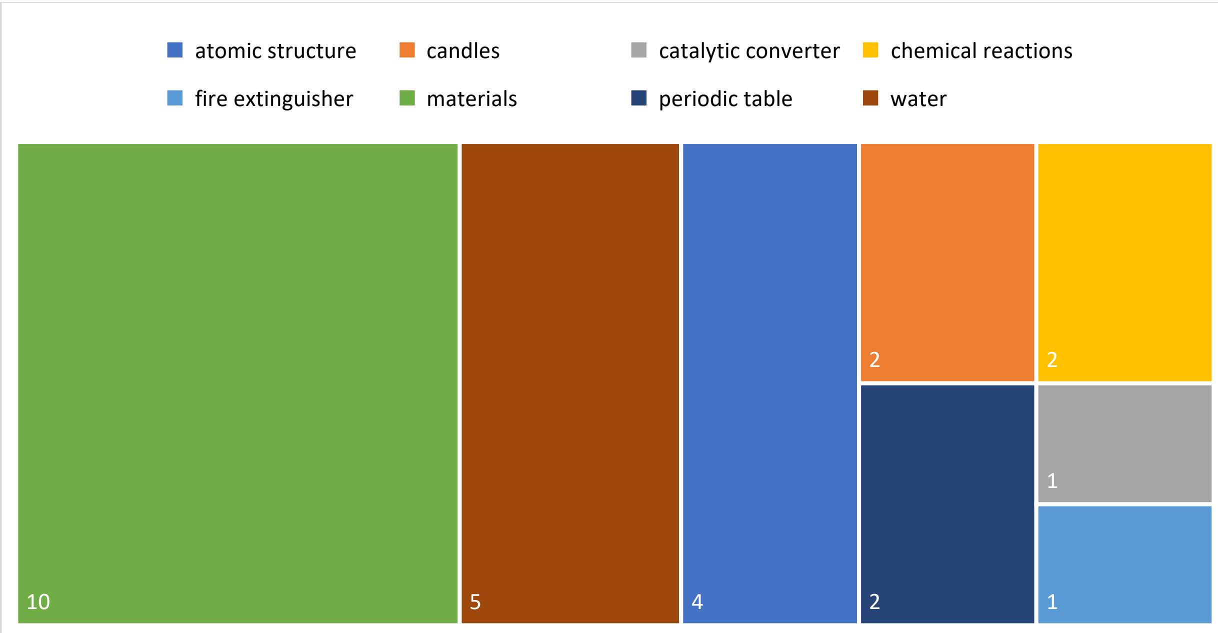


**Figure 9**

*Non-science Major Participant Chemistry Content Frequency*




Some of the other topics that participants wrote about in the remaining science disciplines (astronomy, geology, biochemistry, etc.) included galaxies, the phases of the moon, planets, weather, geologic structures, chemical reactions within the human body (digestion, hormones, etc.), the composition of DNA, and other topics. The science major participants often focused more on biochemistry topics that were related to their study in biology or the health sciences. Geology and astronomy were seen less than these topics. A breakdown of these topics can be seen in Figure 10 for science major participants and in Figure 11 for non-science major participants.

**Figure 10**

*Science Major Participant Miscellaneous Content Frequency*

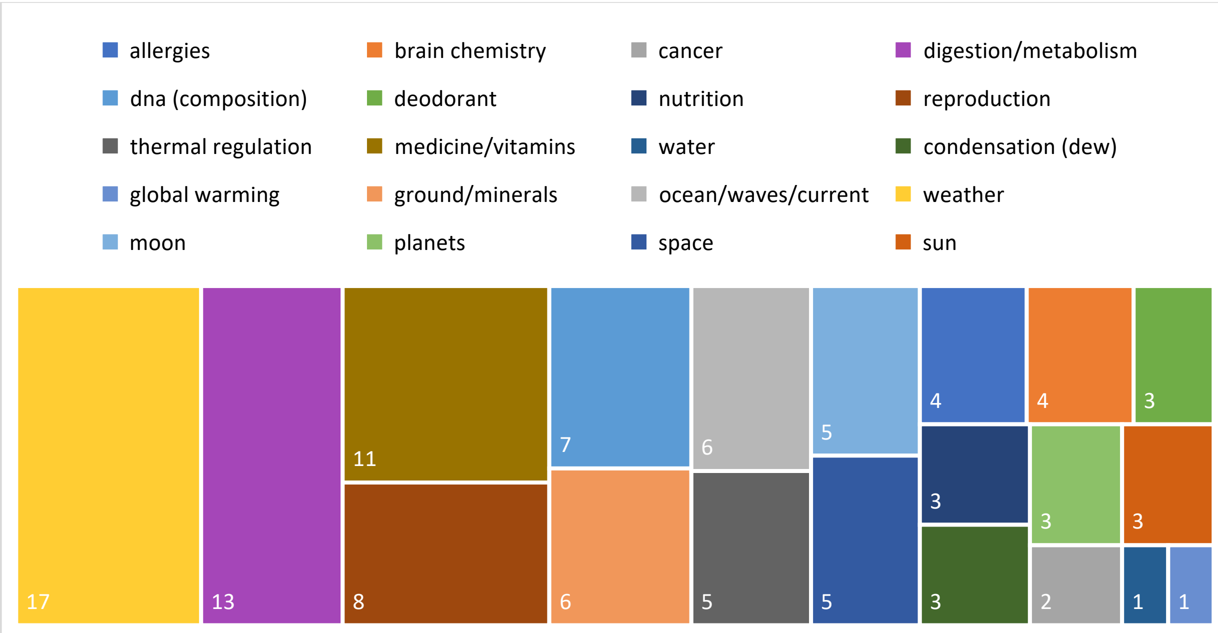
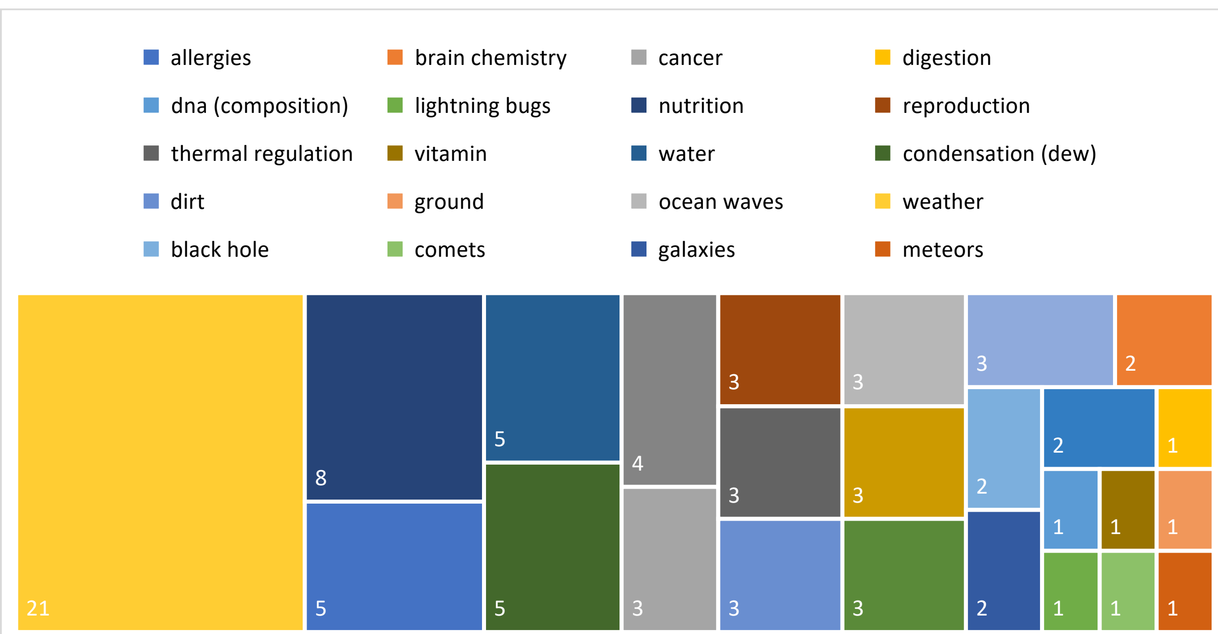



