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Examining the Nexus between Scientific Literacy and Identity in General Chemistry

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By

Tiffany Chamberlain

Accepted in Partial Completion

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Master of Science

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Examining the Nexus between Scientific Literacy and Identity in General Chemistry

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Presented to

The Faculty of

Western Washington University

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Abstract

Scientific literacy is a crucial goal of science education. All citizens need scientific understanding to make rational and informed decisions, and to feel confident in making such decisions. Many students harbor doubts about belonging in science and their identities as *science persons*. As such, science educators are tasked with helping students develop these skills as they engage in various courses. College instructors incorporate scientific literacy skills as part of their courses in which students are encouraged to develop a *science person* identity (i.e. science identity) through science identity work. Therefore, learning can be seen as a process of identity development where the development of a science identity is interconnected with learning scientific literacy skills in science courses.

This quantitative study focused on students in general chemistry courses, and examined their scientific literacy skills alongside their science and chemistry identities in an academic quarter between a pretest and posttest. Validated survey tools from other science disciplines were adapted to create a scientific literacy and identity survey, which was distributed to undergraduate chemistry students at Western Washington University in Spring 2023. Results from 181 students indicated that there were significant changes in students' chemistry identity from pretest to posttest where students felt more like chemistry people ($p = 0.015$) . Using Spearman's rank correlation coefficient to measure the relationship between scientific literacy with science and chemistry identity, there were weak, positive correlations for scientific literacy skills with science identity ($p = 0.013$) and chemistry identity ($p = 0.005$) in the pretest survey responses. In addition, there was a moderate, positive correlation for science identity and chemistry identity in the pretest ($p < 0.001$) and posttest ($p < 0.001$) survey responses.

This study highlights the complexities of scientific literacy skill development for undergraduate students in an academic quarter and emphasizes the importance of ongoing integration of scientific literacy and identity work in science education. By fostering both scientific literacy and science identity, science educators can strengthen students' capabilities as active, informed citizens and prepare them for science-related careers. Thus, this research contributes to the body of literature on the scientific literacy development of undergraduates in chemistry courses, as well as science identity development.

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Table of Contents

List of Tables

1. Introduction

Background of the Problem

Scientific literacy for all has been a major goal of science education for more than 50 years (National Science Teachers Association, 1971). Over this period there have been multiple definitions of scientific literacy, but there is no consensus definition within the community (DeBoer, 2000). The publication of *Science for All Americans by the* American Association for the Advancement of Science (AAAS) represented a crucial step in attempting to more clearly define and describe the complexity of scientific literacy (AAAS, 1990). The AAAS focused their definition of scientific literacy on content knowledge such as the ability to use content knowledge and scientific thinking for various contexts, awareness of science, mathematics, and technology being interrelated; and understanding of the natural world. However, recently there had been a shift in defining scientific literacy away from solely content knowledge-based definitions towards definitions describing actions where science is situational to everyday life and decision-making related to science (Holbrook and Rannikmae, 2007, 2009; Gormally et al., 2012; Vandegrift et al., 2020). Holbrook and Rannikmae (2007, 2009) defined scientific literacy as actions that are situational (where science relates to everyday life) and socially driven (scientific interactions with other individuals), while being structured around content understanding and the nature of science. This broadening in the thinking around scientific literacy has resulted in more definitions focused on describing actions associated with scientific literacy to capture its complexity. As an example, Vandegrift et al. (2020) elaborated on behaviors associated with scientific literacy such as understanding socio-scientific issues and scientific data, decision-making related to science, evaluation of claims, and appreciation of the relevance of science in everyday life. Consistent with the more current view of scientific literacy as a set of skills and understandings demonstrated through particular practices and behaviors, this study adopted Gormally et al.'s (2012) definition of scientific literacy. These researchers define scientific literacy as skills needed to make scientific knowledge useful and usable in everyday life. This definition recognizes that scientific literacy involves the combination of science knowledge content with practical, meaningful application (through skills) to meet the challenges of a science and technology dominant society.

In order to foster scientific literacy in all students, content knowledge in science subjects acts as a foundation for skills such as scientific thinking, problem solving, real-world application, and communication skills. By developing knowledge and understanding (competence) in science subjects, students act as "little scientists" engaging with crucial skills for science-related issues as part of their science education (Holbrook and Rannikmae, 2007). The development of scientific literacy is a lifelong process where colleges and universities play a vital role in continuing to teach and foster these skills in their students. Many colleges and universities require students to take science courses to fulfill general education requirements. In these courses, students are usually part of a community to develop competence by engaging in scientific concepts and processes that foster skills related to scientific literacy. In the case of chemistry, competence in this subject is often essential for other sciences (Tai et al., 2005), as chemistry courses are common prerequisites for other science courses and majors. Thus, chemistry courses have become an important environment for building competence and are therefore important for the development of scientific literacy.

It is important to consider that there are students of various backgrounds that enroll in introductory science courses, some of whom are non-science majors required to take science courses. These introductory courses can either weed out potential science majors or provide a foundation for future courses (Seymour and Hewitt, 1997; National Academies of Science, Engineering, and Medicine [NASEM], 2016). Many students who take chemistry courses as general education requirements may be engaging with this subject for the first time and therefore harbor doubts about belonging in science (chemistry) and their identities as *science (chemistry) persons.* This may be especially so for students who identify as Black, Indigenous, or people of color (BIPOC).

Gee (2000) defines identity as “being recognized as a certain “kind of person” in a given context”. Within a science (chemistry) context, a person must demonstrate competence (knowledge and understanding of science [chemistry] content), coupled with social performances of relevant scientific practices, to be recognized as a *science (chemistry) person* (Carlone and Johnson, 2007). This competence and demonstration of social performances of relevant scientific practices, as a *science (chemistry) person,* is considered synonymous with this study’s definition of scientific literacy, and thus there is a strong link between scientific literacy and identity. Despite, what is to us, an obvious link between students’ scientific literacy and their science (chemistry) identity, there has been little attention given to the examination of the nexus between these two constructs.

Identity is a crucial tool for understanding how students learn (Gee, 2000) and has important implications for goals of science education, specifically scientific literacy. Previous studies on identity have shown how a person’s identity, as an individual or member of certain groups, can affect that person’s experiences with their education (Chang et al., 2011; Chemers et al., 2011). Therefore, it is important to consider how a student’s identity impacts their educational experiences, particularly in science courses that aim to foster skills for scientific literacy. In this context, there are common themes between science identity development and identity work that shape our understanding of students’ identities. Some themes include self-efficacy (e.g. Chemers et al., 2011; Robinson et al., 2019; Syed et al., 2019), interest (e.g. Dou et al., 2019), and recognition (e.g. Carlone and Johnson, 2007; Chemers et al., 2011; Robinson et al., 2019; Syed et al., 2019). An important implication of science identity is persistence within science, technology, engineering and mathematics (STEM; Hazari et al., 2010; Cass et al., 2011; Godwin et al., 2013; Vincent-Ruz and Schunn, 2018). As a result, learning can be seen as a process of identity development – not simply a process of gathering information, but a way of deciding what kind of person one is, and wants to be, and how engaging in those activities makes one part of the relevant community (Brickhouse and Potter, 2001).

Rationale

This research aims to examine the link between scientific literacy and science and chemistry identities in general chemistry courses. Although some research has focused on determining the relationship between scientific literacy and science identity (e.g., Lucas, 2020), I am not aware of any studies that have explored this relationship in a chemistry context. This study therefore addresses a gap in the literature, with its focus on the chemistry context, and also adds to the general research on the relationship between scientific literacy and science broadly. This study also focuses on scientific literacy and science identity in populations of undergraduate students in chemistry courses, which is a population that has not had an abundant focus.

Research Questions

1. Is there a significant change in general chemistry students' scientific literacy skills between the pretest and posttest?
2. Is there a significant change in general chemistry students' scientific literacy skills by demographic group?
3. Is there a significant change in general chemistry students' science or chemistry identities between the pretest and posttest?
4. Is there a significant change in general chemistry students' science or chemistry identities by demographic group?

5. What is the nature of the relationship between general chemistry students' scientific literacy skills and science identity, and scientific literacy skills and chemistry identity? Is this relationship significant?
6. What is the nature of the relationship between general chemistry students' science and chemistry identity? Is this relationship significant?

2. Conceptual Framework and Literature Review

This study is informed by the conceptual frameworks of scientific literacy (e.g., National Research Council, 1996) and science identity (e.g., Carlone and Johnson, 2007). Both scientific literacy and science identity are crucial constructs to understanding how students engage and perceive science in both social and educational contexts. As such, the relationship between scientific literacy and science identity is highly important as students develop their science understanding, their identity in science can strengthen. This chapter explores the conceptual frameworks and current literature on these constructs in STEM education.

Conceptual Framework

Scientific Literacy

There are various definitions of scientific literacy found in the literature (DeBoer, 2000) comprised of common themes that outline the conceptual framework. There are 5 components of scientific literacy: (1) content knowledge (Miller, 1983; AAAS, 1990; National Research Council, 1996; Bybee, 1997), (2) applications of science content knowledge (AAAS, 1990; National Research Council, 1996; National Academies of Sciences, Engineering, and Medicine [NASEM], 2016; Organisation for Economic Co-operation and Development [OECD], 2019), (3) self-efficacy (Baker and Sivaraman, 2018), (4) scientific attitudes and interests (Gardner et al., 2016), and (5) science communication (National

Research Council, 1996; Norris and Phillips, 2003; Brickman et al., 2012; Gormally et al., 2012). These components are described below.

Traditional definitions heavily rely on content knowledge as the primary component of scientific literacy (e.g., Miller, 1983; AAAS, 1990; National Research Council, 1996; Bybee, 1997). However, demonstrations of content knowledge are not limited to assessments (Brickman et al., 2012; Tinsley, 2016; Auerbach and Schussler, 2017; Carmel et al., 2017; Sabel et al., 2017). Specifically, content knowledge is beyond recall of definitions and concepts by including decision making based on science (National Research Council, 1996; Bybee, 1997; NASEM, 2016; Tinsley, 2016) and creating connections between topics (AAAS, 1990; Bybee, 1997; Rathburn, 2015; Vandegrift et al., 2020). However, content knowledge applies to the applications of science content knowledge outside the classroom.

Applications of science content knowledge is an important component of scientific literacy (e.g., AAAS, 1990; National Research Council, 1996; NASEM, 2016; OECD, 2019). Specifically, individuals apply their science content knowledge towards socio-scientific issues (Miller, 1983; National Research Council, 1996; Zeidler and Nichols, 2009; Sabel et al., 2017; OECD, 2019) and civic engagement (AAAS, 1990; National Research Council, 1996; Laugksch, 2000; Rudolph and Horibe, 2016; OECD, 2019) that are important for all citizens. In addition, scientific literacy has connections to how individuals contextualize and use science content knowledge for everyday life (Laugksch, 2000; Meinwald and Hildebrand, 2010) for these applications regardless of their major.