**Figure 11**

*Non-science Major Participant Miscellaneous Content Frequency*




## Science and Engineering Practices

The next interesting analysis that is important to this study is the way that the participants wrote about these subjects. Specifically, which Science and Engineering Practices (SEPs) were used by the participants when writing about these subjects? The National Research Council defines each SEP in their Framework for Science Education (National Research Council, 2012); these definitions were also used to code the participants' journal entries. The participant's entry was coded with SEP 1 (asking questions) when the entry indicated wonder or curiosity about a specific scientific observation or phenomena. Another key characteristic for this SEP was a solution to some problem that the participants noted in their daily life. The code, SEP 2 (developing and using models), was used when "representations that are in some ways analogous to the phenomena they represent" (p. 56). These models could be diagrams of molecules, plants, animals, or some representation of motion, gravity, or other physical concept. These models were used to aid the participant in understanding the scientific world around them.

The code, SEP 3 (planning and carrying out investigations), was used when the entry described a test for potential explanations to an observation, a viable way to answer a scientific question, or conduct a confirmatory analysis of prior knowledge. SEP 3 complements SEP 1 very well; it is a practical method to answer scientific questions. The code SEP 4 (analyzing data) also complements SEP 3 and SEP 1 very well. Scientists must "organize and interpret data…to bring out the meaning of data – and their relevance – so that they may be used as evidence" (National Research Council, 2012, p. 61). Data in this case are considered quantitative and qualitative; participants may use either one to answer their scientific questions.

The code, SEP 5 (mathematics and computational thinking), was used when a participant used mathematics to explain variables using numbers (National Research Council, 2012). Computational thinking incorporates "tools and strategies [to] allow scientists…to collect and analyze---data sets, search for distinctive patterns, and identify relationships and significant features in ways that were previously impossible" (p. 64). The code, SEP 6 (constructing explanations and designing solutions), was used when a participant tried to provide an understanding about specific scientific phenomena. These entries attempted to "link scientific theory with specific observations or phenomena" (p. 67).

The code, SEP 7 (engaging in argument from evidence), was used when a participant makes a case by using sound reasoning and data as evidence. Finally, SEP 8 (obtaining, evaluating, and communicating information) was used when a participant read scientific information, evaluated that information, and communicated that information to others. The participants were not given any instruction on the different SEPs. They were simply told to observe the world around them, ask questions about what they observe, and try to answer that question by a variety of methods (investigation, research, or talk to an expert). The journal assignment was designed to include a variety of methods to answer these questions.

During the coding process, if the participant conducted a scientific investigation, the entry was coded as SEP 3. During the analysis of the participants' journal entries, they may have used multiple practices in the same entry. For example, a participant may have asked a question to start their entry like, "why is the sky blue?" That would be coded as SEP 1. If they researched the answer (whether they included a citation or not), evaluated that information, and communicated it in the journal entry, that would be coded as SEP 8. Table 3 shows the distribution of the SEPs by participant group. For example, 48% of all entries by non-science major participants asked a question, while approximately 50% of all entries by science major participants asked a question.

**Table 3**

*Participant Journal Entries by SEPs*

| SEP | Non-science | Science |
|---|---|---|
| 1 (asking questions) | 48.0% | 49.9% |
| 8 (information) | 46.5% | 41.2% |
| 3 (investigations) | 1.6% | 5.7% |
| 6 (explanations) | 1.5% | 1.3% |
| 7 (argumentation) | 1.3% | 0.5% |
| 4 (analyze data) | 0.8% | 0.6% |
| 5 (mathematics) | 0.2% | 0.6% |
| 2 (models) | 0.0% | 0.1% |

These results are not surprising. In a previous study, the participants mirrored these results closely (Schnittka et al., 2022) with preservice science teacher candidates. The participants focused on the "bookends" of the scientific process: asking a question (SEP 1) and communicating the answer to that question (SEP 8) either by conducting research or using previous knowledge about the subject. There was very little focus by the participants on actively creating and using models (SEP 2), analyzing data (SEP 4), or using mathematics and computational thinking (SEP 5). These results may be a function of the assignment itself. The participants were told at the beginning of the journal assignment to ask questions about the science they observe around them. Participants may simply rely on the "easy" part of science by simply asking the questions and researching the answer, rather than putting in the effort to perform an experiment (SEP 3), analyze data (SEP 4), or construct an argument from evidence (SEP 7).

Another interesting observation from this assignment centers around SEP 3, planning and carrying out investigations. Some participants believed that the focus of the journal assignment was to report on the laboratory experiments they completed during the week. This may have over inflated the data surrounding SEP 3, 4 and 6. The participants wrote about the investigations they performed, analyzed some of the data, and created explanations for the results they observed. However, the investigations were not planned by the participants; they were a function of the laboratory class they were enrolled in during the semester.

**Journal Entry Rubric**

The journals were scored using the rubric at the end of the semester. The rubric had five criteria: number of journal entries, word count, total number of SEPs used, the number of unique SEPs used, and the "difficulty" of the SEPs used. The difficulty of the SEPs was based on previous research (Schnittka et al., 2022). The practices that were used by preservice science teacher candidates most often were identified as Level 1 (SEP 1 and 8). The next level (SEPs 4, 5, and 6) were the next most frequent SEPs used. Finally, SEPs 2, 3, and 7 were identified as Level 3 because they were infrequently used by the preservice science teacher candidates. Each journal entry was coded with the SEPs used and the scientific discipline discussed in the journal entry. The maximum score possible on the Journal Entry Rubric is 15. The journal rubric can be found in Figure 12.

**Figure 12**

*Journal Entry Rubric*

| Criteria | Level 1 | Level 2 | Level 3 | Score |
| --- | --- | --- | --- | --- |
| 2 entries per week for 16 weeks (minimum 32 entries) | 0-10 entries written | 11-22 entries written | 23-32 entries written | |
| Word count (minimum 100 words) per entry | 0-50 words | 51-99 words | 100+ words | |
| Total SEPs used | 0-32 (up to 1 per entry) | 33-64 (up to 2 per entry) | More than 65 (more than 2 per entry) | |
| Unique SEPs used | 1-3 | 4-6 | 7-8 | |
| SEP likelihood | SEPs 1 and 8 | Level 1 + SEPs 4, 5, 6 | Level 2 + 2, 3, 7 | |
| **Total** | | | | **/15** |

**Research Question 2**

Research question 2 dealt with the impact of the weekly scientific journal assignment on the participants' scientific thinking skills, assessed with the change in the LCTSR over the course of the semester. The null hypothesis for this question was that there will be no difference in LCTSR change scores. A mixed model ANOVA was done to decide if the participants completing the journal assignment experienced a larger increase in their LCTSR scores than non-journalers. The descriptive statistics can be found in Table 4.

**Table 4**

*LCTSR Descriptive Statistics for Journalers and Non-journalers Combined*

| Group | *N* | *M* | *SD* | *Skew* | *SE skew* | *kurtosis* | *SE kurtosis* |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Pretest | 56 | 4.946 | 2.818 | 0.188 | 0.319 | -0.850 | 0.628 |
| Posttest | 56 | 3.929 | 2.935 | 0.426 | 0.319 | -0.439 | 0.628 |

The LCTSR pretest and posttest scores show normal distribution in reference to skew and kurtosis. Overall, there was a significant difference between the pretest and posttest scores for all the participants ($F_{1,52} = 11.218$, $p = 0.002$, $\eta^2 = 0.177$), showing that the null hypothesis initially was rejected. There was a statistical difference between pretest and posttest scores. This statistical difference must be analyzed further because there were participants who took the pretest and posttest LCTSR but failed to turn in their journal at the end of the semester.

To better understand this question, participants were categorized as "journalers" and "non-journalers", a necessary classification to analyze whether the scores of the participants who took the LCTSR but did not complete the journal assignment were significantly different from those who did complete the journal assignment. Table 5 shows pretest/posttest descriptive statistics for journalers and non-journalers. Figure 13 shows box plots for these groups.

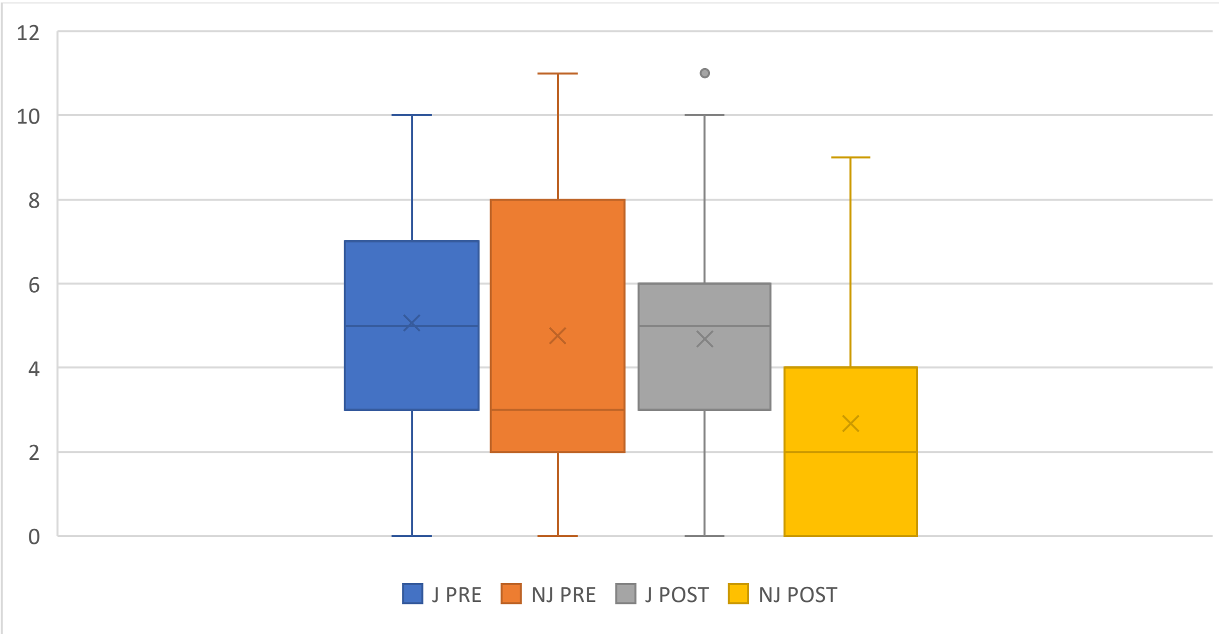
**Table 5**

*LCTSR Pretest and Posttest Descriptive Statistics for Journalers and Non-journalers*

| Group | $N_{pre}$ | $M_{pre}$ | $SD_{pre}$ | $N_{post}$ | $M_{post}$ | $SD_{post}$ |
|---|---|---|---|---|---|---|
| Journalers | 35 | 5.057 | 2.555 | 35 | 4.686 | 2.709 |
| Non-Journalers | 21 | 4.761 | 3.270 | 13 | 2.667 | 2.921 |
| Total | 56 | 4.946 | 2.818 | 48 | 3.929 | 2.935 |

**Figure 13**

*Boxplots for LCTSR Scores for Journalers and Non-Journalers*




The mixed ANOVA analysis showed that there was a significant difference in LCTSR score between journalers and non-journalers ($F_{1, 52} = 4.904$, $p = 0.031$, $\eta^2 = 0.086$). That significant difference was found between the non-journalers' pretest and posttest scores ($F_{1,52} = 12.039$, $p = 0.001$, $\eta^2 = 0.094$), while the journalers' pretest and posttest scores were not significantly different ($F_{1,52} = 0.902$, $p = 0.347$).

While there was no significant difference between the pretest scores of journalers and non-journalers ($F_{1,52} = 0.031$, $p = 0.860$), but there was a significant difference between the posttest scores of journalers and non-journalers ($F_{1,52} = 5.240$, $p = 0.026$, $\eta^2 = 0.094$). This distinction shows that taking the time to complete the journal assignment makes some difference in the scientific thinking skills of the participants. Journalers on average scored 1.762 points higher than non-journalers on the LCTSR posttest.

It is interesting to note that the posttest scores decreased for both journalers and non-journalers at the end of this study. Logically, participants who took a science class while taking part in a journal assignment designed to expose them to scientific thinking should have seen at least a consistent score or even some increase in LCTSR scores. Most of the participants in this study scored lower on the posttest than the pretest. Lack of motivation could play a part in the decrease of LCTSR score. The participants (both journalers and non-journalers) were not provided with any external motivation other than to complete the LCTSR assessment to the best of their ability.

From this study, the journal assignment does have some impact on the participants' LCTSR score. The non-journalers' pretest and posttest mean score difference (2.393) was greater than those participants who completed the journal assignment (0.488). With the very small effect size, there is some impact on the LCTSR scores and the assignment participation. Again, it is important to note that both groups experienced a decrease in their posttest scores; the non-journaler participants simply experienced a much larger decrease in posttest score. Some of that difference can be attributed to the intervention used in this study.

**Research Question 3**

Research question 3 dealt with the difference between pretest and posttest scientific thinking skill scores for science and non-science major participants (journalers and non-journalers). The null hypothesis for this research question was that there is no significant difference in LCTSR scores based on the participants' major. Pretest and posttest descriptive statistics for major and non-major participants can be found in Table 6.