Self-efficacy is the third component of scientific literacy where students' self-efficacy is defined as content knowledge and feelings of confidence in learning or doing science (Baker and Sivaraman, 2018). With increases in grades, students report higher self-efficacy in content knowledge from their science courses. Students' confidence in content knowledge led to further self-efficacy in the laboratory with increased collaboration in the group's knowledge (Baker and Sivaraman, 2018). Additionally, self-efficacy has been studied to relate to student persistence (Barry and Finney, 2009) furthering relating to students' daily lives through career development (Lent et al., 1994; Wright et al., 2013). Self-efficacy is reported to be predictive of student engagement (Bandura and Schunk, 1981) and interest (Zimmerman and Kitsantas, 1997, 1999).

Scientific attitudes and interests are a component of scientific literacy called the “affective dimension” (Gardner et al., 2016, p.43). The affective dimension provides a way for individuals to apply science content knowledge in their daily lives to build greater understanding of the nature of science (Gardner et al., 2016). Attitudes and interest in science play a crucial role in the early years of learning while scientific literacy continues in science education (National Research Council, 1996), so how students interpret science content can be impacted by their learning where attitudes and interest are fostered.

Finally, science communication is a common theme in scientific literacy (e.g., National Research Council, 1996; Norris and Phillips, 2003; Brickman et al., 2012; Gormally et al., 2012). Literacy as a term has two meanings (1) the ability to read and write and (2) knowledgeability that are related to each other (Norris and Phillips, 2003). Reading and writing science content is referred to as the “fundamental sense” of scientific literacy while knowledgeability is the “derived sense” (Norris and Phillips, 2003, p. 224). The fundamental sense emphasizes how reading and writing are more than mere “tools for storage and transmission of science” (Norris and Phillips, 2003, p.226) where these skills are integral aspects of science that cannot be separated. Science communication is an underlying skill to utilize content knowledge to create relevant connections between the “isolated facts, laws, principles, and theories of science” (Norris and Phillips, 2003, p.235) for implications of critical thinking and applications of science content knowledge.

These components of scientific literacy are shared across the literature that inform our understanding and context of scientific literacy over time. As such, definitions for scientific literacy started from science content have shifted towards skills needed to make scientific knowledge useful and usable in everyday life (Gormally et al., 2012).

Science Identity

The concept of “science identity” is relatively new in education research from the early 2000s. Gee’s (2000) definition of identity as “being recognized as a “certain kind of person” in a given context” (p.99), highlights the fact that identity development is a dynamic, continuous process defined by context (Gee, 2000; Carlone and Johnson, 2007). In educational research, identity is viewed through the lens of learning. Brickhouse (2001) described the relationship between identity and learning as formed by an individuals’ engagement with science. To understand identity within social and educational contexts, we need to define “communities of practice”. A community of practice is defined as a group of individuals who engage in collective learning in a shared domain through shared practices (Wenger, 1998, 2000; Lave and Wenger, 2001). Within a science context, a person must demonstrate competence (knowledge and understanding of science content), coupled with social performance of relevant scientific practices to be recognized as a science person (Carlone and Johnson, 2007). This process of science identity is social which is influenced by participation in scientific communities of practice where communities of practice exist within a “broader conceptual framework for thinking about learning in its social dimension” (Wenger, 2000, p.1). Communities of practice “does not separate learning from the becoming of the learner” (Farnsworth et al., 2016, p.7) where identity is a central concept of learning that is contextual in nature (Gee, 2000; Carlone and Johnson, 2007; Hazari et al., 2010). Lave (1992) proposed learning as an apprenticeship where students are creating their identities within communities of practice:

> *Learning is, in this purview, more basically a process of coming to be, of forging identities in activity in the world… learners are never only that, but are becoming certain sorts of subjects with certain ways of participating in the world… Subjects occupy different locations, and have different interests, reasons, and understanding of who they are and what they are up to (Lave, 1992, p. 3).*

Therefore, to understand science identity, the specific scientific communities of practice must be examined for the social and educational contexts. Discipline-based education research (DBER) have used the definitions from Gee (2000) and Carlone and Johnson (2007) to contextualize individuals' identity in their specific scientific communities of practice through disciplinary identity (e.g. chemistry identity). The framework of science identity defines key themes comprised in the literature that provides understanding of the social and educational influences in scientific communities of practice.

There are various themes found in educational research on science identity in scientific communities of practice. The components of science identity are (1) recognition by oneself and others (Carlone and Johnson, 2007; Chemers et al., 2011; Robinson et al., 2019; Syed et al., 2019), (2) self-efficacy (Chemers et al., 2011; Robinson et al., 2019; Syed et al., 2019), (3) competence and performance (Carlone and Johnson, 2007; Hazari et al., 2010), and (4) interest (Carlone and Johnson, 2007; Hazari et al. 2010; Dou et al., 2021). These themes are described below.

Recognition is a critical component of science identity (e.g., Carlone and Johnson, 2007; Chemers et al. 2011; Robinson et al., 2019; Syed et al., 2019) that encompasses how an individual perceives oneself in science and how they are acknowledged by others. This dual recognition (i.e., self-recognition and external recognition) shapes an individual's identity as a science person in the scientific community. When students recognize oneself as a science person, they are more likely to engage and persist in science, while recognition from faculty and peers can boost confidence and commitment to science (Carlone and Johnson, 2007). Within education, producing environments where students gain self-recognition and external recognition is vital for fostering strong science identities in students.

Self-efficacy is a common component of science identity (e.g., Chemers et al., 2011; Robinson et al., 2019; Syed et al., 2019) which influences student confidence and perceptions of their capabilities to engage in science. When students are recognized for their scientific abilities, self-efficacy is strengthened which reinforces students' identities as science people (Carlone and Johnson, 2007). Fostering self-efficacy amongst students has impacts on competence and performance as their self-efficacy is a reflection of their scientific competence where students more likely to engage in performances of relevant scientific practices when they are confident (Bandura, 1997; Britner and Pajares, 2006; Hazari et al., 2010). When students have strong self-efficacy, there's successful performances in relevant scientific practices which further strengthens their science identity (Hazari et al., 2010).

Competence and performance are interrelated components of science identity that shape an individuals' recognition and motivation within scientific communities (e.g., Carlone and Johnson, 2007; Hazari et al., 2010). Competence provides a foundation for performance while performance reinforces a sense of competency for recognition. Competence is based on experience where it "requires appropriate learning experiences" to thrive in which students develop competence differently (Bandura, 1997). When students feel competent, they are more likely to identify as a science person while performance of relevant scientific practices leads to recognition which reinforces one's identity (Carlone and Johnson, 2007; Hazari et al., 2010).

Interest impacts how students engage with science which shapes their science identities (e.g., Carlone and Johnson, 2007; Hazari et al., 2010). Similar to other components (i.e., recognition, competence, and performance), interest is collinear where these components influence one another

(Hazari et al., 2010). When students have an interest in science, they are more likely to engage with science and scientific communities which affirms their recognition as a science person (Carlone and Johnson, 2007; Hazari et al., 2010).

Science identity is a crucial concept in education, yet science identity can lack specificity of the identity experiences in specific communities of practice (i.e. science disciplines). The themes of science identity provide a foundation to understand students' disciplinary identities in their communities of practice such as chemistry.

Chemistry Identity

Discipline-based education research (DBER) on disciplinary identity have used the concept of identity through self-perceptions as a "kind of person" which is common amongst the literature (Carlone, 2004; Carlone and Johnson, 2007; Hazari et al., 2010, Chemers et al., 2011; Godwin et al., 2016). DBER draws upon the science identity conceptual framework from Carlone and Johnson (2007) to contextualize disciplinary identity such as chemistry identity. Therefore, chemistry identity is defined as "being recognized as a chemistry person in a chemistry context" (Hosbein and Barbera, 2020b). Hosbein and Barbera (2020a) sought to use existing constructs of identity to theoretically ground identity in a chemistry context. However, the literature on chemistry identity framework is being developed to further understand the components of chemistry identity formation (e.g., Hosbein and Barbera, 2020a; Hosbein and Barbera, 2020b; Guo et al., 2022). This study adds to previous findings on science and chemistry identity to address gaps in the literature on identity in undergraduate students while exploring the overlap between scientific literacy and identity.

Literature Review

Scientific Literacy

Development of Scientific Literacy

The development of scientific literacy is defined by the time and context for it exists in. *Science for All Americans* (AAAS, 1990) was an early attempt at defining scientific literacy and its complexity. Following *Science for All Americans*, definitions have moved away from content knowledge focus towards definitions involving decision making related to science (Holbrook and Rannikmae, 2009) to benefit all individuals. Holbrook and Rannikmae (2007) emphasized scientific literacy from a teaching perspective as:

> *The science teaching focus is from an understanding of what is important from a scientists' perspective rather than the viewpoint of the learner, or society. It calls upon students to act as "little scientists", even though they have yet to master the problem-solving and decision-making skills that are an integral part of their science learning. (Holbrook and Rannikmae, 2007, p.1349).*

As such, science educators are tasked with the introduction of content and skills that are crucial to use science outside the classroom. Educators emphasize understanding of natural phenomena, science knowledge, and vocabulary for decision-making related to science (Chen et al., 2021) for students' scientific literacy. *Science for All Americans* supports this view of educators as the AAAS recommended educators to guide students with questions about nature and actively engage them in science lessons (AAAS, 1990). A study by Duan et al. (2013) explored the effective ways of improving students' scientific literacy through scientific thinking and awareness in which they concluded that science content conveying the latest scientific developments, research, and applications of technology would improve scientific literacy. Scientific literacy studies have reported that scientific literacy is developed over an extended period of time with prolonged education across disciplines rather than solely in general education science courses (Nuhfer et al., 2016).-As such, changes in scientific literacy seem to be a result of prolonged exposure to themes of scientific literacy across science education.

Achieving Scientific Literacy in Science Education

Science education reform has centered students' scientific literacy development, this reform combines common themes of scientific literacy into standards to achieve scientific literacy for all. The National Science Education Standards (NSES) states skills that a scientifically literate individual can accomplish:

> *…describe, explain, and predict natural phenomena,… read with understanding articles about science … engage in social conversation about the validity of the conclusions, …identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed, …evaluate the quality of scientific information on the basis of its source and the methods, …pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately. (NRC, 1997, p. 22).*

The NSES standards highlight the shift in scientific literacy definitions to encompass the performances (applications) of scientific literacy in daily life. Nearly 20 years later, A Framework for K-12 Science Education (National Research Council, 2012) describes three dimensions of science education for students to engage in for scientific literacy: disciplinary core ideas (DCIs), scientific and engineering practices (SEPs), and crosscutting concepts (CCs). A Framework for K-12 Science Education describes the dimensions as:

> *Standards and performance expectations that are aligned to the framework must take into account that students cannot fully understand scientific and engineering*

> *ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. At the same time, they cannot learn or show competence in practices except in the context of specific content. (NRC, 2012, p. 218).*

The DCIs represent concepts that students are expected to understand in science or engineering, SEPs represent fundamental activities that scientists and engineering engage in to understand or solve problems relating to competence and relevant practices, and CCs function as a bridge between disciplinary boundaries. The three dimensions blend fundamental literacy and competence in science content where “students actively engage in scientific and engineering practices in order to deepen their understanding of crosscutting concepts and disciplinary core ideas” (National Research Council, 2012, p.217). Scientists and engineers are recognized through these dimensions as science persons which links science identity to the three dimensions of science education, the SEPs are relevant scientific practices and engaging in the dimensions demonstrates competence for recognition as a science person.