**Table 6**

*LCTSR Pretest and Posttest Descriptive Statistics by Group Combined*

| Group | $N$ | $M_{pre}$ | $SD_{pre}$ | Min $_{pre}$ | Max $_{pre}$ | $M_{post}$ | $SD_{post}$ | Min $_{post}$ | Max $_{post}$ |
|---|---|---|---|---|---|---|---|---|---|
| Science | 35 | 5.000 | 2.951 | 0 | 11 | 4.457 | 2.984 | 0 | 11 |
| Non-science | 21 | 4.857 | 2.651 | 1 | 9 | 3.048 | 2.692 | 0 | 9 |
| Total | 56 | 4.946 | 2.779 | 0 | 11 | 3.923 | 2.935 | 0 | 11 |

In addition to the pretest and posttest scores from the LCTSR, an item difficulty was calculated for the 24 questions to find areas of success and areas where participants struggled with specific thinking skills. This item analysis shows the specific questions and reasoning patterns for the science major and non-science major participants. The difficulty scores can be found in Table 7.

**Table 7**

*Pretest and Posttest LCTSR Category Item Difficulty by Group Combined*

| Category | Non-science Pretest | Non-science Posttest | Science Pretest | Science Posttest |
|---|---|---|---|---|
| CW (1&2) | 0.952 | 0.867 | 0.800 | 0.774 |
| CDV (3&4) | 0.524 | 0.333 | 0.514 | 0.419 |
| PT (5&6) | 0.048 | 0.067 | 0.229 | 0.258 |
| APT (7&8) | 0.190 | 0.000 | 0.086 | 0.097 |
| ICV (9&10) | 0.333 | 0.400 | 0.571 | 0.548 |
| ICV+PBT (11&12) | 0.143 | 0.067 | 0.057 | 0.065 |
| ICV+PBT (13&14) | 0.143 | 0.200 | 0.200 | 0.161 |
| PBT (15&16) | 0.524 | 0.400 | 0.543 | 0.516 |
| APBT (17&18) | 0.524 | 0.333 | 0.629 | 0.645 |
| CT (19&20) | 0.286 | 0.333 | 0.429 | 0.548 |
| HDT (21&22) | 0.238 | 0.133 | 0.114 | 0.097 |
| HDR (#23) | 0.381 | 0.467 | 0.400 | 0.387 |
| HDR (#24) | 0.571 | 0.667 | 0.429 | 0.516 |

*Note:* item difficulty is calculated using the equation: $D = \frac{correct\ responses}{total\ participants}$.

A mixed ANOVA showed that there was no significant difference between the LCTSR scores for science and non-science major participants ($F_{1,52} = 2.945$ $p = 0.092$), demonstrating the retention of the null hypothesis at the $p > 0.05$ level. There was a significant difference ($F_{1,52} = 9.979$, $p = 0.003$, $\eta^2 = 0.057$), however, in the pairwise comparison of the non-science major participants LCTSR pretest and posttest scores. This indicates that there was a statistically significant difference; the posttest scores for the non-science major participants were significantly lower than their pretest scores. There was no interaction between the major and pretest/posttest score.

The non-science major participants performed better than their science major counterparts in the following areas: Conservation of Weight (CW), Identification and Control of Variables and Probabilistic Thinking (ICV+PBT), Hypothetico-Deductive Thinking (HDT), and Hypothetico-Deductive Reasoning (HDR). The science major participants performed better than their non-science major counterparts in the following areas: Proportional Thinking (PT), Advanced Proportional Thinking (APT), Identification and Control of Variables (ICV), Probabilistic Thinking (PBT), Advanced Probabilistic Thinking (APBT), and Correlational Thinking (CT).

Examining this difference further, looking at the interaction between participant major, journal assignment participation, and pretest/posttest scores, there was a significant difference between pretest and posttest scores ($F_{1,52} = 8.512$, $p = 0.005$, $\eta^2 = 0.002$) for non-science majors who were classified as non-journalers. These participants experienced the largest pretest/posttest score difference (3.286) than any other group. Even though the difference for science major, non-journalers was not significant ($F_{1, 52} = 3.548$, $p = 0.065$), they experienced the second largest pretest/posttest difference (a change in score of 1.500 points). Pretest and posttest descriptive statistics for major and non-major journal assignment participants can be found in Table 8.

**Table 8**

*LCTSR Pretest and Posttest Descriptive Statistics by Group for Journalers*

| Group | $N$ | $M_{pre}$ | $SD_{pre}$ | $M_{post}$ | $SD_{post}$ |
|---|---|---|---|---|---|
| Science | 21 | 5.571 | 2.580 | 5.667 | 2.614 |
| Non-science | 14 | 4.286 | 2.340 | 3.214 | 3.684 |
| Total | 35 | 5.057 | 2.555 | 4.686 | 2.709 |

An added analysis of science major journalers and non-science major journalers seen in Table 8 also shows some interesting patterns. There was no significant difference ($F_{1, 52} = 0.021$, $p = 0.884$) for science major journalers between their mean pretest (5.571) and posttest scores (5.667). The non-science major journalers appeared to experience a decrease from their mean pretest (4.286) to posttest scores (3.214) but it was not a statistically significant change ($F_{1, 52} = 1.810$, $p = 0.184$). Between the two groups at the beginning of the semester, there was no significant difference seen between their LCTSR pretest scores ($F_{1, 52} = 1.780$, $p = 0.188$). However, there was a significant difference seen between the LCTSR posttest scores ($F_{1, 52} = 7.106$, $p = 0.010$, $\eta^2 = 0.088$) at the end of the semester, with the science major journalers having a higher posttest mean score than non-science major journalers. Figure 14 shows the boxplots of science and non-science major journalers and their pretest and posttest scores. Figure 15 shows the change of LCTSR scores for all groups in this study.

**Figure 14**

*Boxplots of LCTSR Pretest and Posttest Scores for Science and Non-science Major Journalers*

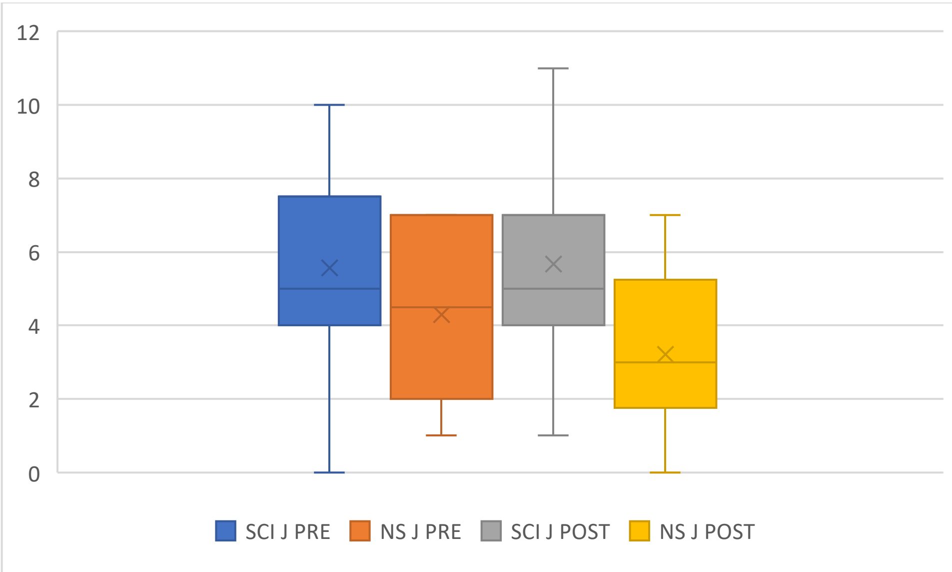
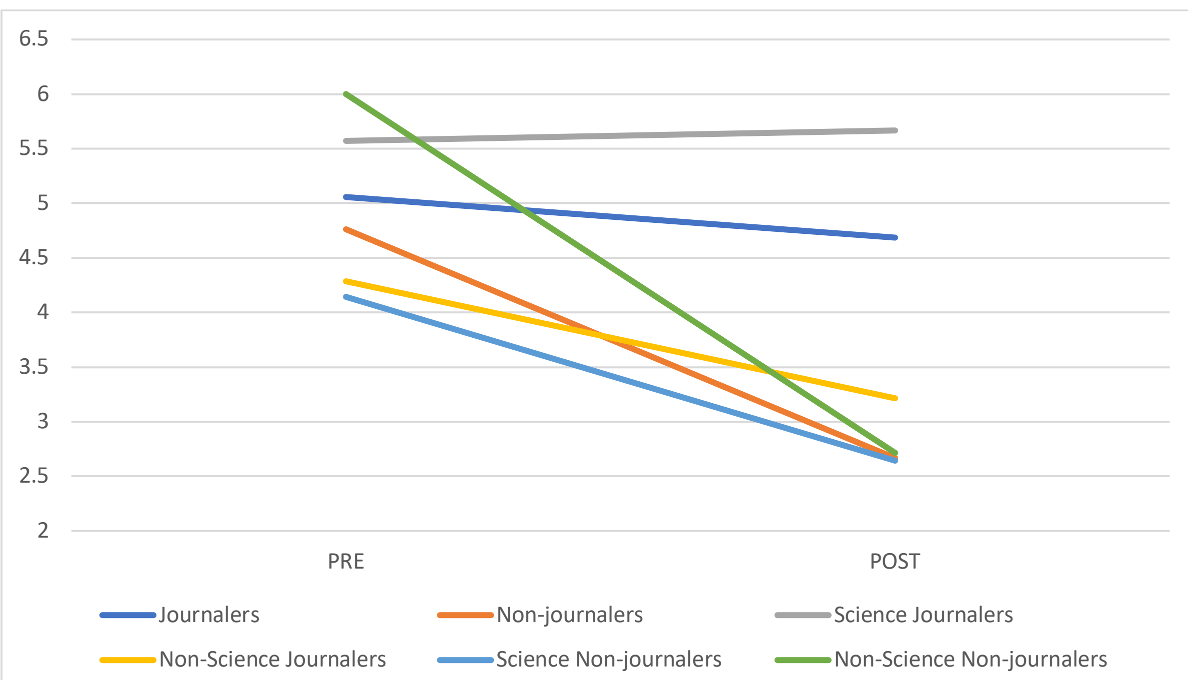



**Figure 15**

*The Change in LCTSR Scores for all Groups*



Even with this evidence, the difference between pretest and posttest scores shows that most of the participants scored lower on the posttest assessment. The pretest and posttest settings were identical regarding the number of questions (24) and the time limit (30 minutes). The evidence shows that completing the journal assignment makes no positive difference in scientific thinking skills for any of the groups analyzed.

Analyzing the pretest and posttest item difficulty shows the areas where science major and non-science major participants experienced a decrease in their scores. Table 9 shows the pretest and posttest LCTSR item difficulty for all participants, journalers and non-journalers.

**Table 9**

*Pretest and Posttest LCTSR Category Scores for Journalers*

| Category | Non-science Pretest | Non-science Posttest | Science Pretest | Science Posttest |
|---|---|---|---|---|
| CW (1&2) | 13 | 12 | 18 | 18 |
| CDV (3&4) | 6 | 4 | 14 | 10 |
| PT (5&6) | 0 | 0 | 6 | 7 |
| APT (7&8) | 0 | 0 | 2 | 3 |
| ICV (9&10) | 5 | 5 | 15 | 13 |
| ICV+PBT (11&12) | 1 | 0 | 1 | 1 |
| ICV+PBT (13&14) | 1 | 2 | 4 | 1 |
| PBT (15&16) | 7 | 6 | 13 | 13 |
| APBT (17&18) | 7 | 4 | 14 | 16 |
| CT (19&20) | 4 | 4 | 10 | 13 |
| HDT (21&22) | 2 | 1 | 3 | 3 |
| HDR (#23) | 5 | 7 | 8 | 10 |
| HDR (#24) | 9 | 10 | 9 | 11 |

The analysis shows that non-science journalers scored worse on the posttest in the following categories: conservation of displaced volume (CDV), identification and control of variables and probabilistic thinking (ICV+PBT) for questions 11 and 12, advanced probabilistic thinking (APBT), and hypothetico-deductive thinking (HDT).

The analysis also shows that science majors scored worse on the posttest in the following categories: conservation of displaced volume (CDV), identification and control of variables (ICV), and identification and control of variables and probabilistic thinking (ICV+PBT) for questions 13 and 14.

The reason for this decline in participant performance is difficult to isolate without further analysis. However, there are some possible explanations: the participants were allowed to leave once they completed the assessment. With no outside motivation (e.g., lower grade affecting their performance in the class), the participants had no reason to take the assessment seriously. The instructions for the assessment even comment that the students should only focus on doing their best; the instructor is not to use the assessment results in any way related to the final course grade.

From the data, I noticed two important results. Logically, participants who are dedicating their future to scientific endeavors should score higher on a science thinking skills assessment than someone pursuing a degree in a non-science field. Another important result seen in the data was the fact that students in both groups scored lower on the posttest than they did on the pretest. These results are interesting when we consider the LCTSR categories that the major participants and the non-science major participants performed well on. One specific result that is noteworthy is that non-science major participants answered the hypothetico-deductive questions better than the science major participants. The hypothetico-deductive method is defined as "a cyclic pattern of reasoning and observation used to generate and test proposed explanations (i.e. hypotheses and/or theories) of puzzling observations in nature" (Lawson, 2015, p. 471). This method is often called the scientific method, which is often the basis of the "cookie-cutter" scientific method taught in science classes as the way science is done. Non-science major participants answered the four questions in the LCTSR (question numbers 21-24) related to hypothetico-deductive thinking and reasoning better than science major participants.

**Research Question 4**

Research question 4 focused on the rubric score for the journal entries and the participants' major. A higher rubric score corresponds to a greater number of entries in the journal, an increased use of the SEPs from the NRC, using more complex SEPs like modeling, planning/carrying out investigations, and using mathematics and computational thinking. There was no significant difference between rubric scores for science and non-science majors ($F_{1,30}$ = 2.928, $p$ = 0.097). Rubric score descriptive statistics for major and non-major participants can be found in Table 9.