Assessment of Scientific Literacy

As the definition of scientific literacy has shifted over time, this change must be reflected in the assessment tools of scientific literacy. Standardized tests, such as the Programme for International Student Assessment (PISA), are meant to address real-life challenges by measuring students’ reading, mathematics, science knowledge and skills. The PISA occurs every 3 years where the Organisation for Economic Cooperation and Development (OECD) measures trends in test scores over time. In the 2006 PISA, the definition of scientific literacy included the “willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen” (OECD, 2006). However, there is criticism for the limitations of the PISA in capturing the full scope of scientific literacy (Sjøberg and Jenkins, 2022). As such, there are recent developments in assessments to offer a greater understanding of students' scientific literacy.

The Test of Scientific Literacy Skills (TOSLS) is an assessment tool designed to measure students' scientific literacy skills at the undergraduate level (Gormally et al., 2012). The TOSLS aims to evaluate students' ability to critically analyze scientific information, interpret numerical information, understand and apply scientific concepts, and solve problems with scientific reasoning using 9 skills (Table 1) using 28 multiple-choice survey items. The assessment focuses on key components of scientific literacy such as the ability to evaluate the validity of scientific information, understand research design and methodology, and interpret data that impact students' everyday lives. By assessing these skills, the TOSLS provides practical insight into students' ability to use skills to make scientific knowledge useful and usable in everyday life (Gormally et al., 2012) in which is an overarching goal of scientific literacy in science education.

Table 1. Skills from the Test of Scientific Literacy Skills (Gormally et al., 2012).

Skill	Description	Questions
1	Identify a valid scientific argument	1, 8, 11
2	Evaluate the validity of sources	10, 12, 17, 22, 26
3	Evaluate the use and misuse of scientific information	5, 9, 27
4	Understand elements of research design and how they impact scientific findings/conclusions	4, 13, 14
5	Create graphical representations of data	15
6	Read and interpret graphical representations of data	2, 6, 7, 18
7	Solve problems using quantitative skills, including probability and statistics	16, 20, 23
8	Understand and interpret basic statistics	3, 19, 24
9	Justify inferences, predictions, and conclusions based on quantitative data	21, 25, 28

Identity

Development of Science Identity

The development of identity is contextual that takes place over the lifetime of an individual. Erickson (1968) reported the beginning of adolescence as important for identity development which includes previous identities prior to adolescence with what the child believes they can do or wanted to become. Over time, students engage with identity work through taking on identities through specific actions and relationships (Calabrese Barton et al., 2013) in which relates to science identity development. Carlone (2012) emphasized three aspects of identity: “identities are formed in practice… people have a say in who they become (agency), but that agency is often limited… social identification occurs within and is influenced by multiple timescales” (p.11). Related to communities of practice, the construction of science identity through learning is partially influenced by educators and peers (Carlone and Johnson, 2007; Eccles, 2009; Brickhouse et al., 2000; Chang et al., 2011; Chemers et al., 2011; Carlone et al., 2015; Chen et al., 2021). As such, time and social factors are important contributing components to science identity development.

Importance of Science Identity

Understanding science identity is crucial in science education as it shapes how individuals engage and succeed in scientific fields, and influences students’ educational goals. By fostering strong science identities, there are implications for student persistence (Hazari et al., 2010; Cass et al., 2011; Godwin et al., 2013; Vincent-Ruz and Schunn, 2018) which contributes to a more diverse scientific community to tackle global scientific challenges. Conversely, a weak science identity can result in attrition in scientific communities that can contribute to underrepresentation of BIPOC students and loss of talent in STEM, emphasizing the importance for supportive science education and environments for students. Both demographics of college students (science and non-science majors) can benefit from encouraging science identity formation as science identity contributes to attitudes towards science and student learning. Specifically, actions like talking about science as a subject that is accessible for everyone instead of only for certain kinds of people are important for fostering science identity and students' educational goals (Aschbacher et al., 2010). Additionally, studies have argued that identity work when teaching non-science majors is just as important for students as students take on a science identity in contexts to learn and interact with science material outside of formal science experiences (Lucas, 2021).

Assessment of Science Identity

The assessment of science identity involves the evaluation of how individuals perceive themselves in relation to science with components such as performance/competence, interest, recognition, and self-efficacy. The theoretical framework of identity theory provides a foundation for understanding the development of science identity and how identity is sustained. Common methods of assessing science identity are longitudinal studies (Brickhouse and Potter, 2001; Carlone and Johnson, 2007; Chang et al., 2011; Bucholtz et al., 2012; Calabrese Barton et al., 2013; Carlone et al., 2014; Holmegaard et al., 2014; Carlone et al., 2015; Williams et al., 2018; Robinson et al., 2019; Puente et al., 2021; Huffmyer et al., 2022), interviews and focus groups (Brickhouse et al., 2000; Le et al., 2019; Lucas and Spina, 2022), and surveys (Chemers et al., 2011; Hazari et al., 2013b; Aghekyan, 2019; Chen et al., 2021; Dou et al., 2021; Newall and Ulrich, 2022; McQuillan et al., 2023). An influential longitudinal study was Carlone and Johnson (2007) as part of a larger ethnographic study of women science students of color. This study included ethnographic interviews during students' undergraduate careers with follow-up interviews 6 years later in which Carlone and Johnson (2007) developed a model of science identity to understand the experiences of these women of color in science.

However, recent studies have used survey items that ask students how they perceive their science or discipline identity (e.g., Hazari et al., 2010; Chemers et al., 2011; Hazari et al., 2013b; Godwin et al., 2016; Hosbein and Barbera, 2020a; Chen et al., 2021; Dou et al., 2021). A survey item from Hazari et al. (2010) Persistence Research in Science and Engineering (PRiSE) has been adopted across DBER studies to measure students' self-perception of identity (Godwin et al., 2016; Hosbein and Barbera, 2020a; Chen et al., 2021; Dou et al., 2021). The survey item (i.e., "Do you see yourself as a physics person?") functions as an extension of conceptualizing science identity through self-perceptions as a "type of person" that is common in the literature (Carlone, 2004). McDonald et al. (2019) argued against a single item measure for science identity previously used in the literature (Hazari et al., 2010, 2013b) as it may not capture the complexity of identity with an "all-or-nothing" item approach. However, the single item measurement from the PRiSE (Hazari et al., 2010) has been adopted into several studies measuring discipline identities (Hazari et al., 2013b; Cribbs et al., 2015; Godwin et al., 2016; Cheng et al., 2019; Hosbein and Barbera, 2020a) which is appropriate when quick self-assessments are desired (Youngblut and Casper, 1993).

Literature on Scientific Literacy and Identity

Current literature on scientific literacy and identity are abundant; however, the overlap between these constructs has received little attention. A study by Lucas (2021) investigated the conceptual overlap between scientific literacy and identity amongst non-STEM majors. They found that students demonstrated connections in their identities as science persons and aspects of scientific literacy. Lucas (2021) also reported strong instances of students describing oneself as a science person with scientific literacy themes of self-efficacy, scientific practices, and interest. These findings support the nexus of scientific literacy and identity demonstrated in conceptual definitions and previous research (Chemers et al., 2011; Carlone et al., 2014; Baker and Sivaraman, 2018; Lucas, 2021).

3. Research Methodology

Research Design

This study is quantitative in nature and uses a pretest-posttest survey design to examine the relationship between students' scientific literacy skills and their science (chemistry) identities, and the changes in scientific literacy and science (chemistry) identity over an academic quarter. Several studies examining students' scientific literacy skills have applied quantitative methods in the analyses of the outcomes (see for example, Gormally et al., 2012; Crowell and Schunn, 2016; Baker and Sivaraman, 2018). It is also well-established in the literature that pretest-posttest survey designs are well-suited to assess changes in participant outcomes (Campbell and Stanley, 1963; Chevalier et al., 2010; Baker and Sivaraman, 2018).

Survey Instrument

The Scientific Literacy and Identity survey (SLIS) was used in this study to measure students' scientific literacy, and science and chemistry identities (Appendix A). The SLIS was developed using all items from the Test of Scientific Literacy Skills (TOSLS) developed by Gormally et al. (2012), as well as select items from the Persistence Research in Science and Engineering (PRiSE) instrument developed by Hazari et al. (2010). The TOSLS measures students' scientific literacy on nine skills (see Table 1) using 28 multiple-choice survey items. The PRiSE measures students' science experiences, science attitudes, and physics identity. The PRiSE item "Do you see yourself as a physics person?" measures students' self-perceptions of their physics identity and was adapted to measure students' science and chemistry identities in this study. In total the SLIS had 36 questions capturing students' demographic information, their science and chemistry identities, and their scientific literacy skills (Table 2).

Table 2. Overview of the SLIS survey structure.

Section	Format	Number of Questions
Demographic Information	Multiple-choice	6
Identity	Likert-scale	2
Scientific Literacy Skills	Multiple-choice	28

Pilot Study

The pilot study was conducted with students enrolled in a general chemistry course at WWU (n = 91). This pilot used a convenience sample to determine the internal consistency of the survey items with our target demographic. The SLIS measures students' scientific literacy skills and their science and chemistry identities using items that rely on established theoretical frameworks and explicitly align with our research objectives. The SLIS was also assessed for content and construct validity to ensure it accurately measures what is intended. Content validity is the degree to which an assessment instrument evaluates all relevant aspects of the topic or construct it aims to measure. Gormally et al. (2012) established high content validity of the scientific literacy skill items from the TOSLS through expert reviews from general education faculty to support that the items are important for scientific literacy, and utility beyond the biology context. The PRiSE identity items underwent content validity through focus groups with STEM education experts (researchers and practitioners) and open-ended survey from 412 STEM education experts to incorporate the breadth of views and hypotheses by the scientific community (Sadler et al., 2012; Hazari et al., 2013a). Additionally, the scientific literacy items from the TOSLS underwent construct validity. Construct validity refers to how well an assessment instrument measures the construct it is intended to measure. Gormally et al. (2012) established high construct validity as the TOSLS was developed on established definitions of scientific literacy and underwent pilot testing for reliability, item difficulty, and test equivalence.

The internal consistency of the identity items was measured using Cronbach alpha. Alpha values equal to or above 0.65 are considered within the acceptable range and values above 0.80 reflect good reliability (Miller & Salkind, 2002). The identity items returned an alpha value of 0.69 which is within the acceptable range of reliability. The internal consistency of the scientific literacy items was measured with Kuder-Richardson 20 (KR-20), which is appropriate for dichotomous data. The scientific literacy items returned a KR-20 value of 0.79, which indicates good reliability. Based on the validity and internal consistency results, we retained all survey items used in the original survey for the main study. Additional adjustments were made to improve the survey's navigation by enabling students to return to previous questions and select more than one option for their race/ethnicity demographics. This study was approved by WWU’s Institutional Review Board.

Main Study

All students enrolled in chemistry courses at WWU in Spring 2023 were invited to participate in this study. The survey was incorporated into the normal coursework of each course, with information and links to the survey provided by the instructors. Students who wished to opt out of the study were instructed to contact the principal investigator using the contact information provided in the survey. The pretest was conducted in weeks 2-3 of a 10-week quarter, while the posttest was conducted in weeks 8-10. A total of 1022 responses were received from students across chemistry courses, including upper division courses and the general chemistry series. There was an insufficient number of responses in upper division chemistry courses to allow for rigorous statistical analyses and so these responses were excluded from the study, leaving the focus of the main study on the responses from students in the general chemistry series (CHEM 161, CHEM 162, and CHEM 163). To be included in the main study, students had to provide demographic information and respond to each survey item in both the pretest and the posttest. Any non-matching responses between the pretest and posttest (e.g., students who took the posttest but not the pretest), incomplete survey items, and duplicate test takers were excluded from the main study. Cleaning of the data resulted in 181 responses for analysis. The demographic data helped to contextualize our analyses of the identity and scientific literacy data.

Students in the main study were identified by their demographic data: major, class standing, race and ethnicity, and course. Majors were defined as declared majors or intended majors. As there was a low number of chemistry majors in the sample, majors were re-classified as “science” majors and “non-science” majors. Class standing responses were grouped as “freshmen” and “sophomore or higher” as there were also low numbers of upperclassmen (juniors or seniors) in the main study. Student responses around race and ethnicity were grouped as “Black, Indigenous, People of Color (BIPOC)” and “White.” BIPOC was chosen to describe students of color at WWU as the term helps with the nuances with race and ethnicity identity (Graham et al., 2022). Lastly, student responses were grouped by general chemistry course “CHEM 161”, “CHEM 162” and “CHEM 163”. The final demographic groupings were majors (“science” and “non-science”), class standing (“freshmen” and “sophomore or higher”), race and ethnicity (“BIPOC” and “White”), and course (“CHEM 161”, “CHEM 162” and “CHEM 163”). The demographic data of the main study are reported in Table 3.

Table 3. Demographic data of the main study.

Group		Sample size
Total		181
Major	Science	123
	Non-science	58
Class standing	Freshmen	105
	Sophomore or higher	76
Race and ethnicity	BIPOC	45
	White	136
Course	CHEM 161	47
	CHEM 162	111
	CHEM 163	23

Course Descriptions

The general chemistry series at WWU is comprised of three courses — CHEM 161, CHEM 162, and CHEM 163 — each having laboratory and lecture components. The lecture meets for 4 hours a week, and labs meet once a week for 2-3 hours. CHEM 161 is the first course in the series and introduces students to matter, dimensional analysis, stoichiometry, atomic and molecular structure, periodic trends, and molecular interactions. CHEM 162, the next course in the series, introduces solutions, types of chemical reactions, gas laws, thermochemistry, thermodynamics and kinetics. CHEM 163 is the final course in the series and focuses on equilibria, acids and bases, and electrochemistry. Completing the general chemistry series is a pre-requisite for upper division chemistry courses and courses in other science disciplines. The courses in the general chemistry series also serve as general university requirement courses as a Natural Sciences with a laboratory component (LSCI) course. Students are required to take at least two LSCI courses.

Data Analysis

The responses to the identity items were set on a Likert scale from 0 to 10 with a maximum possible score of 10, and the scientific literacy items were dichotomously coded to reflect correct responses (0 = incorrect, 1 = correct) with a maximum possible score of 28. The SLIS showed good reliability for identity ($\alpha = 0.85$) and scientific literacy skill items (pretest = 0.82, posttest = 0.88). The data was checked for normality and homogeneity of variances to determine what tests were appropriate for statistical analyses. The data showed non-normal distribution in a Kolmogorov-Smirnov test ($p < 0.05$) and homoscedasticity through a Levene's test ($p > 0.05$). Therefore, common parametric tests to compare the scores between the pretest and posttest were not appropriate on their own for statistical analyses.

4. Results and Discussion

Research Question 1

Is there a significant change in general chemistry students' scientific literacy skills between the pretest and posttest?

General chemistry students' scientific literacy skills scores were examined using a paired samples t-test to determine if there was a significant change between the pretest and posttest. Although the data was non-normal, paired samples t-test are robust to violations of normality (Hatch and Posten, 1966; Posten, 1984), so a paired samples t-test was appropriate to compare the matched student responses. The results are shown in Table 4 below. The results showed that there were no significant changes ($p > 0.05$) in students' scientific literacy scores between the pretest (M=19.5, SD=5.1) and posttest (M=19.4, SD=6.0).

Table 4. Paired samples t-test on general chemistry students' scientific literacy skills.

	Mean Pretest (SD)	Mean Posttest (SD)	Difference	T-value	Sig. (2-tail)
Scientific Literacy Skills	19.5 (5.1)	19.4 (6.0)	-0.1	-0.496	0.620
Maximum obtainable score is 28					

The result of no significant change in scientific literacy skills scores between the pretest and posttest indicates that general chemistry students' scientific literacy skills remained constant over the study period of 8-10 weeks. Previous studies using the TOSLS to measure students' scientific literacy reported no significant change over an 8-week period (Gormally et al., 2012), but significant change for periods greater than 16 weeks (Gormally et al., 2012; Nuhfer et al., 2016; Auerbach and Schussler, 2017). This suggests that more time than the study period (i.e., 8-10 weeks) may be needed to observe significant changes in scientific literacy skills. However, given our 10-week quarter system, this was one of the limitations of our study. Future research could explore the development of scientific literacy in a longitudinal study over two or more quarters.

Research Question 2

Is there a significant change in general chemistry students' scientific literacy skills by demographic group?

Between and within group analyses were used to determine changes in general chemistry students' scientific literacy skills from pretest to posttest (Skvarc and Fuller, 2024).

Within Demographic groups comparisons

Paired samples t-tests were used to compare the changes in scientific literacy from pretest to posttest within demographic groups. The results are shown in Table 5. Within each demographic group there was no significant changes ($p > 0.05$) in scientific literacy skills between the pretest and posttest. A one-way analysis of covariance (ANCOVA) using the pretest scores as the covariate within each demographic group (Appendix B) confirmed the results of the t-tests. The results of no significant changes within demographic groups using both paired samples t-tests and one-way ANCOVA indicate that general chemistry students' scientific literacy skills remained fairly constant over the study period. These results may be linked to the limited study period (Gormally et al., 2012; Nuhfer et al., 2016; Auerbach and Schussler, 2017).

Table 5. Paired samples t-test on scientific literacy skills within demographic groups.

Group		Mean Pretest (SD)	Mean Posttest (SD)	Difference	T-value	Sig. (2-tail)
Major	Science	20.0 (4.8)	20.0 (5.7)	0	0.021	0.983
	Non-science	18.6 (5.7)	18.1 (6.2)	-0.5	-0.847	0.400
Class standing	Freshmen	19.6 (4.9)	19.4 (5.7)	-0.2	-0.554	0.581
	Sophomore or higher	19.5 (5.4)	19.4 (6.4)	-0.1	-0.159	0.874
Race and ethnicity	BIPOC	17.6 (5.6)	17.3 (6.0)	-0.3	-0.364	0.717
	White	20.2 (4.8)	20.1 (5.8)	-0.1	-0.362	0.718
Course	CHEM 161	18.9 (5.1)	18.0 (6.0)	-0.9	-1.230	0.225
	CHEM 162	19.3 (5.1)	19.3 (6.1)	0	-0.021	0.983
	CHEM 163	22.1 (4.2)	22.7 (4.0)	0.6	0.909	0.373

Between Demographic groups comparisons

A comparison of scientific literacy skills between demographic groups was measured using the Mann-Whitney U test (with two groups) and the Kruskal-Wallis H test (with three or more groups). These tests are appropriate for non-normal data. The groups for the Mann-Whitney U tests were major (science and non-science), class standing (freshmen and sophomore or higher), race and ethnicity (BIPOC and White). For courses, the groups were CHEM 161, CHEM 162, and CHEM 163. The effect size was calculated using Pearson's correlation coefficient (r), where values range from -1 to +1 (Tomczak and Tomczak, 2014). Pearson r values of 0.1 are considered small, 0.3 are medium, and 0.5 are large (Cohen, 1988). The results are shown in Table 6. The Mann-Whitney U tests revealed no statistically favored demographic groups for scientific literacy skill scores based on major (science and non-science) or class standing (freshmen and sophomore or higher). For courses (CHEM 161, CHEM 162, and CHEM 163), a Kruskal-Wallis H test was used as a non-parametric alternative for between-group analysis of three groups (i.e., general chemistry series) that is similar to the Mann-Whitney U test (Pallant, 2007). The effect size was calculated by eta-squared (η^2), where values vary between 0 to 1 (Adams and Conway, 2014; Tomczak and Tomczak, 2014). Eta-squared (η^2) values of 0.01 are considered small, 0.06 are medium, and 0.14 are large (Adams and Conway, 2014). The results are shown in Table 7.

Between race and ethnicity, the results indicated that White students had significantly higher scientific literacy skill scores than BIPOC students in both the pretest ($z = -2.749$, $p = 0.006$, $r = 0.20$) and posttest ($z = -2.986$, $p = 0.003$, $r = 0.22$). The effect size revealed that our differences in scientific literacy skills by race and ethnicity were small in magnitude (Table 6). These results are not surprising as STEM spaces are more supportive of White students with representation and alignment of values (Carlone and Johnson, 2007; National Center for Science and Engineering Statistics, 2021). In a supportive environment, White students may have higher self-efficacy influencing their performance (Lent et al., 1994; Baker and Sivaraman, 2018) on the scientific literacy skill items in the SLIS. However, the research on the influence of race and ethnicity on college students' self-efficacy and performance shows mixed results (Aguayo et al., 2011). Additionally, BIPOC students experience barriers to their education such as racism in STEM which lowers persistence and undermines academic performance (Steele, 1997; Cokley, 2002; Chang et al., 2021). This may explain why White students in our study had significantly higher scientific literacy skill scores than BIPOC students. At least one previous study that used the TOSLS also reported significant differences in scientific literacy skills based on ethnicity where non-BIPOC students performed better than BIPOC students (Shaffer et al., 2019). As our study was conducted within an 8-10-

week quarter, repeating the study over a longer period may provide more accurate estimates of the correlation and differences between race and ethnicity. The results of these between-group comparisons are shown in Table 6.

Between courses, the Kruskal- Wallis H (χ^2) test was appropriate for the comparison of scientific literacy skills between the courses (CHEM 161, CHEM 162, and CHEM 163). In the pretest, the Kruskal-Wallis H (χ^2) test indicated that there were statistically significant differences in general chemistry students' scientific literacy skills ($\chi^2(2) = 7.717$, $p = 0.021$) with a small effect size ($\eta^2 = 0.04$). By mean rank, CHEM 163 had the highest scientific literacy skills scores while CHEM 161 had the lowest scientific literacy skills of the courses (Table 7). Similarly in the posttest, there were statistically significant differences in general chemistry students' scientific literacy skills ($\chi^2(2) = 11.313$, $p = 0.003$) with a medium effect size ($\eta^2 = 0.06$). Between the courses, CHEM 163 had the highest scientific literacy skill score while CHEM 161 had the lowest scientific literacy skills by mean rank (Table 7). These results of a significant difference in the scientific literacy skills of students in CHEM 163 and CHEM 161 are not surprising as CHEM 163 is the final course in the general chemistry series that requires CHEM 161 and CHEM 162 as prerequisites. This means students would have taken more science courses by the time they enrolled in CHEM 163. Waldo (2014) reported that students who took more science courses and had more positive attitudes towards science also had higher scientific literacy skills scores. In addition, the changes in students' scientific literacy skill scores between CHEM 161 and CHEM 162 were not significant ($p < 0.05$). Thus, these results suggest that having only completed 1 course in the general chemistry series (i.e., CHEM 161 to CHEM 162 enrollment) on its own may not be enough to produce significant changes in scientific literacy skills, as noted in the non-significant differences between CHEM 161 and CHEM 162.