**Table 10**

*Journal Entry Rubric Descriptive Statistics for Journalers*

| Group | *N* | *M* | *SD* | Min. | Max. |
|---|---|---|---|---|---|
| Science | 21 | 8.905 | 2.644 | 5 | 15 |
| Non-science | 14 | 8.929 | 2.200 | 5 | 12 |
| Total | 35 | 5.571 | 4.759 | 5 | 15 |

The non-science major participants on average had more entries (26) than the science major participants (25). One interesting thing to note is that there were more non-science major participants (71%) who completed the 32 required journal entries versus the science major participants (52%). With fewer entries for the science major participants, the total word count, the number of SEPs used, and the "difficulty" of the SEPs used would be lower, causing the overall rubric score to be lower.

Logically speaking, the science major participants should have a higher score on the journal rubric than non-science major participants. The science major participants should be more inclined to think scientifically, use more SEPs, and use more challenging SEPs. However, in this study non-science major participants scored better on the LCTSR in the hypothetico-deductive thinking and hypothetico-deductive reasoning than the science major participants.

## Research Question 5

### *Participant Questionnaire*

Finally, at the conclusion of the study, the participants were asked to respond to the following questions to get a sense of the level of involvement with the journal assignment:

1. What did you think about the Science Journal assignment?
2. Did you take the assignment seriously or were you writing entries the night before just for a grade?
3. What aspects of the assignment did you enjoy?
4. What aspects were tedious/unenjoyable?
5. While completing the journal entries, do you think you increased your scientific thinking skills?

The participants' responses were collected by email. The participant response rate was 14%. They were analyzed by examining the participant responses for major themes based on each question. Even with a low response rate, the participants reported an overall positive view of the scientific journal assignment. For question 1, Beth said that it was "a very interesting way to engage students". Amanda, even though she was a non-journaler, responded that "it is a great opportunity to learn about everything around us" but did not have time to complete the assignment. Cindy commented that the activity was "very insightful and allowed me to research in areas that would expand my knowledge in my chosen career". Faith commented that the assignment “pushed me to think outside the box and question ‘everyday’ things that I had not thought about questioning before”.

For question 2, six of the eight participants commented that they took the assignment seriously, with Amy commenting that she “created a schedule where I did an entry every Tuesday and Thursday so I that I would not have to complete them all in one night”. However, Beth wrote that “as the semester went by, my major-specific classes' workloads became heavier to the point that I either truly did not have time to do them within the day or did not choose to prioritize the entries over those courses”.

For question 3, Danielle stated that the assignment helped her focus on “health and wellness topics that will be able to help me long term with my career goals”. Faith commented that she liked completing the assignment because she “probably would have simply shrugged the questions off and not thought about finding their answers”. Becky wrote that she “liked how it made me think”. Beth said that she “enjoyed that it was truly our journal and therefore we could write in whatever format/organization we each individually wanted”.

For question 4, one of the critiques of the assignment was the time requirement. Cindy specifically said that she took writing the entries seriously, but “some nights I did feel rushed to complete them with how busy my schedule is.” Danielle noted that it she “felt rushed to complete the assignment, when, in reality, I would have liked to elaborate more on each topic I wrote about.” Faith commented that it was tedious “just trying to find 32 things to ask about without repeating myself too much.” Becky stated that she found the middle of the semester a challenge because her “schedule was very busy, and the entries kept piling up.”

For question 5, Amy responded positively say that the assignment “increased my scientific thinking skills… and maybe even developed a little more enjoyment for the subject as well". Cindy wrote that "while completing the journal entries, it did expand my knowledge on many scientific topics, such as my interest in the medical field and how basic scientific aspects work in the world today. The use of technology has expanded greatly, so being able to research the science behind the technology also will help me in the future". Elizabeth commented that she thought that her "scientific thinking skills were increased because I was thinking about different topics at least two times a week".

**Summary**

In this study, there was a statistically significant difference between the pretest and posttest LCTSR scores for science major journalers and non-science major journalers. However, these analyses show that there are some important conclusions that we can infer from this study. Participants who did not complete the journal assignment (both science and non-science major participants) had a larger decrease in their pretest/posttest LCTSR scores than participants who did complete the journal assignment.

It is difficult, from this study, to isolate the relationship of journal participation and LCTSR score completely. There are several other factors that could possibly account for these differences. Motivation, attention to academic progress, academic achievement, stress, and participant persistence all impact the assessment scores for the participants. Attempting to control these variables in an educational setting is challenging, particularly at the end of a semester, where the participants are most likely at their highest stress level.

The question remains, is there any educational value to completing the journal assignment if it does not directly affect scientific thinking skills? While there was no significant difference in this study, the use of scientific journals can highlight the relationship between science and students' daily lives. When the students are engaged in science in their everyday lives, it increases the likelihood that they will have a more positive attitude toward science. Giving students the opportunity to explore science outside of the classroom and laboratory is important to develop citizens who think scientifically.

## Chapter 5: Discussion

The purpose of this study was to determine whether scientific journal writing improves scientific thinking and reasoning skills.

This chapter discusses the major findings about the content and quality of journal entries, the LCTSR pretest and posttest scores, and the relationship between the major of the participants and their assignment participation. The chapter includes implications for science professors and science education faculty. Finally, the limitations of this study and future research are discussed. This chapter focuses on interpreting the answers to the following research questions:

1. What are the topics, as well as the Science and Engineering Practices (SEPs) that natural science major participants wrote about, as well as participants not majoring in natural science?
2. How does the use of a weekly science journal impact scientific thinking skill scores for students majoring in natural science and students not majoring in natural science?
3. Is there a significant difference in pre- and post-scientific thinking skill scores for participants based on the student's major (science versus non-science major)?
4. Is there a significant difference between the journal entry quality depending on the participants' major?
5. How do journalers describe their attitudes towards the assignment?

### Finding 1: Participants wrote about every day and classroom science

The participants who completed journal entries generally wrote about topics that were relevant to their everyday lives, whether through their experiences around campus, at home, or what they were learning in their science coursework. Both science and non-science majors wrote about similar topics, using similar Science and Engineering Practices (SEPs). Both groups often wrote about content related to their science coursework, focusing on the practical application of those topics.

The participants who completed the journal assignment did so in the context of their daily lives, a key comment to situated cognition (Brown et al., 1989; Choi & Hannafin, 2008; Herrington & Oliver, 2000). They had access to and were encouraged to consult a variety of experts in chemistry, physics, and biology who could assist them with their questions and observations. The freedom that the participants were given allowed them to see the connections between disciplines. The assignment aligns well with the tenets of situation cognition (Herrington & Oliver, 2000).

There are other methods that teachers and professors can use to check student understanding of the SEPs that could accompany this assignment. Individual projects are useful in incorporating SEPs into the classroom setting. One method that instructors at the middle and high school level can use is the simple independent science fair project (Koomen et al.,2021). Another method is using project-based instruction (Stuart et al., 2021). Again, project-based instruction would fit alongside this assignment because students would be participating in the process of science by completing a designed experiment, along with recording their questions, observations, and data analysis.

The equivalent experience at the post-secondary level is the capstone course where the students who major in natural science complete a scientific research study. This course is designed to encapsulate the process of science and indirectly use the SEPs, if not overtly said by the instructor. This assignment could go with the independent research project to determine the student's methodology and thought process used to design and carry out the experiment, as well as the analysis and reporting of data.

From this study, it is evident that educators need to incorporate the SEPs into their daily instruction (Malkawi & Rababah, 2018). The participants in this study had a limited understanding of SEPs without instruction or modeling from the instructor. The classes the participants were involved in were not focused on the study of SEPs, but rather they were focused on science content.