Table 6. Mann-Whitney U test on scientific literacy skills between demographic groups.

		Pretest				Posttest			
Group		Mean rank	Z-value	Asymp. Sig. (2-tail)	r	Mean rank	Z-value	Asymp. Sig. (2-tail)	r
Major	Science	93.49	-0.898	0.369		96.41	-1.954	0.051	
	Non-science	86.11				80.35			
Class standing	Freshmen	90.51	-0.148	0.882		89.36	-0.496	0.620	
	Sophomore or higher	91.68				93.26			
Race and ethnicity	BIPOC	72.43	-2.749**	0.006	0.20	70.83	-2.986**	0.003	0.22
	White	97.14				97.67			

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 7. Kruskal-Wallis H test on scientific literacy skills between courses.

		Pretest				Posttest			
Group		Mean rank	χ^2	Asymp. Sig	η^2	Mean rank	χ^2	Asymp. Sig	η^2
Course	CHEM 161	83.19	7.717*	0.021	0.04	76.24	11.313**	0.003	0.06
	CHEM 162	88.58				91.04			
	CHEM 163	118.63				120.98			

*$p < 0.05$, **$p < 0.01$

Research Question 3

Is there a significant change in general chemistry students’ science or chemistry identities between the pretest and posttest?

Students’ identity scores were examined using a Wilcoxon signed-rank tests (Wilcoxon tests) to determine if there were significant changes in science and chemistry identities between the pretest and posttest. Wilcoxon tests are non-parametric tests for paired samples with ordinal data such as Likert-scale data and are appropriate for use when there are violations of normality (Kim, 2014). The effect size was calculated using Spearman’s rank correlation coefficient (Spearman’s ρ). Spearman’s ρ was an appropriate measure of association between the pretest and posttest identity scores, as a non-parametric equivalent statistical test of the Pearson correlation coefficient (Lehman et al., 2005). Spearman’s ρ values range from -1 to +1, where correlation values from 0.1 to 0.3 are considered weak, 0.4 to 0.6 are moderate, and 0.7 to 0.9 are strong (Dancey and Reidy, 2011). The results are shown in Table 8 below.

Table 8. Wilcoxon test on general chemistry students’ science and chemistry identities.

	Mean Pretest (SD)	**Mean Posttest (SD)**	**Difference**	**Z-value**	**Asymp. Sig. (2-tail)**	**ρ**
Science Identity	7.4 (1.8)	7.4 (1.8)	0	-0.653	0.514	
Chemistry Identity	5.1 (2.3)	5.3 (2.3)	0.2	-2.431*	0.015	0.801
Maximum obtainable score is 10						
*p < 0.05						

Science identity

The Wilcoxon test results indicated no significant difference ($p > 0.05$) in science identity between the pretest and posttest. The finding of no significant changes in students’ science identity suggests that their science identity remained fairly unchanged between the pretest and posttest. In the literature, there are mixed findings on changes in science identity over time (Robinson et al., 2018; Puente et al., 2021) that highlight how students' identities are impacted by their experiences (Eccles and Wigfield, 2020). Previous studies on science identity report that overall science identities are stable unless there are significant experiences that alter the balance of the science identity sub-constructs (Eccles, 2009; Godwin et al., 2016; Robinson et al., 2018). The results of this study are consistent with these findings. Carlone and Johnson (2007) describe science identity as "both situationally emergent and potentially enduring over time and context" (p.1192) where students' identities are dynamic, but overall student experiences may have remained more or less similar between the pretest and posttest.

Chemistry Identity

The results of a Wilcoxon test also indicated significant differences ($z = -2.431$, $p = 0.015$) in chemistry identity between the pretest (M=5.1, SD=2.3) and posttest (M=5.3, SD=2.3) with a strong effect size ($\rho = 0.801$). Students enrolled in the general chemistry series are invited to participate in a specific community of practice where they engage in chemistry content knowledge and relevant practices in the lecture and laboratory that can impact their perception of their identity in chemistry. As such, these students underwent significant changes in chemistry identity which supports the claims of learning as an identity development process (Brickhouse and Potter, 2001). Interestingly, general chemistry students report higher science identities in both the pretest and posttest in comparison to chemistry identities. As mentioned, the general chemistry series serves as a general university requirement in which students from various backgrounds are enrolled in these courses (i.e., CHEM 161, CHEM 162, and CHEM 163) may be taking chemistry courses for the first time. However, these students are coming into the general chemistry series with previous science experiences and interest in STEM as science majors where these general chemistry students have well-developed science identities. Unlike science identity, these general chemistry students' chemistry identities are not well-developed which can be attributed to first experiences in chemistry courses and interest in sciences – not necessarily an interest in chemistry as a discipline.

Research Question 4

Is there a significant change in general chemistry students' science or chemistry identities by demographic group?

For analysis of students' science and chemistry identities by demographic groups, within and between group comparisons of pretest and posttest scores were conducted (Skvarc and Fuller, 2024).

Within Demographic groups comparisons

The Wilcoxon test compared differences in science and chemistry identities within demographic groups. The results are reported for science identity and chemistry identity below.

Science Identity

Wilcoxon tests returned no significant changes ($p > 0.05$) in science identity by demographic groups between the pretest and posttest. The results are reported in Table 9. Similar results were obtained with a one-way ANCOVA within each demographic group (Appendix B). These results indicate that science identity within demographic groups remained more or less similar between the pretest and posttest. This finding supports the view that science identity remains relatively stable (Eccles, 2009; Godwin et al., 2016; Robinson et al., 2018). As we found with research question 3, our results indicate that students had relatively high science identity within each demographic group, and this could be attributed to students' previous science experiences (Hazari et al., 2010).

Table 9. Wilcoxon test on science identity within each demographic group.

Group		Mean Pretest (SD)	Mean Posttest (SD)	Difference	Z-value	Asymp. Sig. (2-tail)
Major	Science	7.7 (1.6)	7.5 (1.7)	-0.2	-1.563	0.118
	Non-science	6.8 (2.0)	7.0 (1.9)	0.2	-1.221	0.222
Class standing	Freshmen	7.6 (1.6)	7.5 (1.7)	-0.1	-1.579	0.114
	Sophomore or higher	7.1 (2.0)	7.3 (1.9)	0.2	-0.761	0.447
Race and ethnicity	BIPOC	7.1 (1.7)	7.3 (1.6)	0.2	-0.445	0.656
	White	7.5 (1.9)	7.4 (1.9)	-0.1	-1.038	0.299
Course	CHEM 161	6.7 (2.2)	6.8 (1.9)	0.1	-0.340	0.734
	CHEM 162	7.6 (1.6)	7.5 (1.8)	-0.1	-0.803	0.422
	CHEM 163	7.3 (1.8)	7.8 (1.8)	0.5	-0.686	0.493

Chemistry Identity

The Wilcoxon test revealed that there were significant changes in chemistry identity ($p < 0.05$) within demographic groups: major (science), class standing (sophomore or higher), race and ethnicity (White), and course (CHEM 162). The results are reported in Table 10. General chemistry students had higher science identity scores than chemistry identity scores within demographic groups (Table 9) that revealed students had higher science identity scores than chemistry identity scores in the general chemistry series. Unlike science identity, there were significant changes in chemistry identity scores within demographic groups. Therefore, the results suggest that disciplinary identities (i.e., chemistry identity) may be less stable than science identities as general chemistry students engage in the discipline’s community of practice.

Table 10. Wilcoxon test on chemistry identity within each demographic group.

Group		Mean Pretest (SD)	Mean Posttest (SD)	Difference	Z-value	Asymp. Sig. (2-tail)	ρ
Major	Science	5.2 (2.3)	5.5 (2.2)	0.3	-2.029*	0.042	0.785
	Non-science	4.8 (2.3)	5.0 (2.4)	0.2	-1.372	0.170	
Class standing	Freshmen	5.4 (2.3)	5.5 (2.3)	0.1	-0.798	0.425	
	Sophomore or higher	4.6 (2.3)	5.0 (2.2)	0.4	-2.924**	0.003	0.845
Race and ethnicity	BIPOC	5.4 (2.4)	5.5 (2.2)	0.1	-0.712	0.476	
	White	5.0 (2.3)	5.3 (2.3)	0.2	-2.412*	0.016	0.800
Course	CHEM 161	4.5 (2.4)	4.6 (2.3)	0.1	-0.151	0.880	
	CHEM 162	5.1 (2.3)	5.5 (2.3)	0.4	-2.596**	0.009	0.785
	CHEM 163	6.0 (1.7)	6.2 (1.5)	0.2	-0.836	0.403	

$*p < 0.05$, $**p < 0.01$

By major, science majors had significant changes in chemistry identity between the pretest (M = 5.2, SD = 2.3) and posttest (M = 5.5, SD = 2.2) with a strong effect size (ρ = 0.785). This increase in chemistry identity may reflect increased self-efficacy or interest in STEM over the quarter and may be linked to their status as a science major (Hazari et al., 2013b; Duo et al., 2021; Newall and Ulrich, 2022).

Similarly, results from sophomore or higher students indicate significant changes in chemistry identity between the pretest (M = 4.6, SD = 2.3) and posttest (M = 5.0, SD = 2.2) with a strong effect size (ρ = 0.845). An increase in chemistry identity from sophomore or higher students may indicate an increased self-perception or self-recognition, which may have come about because of more opportunities for chemistry coursework which could positively impact identity (Waldo, 2014). Students who are sophomores or higher are also more likely to be more settled in the college environment than freshmen, which could account for their increased chemistry identity.

Within race and ethnicity, White students reported significant changes in chemistry identity between the pretest (M = 5.0, SD = 2.3) and posttest (M = 5.3, SD = 2.3) with a strong effect size (ρ = 0.800). These results are not surprising as STEM spaces are more supportive of White students (Carlone and Johnson, 2007; National Center for Science and Engineering Statistics, 2021) where these students may begin to imagine themselves as part of this community of practice (Wenger, 1998; Carlone and Johnson, 2007) from the supportive environment. Wenger (1998) outlined models of belonging for identity formation including imagination; imagination is the "creative process of producing new 'images' and of generating new relations through time and space that become constitutive of the self" (Wenger, 1998, p.177). However, BIPOC students experience less support within STEM spaces through the experience of negative racial experiences where the literature reveals that lower frequencies of negative racial experiences result in stronger disciplinary identities (Chang et al., 2011). Interestingly, BIPOC students reported higher chemistry identities than White students on both the pretest and posttest (Table 10), yet there were no significant changes in chemistry identity for BIPOC students.

Examining the courses, only CHEM 162 had significant changes in chemistry identity between the pretest (M = 5.1, SD = 2.3) and posttest (M = 5.5, SD = 2.3) with a strong effect size (ρ = 0.785). This means as general chemistry students progress through the series, students are perceiving themselves as chemistry people as shown in Table 10. CHEM 162 builds upon the skills and foundational knowledge acquired in CHEM 161 further focusing on conceptual understanding which is a critical component to disciplinary identity (Hazari et al., 2010). In addition, students have formed foundational knowledge from the previous course that could increase their self-efficacy resulting in greater positive science experiences to increase students' identity (Aschbacher et al., 2010; Chemers et al., 2011; Cole, 2012; Hosbein and Barbera, 2020a; Hazari et al., 2022). Notably, this is a cross-sectional study - not a longitudinal study which implies that there are filtering effects from the cleaning of the data that present as a limitation in course analysis across this study.