**Finding 2: Science journaling impacted scientific thinking**

Overall, there was a significant difference between pretest and posttest scores on the LCTSR ($p = 0.002$). However, the difference seen in the LCTSR scores was that the scores decreased from pretest to posttest. When the analysis focused on the participants' major, there also was no significant difference between science major and non-science major participants ($p = 0.092$). However, there was a significant difference seen in the non-science major participants' pretest and posttest scores on the LCTSR ($p = 0.003$), a decrease in scores.

There was a significant difference seen between journalers and non-journalers' LCTSR score ($p = 0.026$). Journalers scored higher on average than non-journalers. Science major journalers were the only group to not experience a decrease in LCTSR scores. Non-science major participants classified as non-journalers experienced the largest drop in posttest scores.

The lack of increase in scientific thinking and reasoning skills experienced in this study is not unexpected. In their study, Ding et al. (2016) found no significant difference in LCTSR scores based on major or year of study in Chinese students majoring in physics, chemistry, electrical engineering, computer engineering, and science education. The LCTSR scores remained statistically consistent throughout the participants' four years of study. They noted that the educational concept in China is product over process; professors still focus on teaching knowledge rather than teaching the process of thinking.

The students participating in the journal assignment could benefit from a discussion about scientific thinking skills during the process. Students may have knowledge about specific scientific content but may have trouble with scientific thinking skills. Generally, science courses focus more on the content of the discipline rather than the thought process that goes into science. This study shows that the participants gained content knowledge by the questions they asked and the answers they found, but they did not develop their scientific thinking skills by completing the journal assignment alone. Research shows that focusing on a specific area of weakness generally leads to an improvement in that area (Hicks et al., 2017).

Reflective journals are also unique ways to increase student motivation and awareness, as well as a reflection on what students have learned (Stephens & Winterbottom, 2010). Motivation was not a direct measure of this study. However, with 63% of the journals turned in at the end of the study, there seems to be a lack of motivation involved with this assignment. When we look at the reflection on student learning, the questionnaire given at the end of the study sheds some light on this. Fifty percent of the respondents reported that they increased their scientific thinking skills; 25% responded that they learned more about science in general.

One way to combat the thought of teaching science content over teaching the process of scientific thinking was the creation of the NRC Framework. The NRC identified that science is often taught where it "emphasizes discrete facts with a focus on breadth over depth and does not provide students with engaging opportunities to experience how science is actually done" (NRC, 2012, p. 1). This concept of how science should be taught is not a new idea. Science education reform was proposed a century before the NRC Framework by John Dewey and Alfred Whitehead in 1916 (Gallagher, 2000). They were concerned about how much weight teachers place on simple memorization and not enough time on the application of scientific knowledge.

“In spite of nearly a century of thought and action, much science teaching still fails to result in understanding and application of science” (Gallagher, 2000, p. 310).

Another way to combat this concept is through discipline based, evidence-based reform. One method used in evidence-based reform is that students construct their knowledge (Cooper, 2014), rather than simply memorizing what is presented to them in the science classroom. “The learner must have opportunities to actively construct and try out ideas and skills and receive meaningful feedback” (Cooper, 2014, p. 2). This assignment gives the students the opportunity to construct their knowledge and reasoning. It gives the instructor the opportunity to provide feedback to guide the student rather than give the student the answer to their question.

The second method used in evidence-based reform is using meaningful learning (Cooper, 2014). The learning opportunities provided by this assignment give the opportunity for students to write about what is meaningful to them.

**Finding 3: Journal quality was no different between science and non-science majors**

There was no significant difference seen between the science and non-science majors on their journal entry quality ($p = 0.097$). This result is unexpected, because science major participants should have a higher quality score for their journal entries than non-science majors. This could relate to the non-science major participants scoring better in certain categories of the LCTSR than the science major participants.

Some of the participants wrote about topics they experienced in class or lab. For example, one participant wrote about their experience in biology lab where they examined plant and animal cells using microscopes. The entry was simply a “report” of what they experienced during lab. There was no connection to anything that this participant was interested in; every entry was a summary of a lab experiment this participant did in class. With this simple summary of an experiment, the participant may retain some of the information as way to "memorize in a rote or shallow fashion" (Cooper, 2014, p. 3) rather than connecting it to something that provides them meaning.

However, there were other participants who wrote about what was interesting to them. For example, another participant wrote about experiencing the northern lights was something on their "bucket list." The entry caused them to ask about the phenomenon and to research what happens during the aurora borealis. A common theme in this participant's journal was nature (national parks they wanted to visit, geologic structures that were interesting to them, etc.). The knowledge gained by this participant about these subjects will have an impact on their learning because it genuinely means something to them (Cooper, 2014).

Very few participants mentioned experiencing chemistry in their everyday lives, other than the chemicals they mentioned, for example, the bleach used to dye hair. It must be harder to see specific chemistry topics in their daily lives. That may be one of the downfalls of General Chemistry rather than a non-science majors course designed around the study of chemistry in the context of everyday life. In the non-science major chemistry course (not physical science) the discussion of chemistry is grounded in everyday topics such as climate change, the composition of smartphones, energy production, and the ozone layer. The General Chemistry course focuses on academic chemistry with little mention of the topics related to everyday life.

The non-science major participants wrote more about geology and astronomy than the science major participants. It would be interesting to see how these topics would change if this assignment were given in the second semester physical science class. That course focuses on geology, astronomy, and meteorology, rather than physics and chemistry. For example, the second semester course discusses the phases of the moon. This assignment could be used to observe the phases of the moon during an entire cycle, allowing the students to draw diagrams to better understand the motion of the moon throughout the month. Also, in this course, students learn about how a solar eclipse happens. With the total solar eclipse having just occurred April 8, 2024, this assignment could have increased student interest and participation in observing this phenomenon.

Science notebooks like the notebooks in this study have been a proven method "for students to better learn through an authentic, inquiry-based methodology" (Mohr et al., 2014, p. 386). Spending time outdoors, recording observations, asking questions, collecting data, and solving problems in a notebook are ways for students to develop key scientific skills. However, they are not guaranteed to produce results. Langer & Applebee (1987, as cited in Rowell, 1997) found mixed results. A chemistry teacher tried learning journals to exchange ideas about the environment and nuclear power. She also used research papers in her class. They found that students either were not interested in engaging in a conversation in the learning journals or they "copied chunks from encyclopedias" (Rowell, 1997, p. 35) to write their research papers. In the age of ChatGPT and other generative AI software, motivation to complete assignments becomes even more important.

**Implications**

The question remains, how can instructors increase student scientific thinking skills? The journal assignment, while not showing a significant improvement in scientific thinking skills, motivated the students who completed the assignment to engage in the scientific process. All the participants in this study who returned the post-assignment questionnaire commented that they enjoyed the unique way the assignment caused them to focus on science. They enjoyed that they were free to research topics that were interesting to them, rather than a required topic. However, that motivation did not extend to the 21 non-journalers who did not complete the assignment. One factor that may increase participation in the journal assignment that was not used in this assignment was effective feedback (Butler & Nesbit, 2008). Effective feedback shows how the instructor cares about the student and values the effort of the student (Jones, 2009).