Between Demographic groups comparisons

Science Identity

Differences in science identity between demographic groups were measured with a Mann-Whitney U test. The groups for the Mann-Whitney U test were major (science and non-science), class standing (freshmen and sophomore or higher), race and ethnicity (BIPOC and White). The results are shown in Table 11. For courses (CHEM 161, CHEM 162, and CHEM 163), a Kruskal-Wallis H test was used as a non-parametric alternative for between-group analysis of three groups (i.e., general chemistry series) that is similar to the Mann-Whitney U test (Pallant, 2007). The results in reported in Table 12.

Between majors, the results revealed that science majors had significantly greater science identity than non-science majors in both the pretest ($z = -3.313$, $p < 0.001$, $r = 0.25$) and posttest ($z = -1.959$, $p = 0.05$, $r = 0.15$). Interest has a crucial role in identity (Hazari et al., 2010; Godwin et al., 2016) where interest “is mediated by recognition and performance/competence” (Hazari et al., 2020). Science majors display strong interest in the sciences from affiliation with their major status in comparison to non-science majors who may foster identity only through positive experiences in science (Garcia et al., 2015). Considering their strong interest in science, as well as their strong affiliations related to their status as majors, it was unsurprising that science majors had greater science identities than non-science majors.

Between courses, the Kruskal- Wallis H (χ^2) test was appropriate for the comparison of science identity between the courses (CHEM 161, CHEM 162, and CHEM 163). In the pretest, the Kruskal-Wallis H (χ^2) test indicated that there were statistically significant differences in general chemistry students’ science identity scores ($\chi^2(2) = 7.439$, $p = 0.024$) with a small effect size ($\eta^2 = 0.04$). By mean rank, CHEM 163 had the highest science identity scores while CHEM 161 had the lowest science identity of the courses (Table 12). Similarly in the posttest, there were statistically significant differences in general chemistry students' science identity scores ($\chi^2(2) = 6.243$, $p = 0.044$) with a small effect size ($\eta^2 = 0.03$). Between the courses, CHEM 163 had the highest science identity scores while CHEM 161 had the lowest science identity scores by mean rank (Table 12). This was not surprising as when students are progressing in the general chemistry series, they are gaining formal science experiences where their identities are informed by their science experiences and social interactions (Aschbacher et al., 2010; Chemers et al., 2011; Bucholtz et al., 2012; Cole, 2012; Calabrese Barton et al., 2013; Hosbein and Barbera, 2020a; Hazari et al., 2022). In addition, we hypothesized that students enrolled in CHEM 163 may be more settled into the college environment and expectations in the general chemistry series in which students engage in scientific practices and position themselves into this community (e.g., science course) that strengthens their science identities (Calabrese Barton et al., 2013). As the final course in the series, students enrolled in CHEM 163 have more formal science experiences in the university setting where students are actively engaging in identity work with the course materials as being settled into the college environment. Alongside the completion of the prior courses, students advancing through the series may develop more self-efficacy through their academic achievements in the general chemistry series which fosters greater science identity amongst students.

Table 11. Mann Whitney-U test on science identity between demographic groups.

		Pretest				Posttest			
Group		Mean rank	Z-value	Asymp. Sig. (2-tail)	r	Mean rank	Z-value	Asymp. Sig. (2-tail)	r
Major	Science	100.00	-3.313	< 0.001***	-0.25	96.31	-1.959	0.050*	-0.15
	Non-science	73.30				80.56			
Class standing	Freshmen	96.65	-1.744	0.081		93.33	-0.722	0.470	
	Sophomore or higher	83.19				87.78			
Race and ethnicity	BIPOC	82.22	-1.326	0.185		84.66	-0.960	0.337	
	White	93.90				93.10			

*p < 0.05, **p < 0.01, ***p < 0.001

Table 12. Kruskal-Wallis H test on science identity between courses.

		Pretest				Posttest			
Group		Mean rank	χ^2	Asymp. Sig.	η^2	Mean Rank	χ^2	Asymp. Sig.	η^2
Course	CHEM 161	74.82	7.439	0.024*	0.04	75.62	6.243	0.044*	0.03
	CHEM 162	94.55				94.98			
	CHEM 163	106.91				103.22			

*p < 0.05

Chemistry Identity

The differences in chemistry identity between demographic groups were measured using Mann-Whitney U tests. The groups for the Mann-Whitney U test were major (science and non-science), class standing (freshmen and sophomore or higher), race and ethnicity (BIPOC and White). The results are shown in Table 13. The results showed no statistically favored ($p < 0.05$) demographic group for chemistry identity based on major (science and non-science) and race and ethnicity (BIPOC and White) on both pretest and posttest. For courses (CHEM 161, CHEM 162, and CHEM 163), a Kruskal-Wallis H test was used as a non-parametric alternative for between-group analysis of three groups (i.e. general chemistry series) that is similar to the Mann-Whitney U test (Pallant, 2007). The results are shown in Table 14.

Based on class standing, freshmen had significantly higher chemistry identity than sophomore or higher students in the pretest ($z = -2.530$, $p = 0.011$) with a small effect size ($r = 0.19$). A study by Hazari et al. (2010) reported that high school experiences were a significant predictor of students' physics identity that links conceptual understanding to physics identity. These results suggest that freshmen may have entered college with a relatively high chemistry identity from positive chemistry experiences and optimism that bolstered their identity in the pretest. Carlone and Johnson (2007) reported how some women of color in STEM felt more disconnected from science, despite their initial interest and affiliation with science, due to their academic and social experiences while persisting in STEM. As such, sophomore or higher students' experiences in college differ from freshmen entering with positive science experience resulting in significantly higher chemistry identity in freshmen than sophomore or higher students. A previous study by Chemers et al. (2011) on efficacy and identity also found that undergraduate students had higher science identity than graduate/postdoctoral students. However, there was no statistically favored demographic group (freshmen or sophomore or higher) in the posttest as sophomore or higher students had a significant increase in chemistry identity (Table 8)

Between courses, the Kruskal- Wallis H (χ^2) test was appropriate for the comparison of chemistry identity between the courses (CHEM 161, CHEM 162, and CHEM 163). In the pretest, the Kruskal-Wallis H (χ^2) test indicated that there were statistically significant differences in general chemistry students' chemistry identity scores ($\chi^2(2) = 6.413$, $p = 0.041$) with a small effect size ($\eta^2 = 0.04$). By mean rank, CHEM 163 had the highest science identity scores while CHEM 161 had the lowest science identity of the courses (Table 14). Similarly in the posttest, there were statistically significant differences in general chemistry students' science identity scores ($\chi^2(2) = 7.673$, $p = 0.022$) with a small effect size ($\eta^2 = 0.04$). Between the courses, CHEM 163 had the highest science identity scores while CHEM 161 had the lowest science identity scores by mean rank (Table 14). By advancing in the general chemistry series, students are gaining academic achievements that strengthen competence and recognition. The transition from CHEM 161 to CHEM 162 is facilitated by continuing content knowledge and scientific practices with stoichiometry in lecture and lab prior to introducing new material. These findings align with existing studies that emphasize the importance of scientific practices and performances in science identity development (Carlone and Johnson, 2007; Hazari et al., 2010). Previous studies have reported that accumulated academic achievements contribute significantly to students' science identities (Glynn et al., 2011; Syed et al., 2011). In a chemistry context, students who persist and advance through the general chemistry series are accumulating academic achievement in chemistry that contributes to students in CHEM 163 having significantly higher chemistry identity than students at the beginning of the series (i.e., CHEM 161 and CHEM 162).

Table 13. Mann Whitney-U test on chemistry identity between demographic groups.

		Pretest				Posttest			
Group		Mean rank	Z-value	Asymp. Sig. (2-tail)	r	Mean rank	Z-value	Asymp. Sig. (2-tail)	r
Major	Science	93.93	-1.063	0.288		93.83	-1.031	0.302	
	Non-science	85.25				85.43			
Class standing	Freshmen	99.31	-2.530*	0.011	0.19	95.71	-1.438	0.150	
	Sophomore or higher	79.52				84.49			
Race and ethnicity	BIPOC	97.81	-1.015	0.310		96.00	-0.746	0.455	
	White	88.75				89.35			

*p < 0.05, **p < 0.01, ***p < 0.001

Table 14. Kruskal-Wallis H test on chemistry identity between courses.

		Pretest				Posttest			
Group		Mean rank	χ^2	Asymp. Sig.	η^2	Mean rank	χ^2	Asymp. Sig.	η^2
Course	CHEM 161	79.16	6.413*	0.041	0.04	75.20	7.673*	0.022	0.04
	CHEM 162	91.55				93.82			
	CHEM 163	112.54				109.65			

*p < 0.05

Research Question 5

What is the nature of the relationship between general chemistry students' scientific literacy skills and science identity, and scientific literacy skills and chemistry identity? Is this relationship significant?

Students' scores were correlated through a Spearman's rank correlation coefficient (Spearman's ρ) to determine if there is an association between general chemistry students' scientific literacy and their science and chemistry identity. Spearman's ρ was an appropriate measure of association for scientific literacy and identity as a non-parametric equivalent statistical test of the Pearson correlation coefficient (Lehman et al., 2005). Although the data contain different variables (i.e., continuous and ordinal data), Spearman's ρ is appropriate for large sample sizes and when the ordinal data (Likert scale) has a large number ($x \geq 5$) of levels (Khamis, 2008). Correlation values from 0.1 to 0.3 are considered weak, 0.4 to 0.6 are moderate, and 0.7 to 0.9 are strong (Dancey and Reidy, 2011). The results are in Table 15 below.

Table 15. Spearman's ρ correlation test between general chemistry students' scientific literacy and science identity, and scientific literacy skills and chemistry identity.

	Pretest Science Identity	**Sig. (2-tail)**	**Pretest Chemistry Identity**	**Sig. (2-tail)**
Pretest Scientific Literacy Skills	0.184*	0.013	0.210**	0.005
	Posttest Science Identity	**Sig. (2-tail)**	**Posttest Chemistry Identity**	**Sig. (2-tail)**
Posttest Scientific Literacy Skills	0.120	0.107	0.114	0.126
*p < 0.05, **p < 0.01				

Scientific Literacy Skills and Science Identity

The results show that there was a weak, positive correlation between scientific literacy skills and science identity in the pretest (ρ (179) = 0.184, *p* = 0.013). This finding supports the claim that there is a significant relationship between scientific literacy and science identity in which these constructs overlap in the student experience (Lucas, 2021). However, in the posttest this relationship was no longer significant between scientific literacy skills and science identity (Table 12). Lucas (2021) described that scientific literacy and science identity worked together as students spoke about less scientific literacy skills resulting in feeling less like a science person. The change in this relationship could be due to several factors. One limitation throughout the study is the 10-week quarter system that presented limitations in measured changes in both scientific literacy skills and science identity which may attribute to the change in the relationship in the posttest. In addition to this limitation, there was an increase in standard deviation for general chemistry students' scientific literacy skills (Table 4) which increases the variance of the results. Specifically, variance influences the value of correlation coefficients (Janse et al., 2021) through an inverse relationship – as standard deviation increases, correlation decreases. Therefore, the increased variance in general chemistry students' scientific literacy skills in the posttest (Table 4) could contribute to the non-significant correlation in comparison to the significant correlation from the pretest.

Scientific Literacy Skills and Chemistry Identity

Similarly, there was a weak, positive correlation between scientific literacy and chemistry identity in the pretest (ρ (179) = 0.210, *p* = 0.005). This finding revealed that disciplinary identity, such as chemistry identity, has a significant relationship with scientific literacy skills. However, in the posttest this relationship was no longer significant between scientific literacy skills and chemistry identity (Table 12) which was similar to the relationship with science identity. Thus, the relationship between scientific literacy skills, and science and chemistry identity are similar as the relationships were significant in the pretest. As mentioned, the 10-week quarter system presented limitations in measured changes in scientific literacy skills which may attribute to the change in the relationship in the posttest. As previously mentioned, there was an increase in variance in general chemistry students' scientific literacy skills in the posttest (Table 4) which could contribute to the non-significant correlation between scientific literacy skills and chemistry identity in the posttest.

Research Question 6

What is the nature of the relationship between general chemistry students' science and chemistry identity? Is this relationship significant?

Students' scores were correlated with Spearman's ρ to determine if there's an association between science and chemistry identity. The results are shown in Table 16 below. In the pretest, there was a moderate, positive correlation between science and chemistry identity that was significant (ρ (179) = 0.542, $p < 0.001$). Similarly in the posttest, there was a moderate, positive correlation between science and chemistry identity that was significant (ρ (179) = 0.513, $p < 0.001$). This result was intriguing as we hypothesized a strong correlation between science and chemistry identity as the framework from Carlone and Johnson (2007) has been key contributions to the components of discipline identity that has expanded DBER on identity (Hazari et al., 2010; Godwin et al., 2016; Hosbein and Barbera, 2020a). Thus, further research on the components of chemistry identity in relation to other identity frameworks (Hosbein and Barbera, 2020a, 2020b) could provide greater understanding of the differences between these identities.

Table 16. Spearman's ρ correlation test between general chemistry students' science and chemistry identities.

	Pretest Chemistry Identity	**Sig. (2-tail)**
Pretest Science Identity	0.542***	< 0.001
	Posttest Chemistry Identity	**Sig. (2-tail)**
Posttest Science Identity	0.513***	< 0.001
***p < 0.001		

Summary of Findings

This study aimed to examine the nexus between scientific literacy skills and science (chemistry) identity in general chemistry students, and explore the changes in scientific literacy and science (chemistry) identity between a pretest-posttest in a 10-week academic quarter. Specifically, this study sought to answer the following questions:

(1) Is there a significant change in general chemistry students' scientific literacy skills between the pretest and posttest?

(2) Is there a significant change in general chemistry students' scientific literacy skills by demographic group?

(3) Is there a significant change in general chemistry students' science or chemistry identities between the pretest and posttest?

(4) Is there a significant change in general chemistry students' science or chemistry identities by demographic group?

(5) What is the nature of the relationship between general chemistry students' scientific literacy skills and science identity, and scientific literacy skills and chemistry identity? Is this relationship significant?

(6) What is the nature between general chemistry students' science and chemistry identities? Is this relationship significant?

1. There were no significant changes in students' scientific literacy skills between the pretest and posttest.
2. There were no significant changes in students' scientific literacy skills within demographic groups. However, there were significant changes in general chemistry students' scientific

literacy skills between demographic groups: race and ethnicity (White and BIPOC) and courses (CHEM 161, CHEM, 162, and CHEM 163). Between race and ethnicity, White students had significantly higher scientific literacy skill scores than BIPOC students in the pretest and posttest. Between courses, there were significant differences in general chemistry students' scientific literacy skills; by mean rank CHEM 163 had the highest scientific literacy skills between the general chemistry courses.

3. There were no significant changes in students' science identity between the pretest and posttest. However, there were significant changes in students' chemistry identity between the pretest and posttest.
4. There were no significant changes in students' science identity within demographic groups, but between demographic groups there were significant differences between majors (science and non-science) and courses (CHEM 161, CHEM 162, and CHEM 163) in science identity. For chemistry identity, there were significant changes in students' identity within demographic groups: science majors, sophomore or higher students, White students, and CHEM 162 students between the pretest and posttest. Additionally, there were significant differences in students' chemistry identity between demographic groups: class standing (freshmen and sophomore or higher) and courses (CHEM 161, CHEM 162, and CHEM 163).
5. There was a weak, positive correlation between students' scientific literacy and their science and chemistry identities in the pretest. However, there was no significant correlation between students' scientific literacy and their science and chemistry identities in the posttest.
6. There was a moderate, positive correlation between students' science and chemistry identities in the pretest and posttest.

5. Conclusion

This study addresses the lack of research on the examination of the nexus between general chemistry students' scientific literacy skills and their science identities using quantitative methods. In a chemistry context, there is little research that examines both scientific literacy and science identity in undergraduate students. As a response to the lack of attention, this study had expanded upon previous research on the two constructs had focused on non-STEM majors in a biology context (Lucas, 2020) while adding to the quantitative research on scientific literacy (e.g. Chemers et al., 2011; Gormally et al., 2012; Waldo, 2014; Auerbach and Schussler, 2017; Shaffer et al., 2019). The results indicate that there was a weak, positive correlation between general chemistry students' scientific literacy skills and their science and chemistry identities in the pretest. These results indicate that there must be significance to the conceptual overlap between scientific literacy and science identity found in the literature as these constructs are positively correlated. Therefore, prioritizing efforts for identity work in science education has important implications for scientific literacy development in general chemistry students, and potentially all science students. By improving identity work in science education, students have access to positive, formal science experiences that foster their identities as science persons that allow for general chemistry students to develop stronger scientific literacy skills. Further studies of the nexus between scientific literacy and science identities could provide information to the implications of this relationship with upperclassmen and students in other science disciplines. As scientific literacy remains an important goal of science education, efforts to elicit stronger science identities in students will allow for stronger scientific literacy skills for science related issues in everyday life.

Scientific Literacy Skills

The finding that students' scientific literacy skills did not have significant changes in 10-weeks which includes the paired samples t-test results within demographic groups to compare survey responses. This implies that scientific literacy skills develop over greater periods of time than 10 weeks, ideally a 16-week minimum as indicated by Gormally et al. (2012). Additionally, the results indicate that scientific literacy development is complex as shorter measurements (i.e. 10-weeks) are insufficient where learning requires extended periods of time and continuous interventions to manifest significant changes (Bandura, 1997).

Science and Chemistry Identity

Despite no significant changes in science identity, science identity scores were higher than chemistry identity scores from students. In particular, these lower chemistry identity scores had significant changes between testing which implies students' chemistry identities are less stable than their science identities in this chemistry context. Findings on chemistry identity within demographic groups highlights how White students had significant changes in identity between the pretest (M=5.0, SD=2.3) and posttest (M=5.3, SD=2.3). Despite the small study period, White students had transformative chemistry identity scores indicating that there is a difference in science experiences between White students and BIPOC students. However, BIPOC students had higher chemistry identity scores in the pretest (M=5.4, SD=2.4) and posttest (M=5.5, SD=2.2) than White students, although this difference between demographic groups were not significant. This differs from other studies that revealed that BIPOC students identified less strongly as science persons than their White peers (Carlone and Johnson, 2007; Chang et al., 2011; Hazari et al., 2013b). However, the significant increases in chemistry identity for White students in comparison to BIPOC students implies that there are disparities in chemistry identity where STEM spaces are consistently more supportive of White students allowing for transformative opportunities with their science identities.

Scientific Literacy and Identity

In our examination of the nexus between scientific literacy skills and identity, there were weak, positive correlations with science and chemistry identity that suggests that learning functions as a skill building and identity development process. These findings support the view that there is a significant relationship between scientific literacy and identity as reported by Lucas (2020). By fostering scientific literacy skills in students, students are strengthening their capabilities of making scientific knowledge useful and usable in everyday life to make informed decisions and in turn students are developing a greater science identity.

Recommendations

1. A longitudinal study in general science education courses, such as the general chemistry series, would provide greater insight into how students' scientific literacy skills change over time. A longitudinal study would also help us to better understand the relationship between science literacy and science identity. Therefore, a longitudinal study is important for future research into the relationship between scientific literacy and science (chemistry) identity. Additionally, a longitudinal study would be beneficial for further statistical analysis on scientific literacy and science (chemistry) identity broadly to account for filtering effects from clearing data.
2. Chemistry curricula should reassess the interdisciplinary connection between chemistry and other science disciplines to foster science identity work that is transformative of science and chemistry identities.

Limitations

Due to the nature of survey-based studies, our main study faced limitations such as the inability to follow-up with students for additional insights to their scientific literacy, and science and chemistry identities. The findings of this study are limited i due to the study taking place at a single institution, Western Washington University, the results are limited in their applicability to a broader context at other institutions. Additionally, the sample population reflects homogeneity in terms of demographic data such as majors and race/ethnicity where these results may not be applicable to more diverse populations at other institutions. As such, we can generalize the changes and relationship of scientific literacy, and science and chemistry identity in general chemistry students at Western Washington University.

This study was limited by the 10-week quarter study period for the pretest and posttest. The findings revealed that the 10-week study period was not a sufficient amount of time to measure significant changes in students' scientific literacy skills as these skills are developed over at least 16-weeks (Gormally et al., 2012). As such, this limited the opportunity for significant changes in scientific literacy skills in the study. Previous studies have used single measurements of scientific literacy skills (Waldo, 2014; Shaffer et al., 2019) and pretest-posttest measurements on study periods of 16-weeks or greater (Gormally et al., 2012; Nuhfer et al., 2016; Auerbach and Schussler, 2017), but Western Washington University has a quarter system resulting in the 10-week study period. Although there were no significant changes in scientific literacy skills within our study period, the study indicated that significant changes in scientific literacy skills are achievable over a minimum of 16-weeks as shown by Gormally et al. (2012).

Additionally, the pretest posttest design was a limitation that despite the significant findings, did present some limitations that can affect our findings. There were students from upper division chemistry courses that were excluded due to insufficient numbers for rigorous statistical analyses that further limits the applicability of the findings to upper division students further in their academic careers. However, the focus of the study was students in the general chemistry series that provides valuable information to scientific literacy and science (chemistry) identity in the early stages of academic careers. Students were excluded from the main study due to complications from the pretest posttest design such as non-matching student responses alongside incomplete or duplicate responses which further limited the sample size of the main study. This cleaning of the data for the pretest-posttest design presents the potential for filtering effects in the general chemistry series course analysis.

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Appendices

Appendix A. Science Literacy and Identity survey.

Section I.

What is your name?

What is your WWU email?

Which of the following best describes you? You may choose more than one.

1. American Indian or Alaska Native
2. Asian
3. Black or African American
4. Hispanic
5. Native Hawaiian or Other Pacific Islander
6. White
7. I prefer not to answer

Which year are you in?