The journal assignment is designed for the students to engage in science separate from the classroom or laboratory setting. The journal assignment does not need a laboratory space to allow students to relate science to their everyday lives. The assignment situates scientific thinking in the context of the daily life of the student. It allows them to focus on the scientific principles they experience daily. It is a learning opportunity that students can use to practice scientific thinking in a low risk, low pressure environment. The focus of this assignment is not necessarily having the correct scientific content knowledge. The assignment is designed to allow the students to explore topics of interest to them without the need to have the correct answer to their questions. It is also designed as a learning tool, with the instructor providing guidance and direction with the questions asked by the student.

### *Implications for Science Professors*

Science content professors can use this assignment in their course to increase student engagement in science outside of the classroom setting. Eighty-eight percent of the participants who returned the post-assignment questionnaire commented that the journal assignment increased their engagement in science beyond the classroom or laboratory setting. Beth commented that “it was a very interesting way to engage students in any course (but especially science) by doing something new and encouraging them to ‘do science’ in whatever format is comfortable to them”. Amy, a non-science major, commented that the assignment was “great to look back at the end of the semester and realize just how much science happens around us each day in every aspect of life”. This assignment can be used to help teachers bring the real world into the classroom.

Student scientific thinking skills have been declining for years (Deming et al., 2012). Focusing solely on scientific content teaches the individual information, but not how that information connects to other content. This could be the reason for the results of studies that show over the course of a students’ college science career, there is no significant difference in LCTSR assessment scores (Ding et al., 2016). One student might learn about density as the ratio between mass and volume but may not translate that to other content in chemistry, while another student may realize that both topics are related by proportional reasoning (Deming et al., 2012).

This assignment, if used in conjunction with content about scientific thinking and the nature of science, can provide the instructor and students with the necessary environment to experience science in the students’ everyday life. Frequently, instructors focus on the content of science rather than the process and skills of science. This is clear in the non-science major science classroom (Heil et al., 2023).

The journal assignment is useful to connect daily life to science content learned in the classroom. Situating the assignment in the context of the students’ lives increases the likelihood that students will enjoy science more (Brown et al, 1989; Altalib, 2002; Kim & Hannafin, 2008; Choi & Hannafin, 1995; Herrington & Oliver, 2000). Learning becomes meaningful when the student connects it to their everyday lives (Prain et al., 2017). That is one way to increase the students’ interest in science and science-related careers (Zubrzycki, 2016). Science programs can use assignments like this to prepare students in the real-life context, acting like an apprenticeship model (Brown et al., 1989). This assignment, like other journal assignments, can be used to develop students' ability to ask higher level questions and improve observational skills (Mohr et al., 2014).

**Limitations**

This study was limited by several factors. This study focused on a single university in the southeastern part of the United States. It was a small private, Christian university, where participants might have alternative views about the nature of science and the role of science in everyday life. Also, a control group in the original study design that did not complete the journal assignment that was in a completely different course would have allowed for better generalization of the results of this study.

Another possible limitation could be assignment fatigue; the participants completed the assignment over the course of a 16-week semester, writing two entries per week. The quality of participant entries may have suffered from such an extended assignment. All the participants that responded to the questionnaire stated that they thought that the assignment was interesting but became difficult to manage when other coursework became more pressing during the semester. This limitation could be eliminated if the participants were provided time during class to complete journal entries.

Also, taking the LCTSR posttest on the final day of the semester may have affected the participants' scores. Some of the non-journaler participants who took the pretest were absent from the last class and were not available to make up the assessment. There were three individuals in the non-science major course who withdrew from the course midway through the semester. Five other non-journalers were absent from the course. With participant identity removed from the LCTSR and the journal, the participants who did not complete the posttest could not be contacted. All the participants who completed the journal assignment took the posttest assessment. Other participants may have suffered from fatigue near the end of the semester and did not take the assessment seriously. Final exams were the following week, and the participants may have been split in their focus.

The journal scoring rubric needs some modification to be a useful tool to analyze the journal assignment. The rubric, while useful in analyzing the journal entries, could be changed to create a better tool to grade the journals with respect to the Practices. Increasing the number of criteria or ratings would generate a better score to compare it to the LCTSR scores. Using the results from this study can be used to further refine criterion 5, the likelihood of a specific practice appearing in a students' journal entry.

A final limitation to this study was the number of participants in the study. There were not enough participants to support generalization to other students in other universities. Also, the number of participants who did not complete the journal assignment or LCTSR posttest may have caused a significant difference between groups where one may not have existed.

**Recommendations for Future Research**

There is plenty of research to be done in this area. There are only a few studies that link scientific thinking skills to journal writing in a science program. Most of the studies done in this area focused on reflection on the learning process (Ahmed, 2019; Trauth-Nare & Buck, 2011; Stephens & Winterbottom, 2010, Seeharaj & Samiphak, 2019) or respond to hands-on, inquiry teaching (Kawalkar & Vijapurkar, 2015). There is an opportunity to involve students in the scientific writing process using a real-world context.

Another important recommendation that arose from this study is finding ways to engage and motivate the students to complete this assignment. With only 38% of the participants completing the journal assignment, how can student motivation be altered with this assignment?

The number of entries required for this assignment could be adjusted. Providing class time to complete journal entries could also increase student involvement, as well as helping the instructor provide feedback to the students.

Future research should focus on how to modify the science journaling intervention so that scientific thinking skills are enhanced for all students, not just science majors. With the rise of artificial intelligence (AI), false claims on social media, and various socio-scientific issues, students must be taught to think scientifically. Teachers and professors need a variety of tools to help students increase their scientific thinking skills while increasing their science content knowledge and attitudes toward science.

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## Appendix A

Scientific Journal Assignment Handout

How many times in your life have you asked yourself, “I wonder how that works?”

Now, where does that question go? Do you look into it further or was it simply a question and nothing more? This assignment is a chance to dig a little further!

This assignment is designed for you to explore science in your everyday life. How do you do that? Here are a few things to try:

1. Make observations about things in your daily life. Observations are a vital part of scientific practice.
2. Ask a scientific question about those observations.
3. Investigate, through experimentation, your observations and answer your questions.
4. Collect and analyze data from your experimental investigation.
5. Make a case for the conclusions your draw from your data analysis.
6. Conduct research to answer your questions or interpret your observations.

This assignment will occur during the entire semester.

Directions:

- ✓ You will be provided a blank journal to record at least 2 entries per week, for a minimum total of 32 entries during the semester. Each entry should be at least 100 words.

- ✓ Record entries about scientific things you notice in your daily life. Do you have a question about something? Write it down, look it up, listen to a podcast, do an experiment, or talk to someone else who might have some insight into your questions or observations.

- ✓ At the midpoint of the semester, your notebook will be collected. If you have the required number of entries, you will receive full credit for your first participation grade. The same thing will occur at the end of the semester.

- ✓ Don't be afraid to try something new! You may have never conducted an experiment in your life. Just make sure you are safe! You have been introduced to laboratory safety in your lab class this semester. Follow those rules if you plan to do an experiment and write about it in your journal. Always ask your instructor for help if you have any doubts.

Checkpoints

- ✓ The journal assignment will be collected twice during the semester: midterm and final.

- ✓ Focus on scientific practices; be a scientist!