1. 1st year
2. 2nd year
3. 3rd year
4. 4th year
5. 5th year or more

What is your major or intended major?

What are some previous courses you have taken in the College of Science and Engineering (include department and course number, e.g. CHEM 161)?

1. Advanced Material Science & Engineering (AMSEC)
2. Biology
3. Chemistry
4. Computer Science
5. Engineering & Design
6. Geology
7. Mathematics
8. Physics & Astronomy
9. Science, Mathematics, and Technology Education (SMATE)

Section II.

To what extent do you see yourself as a science person? (0 = Not at all, 10 = Totally).

To what extent do you see yourself as a chemistry person? (0 = Not at all, 10 = Totally).

(Adapted from Hazari et al., 2010.)

Section III.

Which of the following is a valid scientific argument?

1. Measurements of sea level on the Gulf Coast taken this year are lower than normal; the average monthly measurements were almost 0.1 cm lower than normal in some areas. These facts prove that sea level rise is not a problem.
2. A strain of mice was genetically engineered to lack a certain gene, and the mice were unable to reproduce. Introduction of the gene back into the mutant mice restored their ability to reproduce. These facts indicate that the gene is essential for mouse reproduction.
3. A poll revealed that 34% of Americans believe that dinosaurs and early humans co-existed because fossil footprints of each species were found in the same location. This widespread belief is appropriate evidence to support the claim that humans did not evolve from ape ancestors.

4. This winter, the northeastern US received record amounts of snowfall, and the average monthly temperatures were more than 2°F lower than normal in some areas. These facts indicate that climate change is occurring.

While growing vegetables in your backyard, you noticed a particular kind of insect eating your plants. You took a rough count (see data below) of the insect population over time. Which graph shows the best representation of your data?

1. A
2. B
3. C
4. D

A study about life expectancy was conducted using a random sample of 1,000 participants from the United States. In this sample, the average life expectancy was 80.1 years for females and 74.9 years for males. What is one way that you can **increase your certainty** that women truly live longer than men in the United States' general population?

1. Subtract the average male life expectancy from the average female expectancy. If the value is positive, females live longer.
2. Conduct a statistical analysis to determine if females live significantly longer than males.
3. Graph the mean (average) life expectancy values of females and males and visually analyze the data.
4. There is no way to increase your certainty that there is a difference between sexes.

Which of the following research studies is **least likely** to contain a confounding factor (variable that provides an alternative explanation for results) in its design?

1. Researchers randomly assign participants to experimental and control groups. Females make up 35% of the experimental group and 75% of the control group.
2. To explore trends in the spiritual/religious beliefs of students attending U.S. universities
3. To evaluate the effect of a new diet program, researchers compare weight loss between participants randomly assigned to treatment (diet) and control (no diet) groups, while controlling for average daily exercise and pre-diet weight.
4. Researchers tested the effectiveness of a new tree fertilizer on 10,000 saplings. Saplings in the control group (no fertilizer) were tested in the fall, whereas the treatment group (fertilizer) were tested the following spring.

Which of the following actions is a valid scientific course of action?

1. A government agency relies heavily on two industry-funded studies in declaring a chemical found in plastics safe for humans, while ignoring studies linking the chemical with adverse health effects.
2. Journalists give equal credibility to both sides of a scientific story, even though one side has been disproven by many experiments.
3. A government agency decides to alter public health messages about breast-feeding in response to pressure from a council of businesses involved in manufacturing infant formula.
4. Several research studies have found a new drug to be effective for treating the symptoms of autism; however, a government agency refuses to approve the drug until long term effects are known.

The following graph appeared in a scientific article about the effects of pesticides on tadpoles in their natural environment. When beetles were introduced as predators to the Leopard frog tadpoles, and the pesticide Malathion was added, the results were unusual. Which of the following is a plausible hypothesis to explain these results?

1. The Malathion killed the tadpoles, causing the beetles to be hungrier and eat more tadpoles.
2. The Malathion killed the tadpoles, so the beetles had more food and their population increased.
3. The Malathion killed the beetles, causing fewer tadpoles to be eaten.
4. The Malathion killed the beetles, causing the tadpole population to prey on each other.

Which of the following is the **best** interpretation of the graph below?

1. Type “A” mice with Lymphoma were more common than type “A” mice with no tumors.
2. Type “B” mice were more likely to have tumors than type “A” mice.
3. Lymphoma was equally common among type “A” and type “B” mice.
4. Carcinoma was less common than Lymphoma only in type “B” mice.

Creators of the Shake Weight, a moving dumbbell, claim that their product can produce “incredible strength!” Which of the additional information below would provide the **strongest evidence** supporting the effectiveness of the Shake Weight for increasing muscle strength?

1. Survey data indicates that on average, users of the Shake Weight report working out with the product 6 days per week, whereas users of standard dumbbells report working out 3 days per week.
2. Compared to a resting state, users of the Shake Weight had a 300% increase in blood flow to their muscles when using the product.
3. Survey data indicates that users of the Shake Weight reported significantly greater muscle tone compared to users of standard dumbbells.
4. Compared to users of standard dumbbells, users of the Shake Weight were able to lift weights that were significantly heavier at the end of an 8-week trial.

Which of the following is **not** an example of an appropriate use of science?

1. A group of scientists who were asked to review grant proposals based their funding recommendations on the researcher's experience, project plans, and preliminary data from the research proposals submitted.
2. Scientists are selected to help conduct a government-sponsored research study on global climate change based on their political beliefs.
3. The Fish & Wildlife Service reviews its list of protected and endangered species in response to new research findings.
4. The Senate stops funding a widely used sex-education program after studies show limited effectiveness of the program.

Your interest is piqued by a story about human pheromones on the news. A Google search leads you to the following website:
For this website (Eros Foundation), which of the following characteristics is **most important** in your confidence that the resource is accurate or not.

1. The resource may not be accurate, because appropriate references are not provided.
2. The resource may not be accurate, because the purpose of the site is to advertise a product.
3. The resource is likely accurate, because appropriate references are provided.
4. The resource is likely accurate, because the website's author is reputable.

Use the excerpt below (modified from a recent news report on MSNBC.com) for the next few questions.

"A recent study, following more than 2,500 New Yorkers for 9+ years, found that people who drank diet soda every day had a 61% higher risk of vascular events, including stroke and heart attack, compared to those who avoided diet drinks. For this study, Hannah Gardner's research team randomly surveyed 2,564 New Yorkers about their eating behaviors, exercise habits, as well as cigarette and alcohol consumption. Participants were also given physical check-ups, including blood pressure measurements and blood tests for cholesterol and other factors that might affect the risk for heart attack and stroke. The increased likelihood of vascular events remained even after Gardener and her colleagues accounted for risk factors, such as smoking, high blood pressure and high cholesterol levels. The researchers found no increased risk among people who drank regular soda."

The findings of this study suggest that consuming diet soda might lead to increased risk for heart attacks and strokes. From the statements below, identify **additional evidence that supports** this claim:

1. Findings from an epidemiological study suggest that NYC residents are 6.8 times more likely to die of vascular-related diseases compared to people living in other U.S. cities.
2. Results from an experimental study demonstrated that individuals randomly assigned to consume one diet soda each day were twice as likely to have a stroke compared to those assigned to drink one regular soda each day.
3. Animal studies suggest a link between vascular disease and consumption of caramel-containing products (ingredient that gives sodas their dark color).
4. Survey results indicate that people who drink one or more diet soda each day smoke more frequently than people who drink no diet soda, leading to increases in vascular events.

The excerpt above comes from what type of source of information?

1. Primary (Research studies performed, written and then submitted for peer-review to a scientific journal.)

2. Secondary (Reviews of several research studies written up as a summary article with references that are submitted to a scientific journal.)
3. Tertiary (Media reports, encyclopedia entries or documents published by government agencies.)
4. None of the above.

The lead researcher was quoted as saying, “I think diet soda drinkers need to stay tuned, but I don’t think that anyone should change their behaviors quite yet.” Why didn’t she warn people to stop drinking diet soda right away?

1. The results should be replicated with a sample more representative of the U.S. population.
2. There may be significant confounds present (alternative explanations for the relationship between diet sodas and vascular disease).
3. Subjects were not randomly assigned to treatment and control groups.
4. All of the above.

Which of the following attributes is **<u>not</u>** a strength of the study’s research design?

1. Collecting data from a large sample size.
2. Randomly sampling NYC residents.
3. Randomly assigning participants to control and experimental groups.
4. All of the above.

Researchers found that chronically stressed individuals have significantly higher blood pressure compared to individuals with little stress. Which graph would be most appropriate for displaying the mean (average) blood pressure scores for high-stress and low-stress groups of people?

1. A
2. B
3. C
4. D

Energy efficiency of houses depends on the construction materials used and how they are suited to different climates. Data was collected about the types of building materials used in house construction (results shown below). Stone houses are more energy efficient, but to determine if that efficiency depends on roof style, data was also collected on the percentage of stone houses that had either shingles or a metal roof.

What proportion of houses were constructed of a stone base with a shingled roof?

5. 25%
6. 36%
7. 48%
8. Cannot be calculated without knowing the original number of survey participants.

The **<u>most important</u>** factor influencing you to categorize a research article as trustworthy science is:

9. the presence of data or graphs
10. the article was evaluated by unbiased third-party experts

11. the reputation of the researchers
12. the publisher of the article

Which of the following is the **most accurate** conclusion you can make from the data in this graph?

1. The largest increase in meat consumption has occurred in the past 20 years.
2. Meat consumption has increased at a constant rate over the past 40 years.
3. Meat consumption doubles in developing countries every 20 years.
4. Meat consumption increases by 50% every 10 years.

Two studies estimate the mean caffeine content of an energy drink. Each study uses the same test on a random sample of the energy drink. Study 1 uses 25 bottles, and study 2 uses 100 bottles. Which statement is true?

1. The estimate of the actual mean caffeine content from each study will be equally uncertain.
2. The uncertainty in the estimate of the actual mean caffeine content will be smaller in study 1 than in study 2.
3. The uncertainty in the estimate of the actual mean caffeine content will be larger in study 1 than in study 2.
4. None of the above.

A hurricane wiped out 40% of the wild rats in a coastal city. Then, a disease spread through stagnant water killing 20% of the rats that survived the hurricane. What percentage of the original population of rats is left after these 2 events?

1. 40%
2. 48%
3. 60%
4. Cannot be calculated without knowing the original number of rats.

A videogame enthusiast argued that playing violent video games (e.g., Doom, Grand Theft Auto) does not cause increases in violent crimes as critics often claim. To support his argument, he presents the graph below. He points out that the rate of violent crimes has decreased dramatically, beginning around the time the first “moderately violent” video game, Doom, was introduced.

Considering the information presented in this graph, what is the **most critical flaw** in the blogger’s argument?

1. Violent crime rates appear to increase slightly after the introduction of the Intellivision and SNES game systems.
2. The graph does not show violent crime rates for children under the age of 12, so results are biased.
3. The decreasing trend in violent crime rates may be caused by something other than violent video games.
4. The graph only shows data up to 2003. More current data are needed.

Your doctor prescribed you a drug that is brand new. The drug has some significant side effects, so you do some research to determine the effectiveness of the new drug compared to similar drugs on the market. Which of the following sources would provide the **most accurate** information?

1. the drug manufacturer’s pamphlet/website
2. a special feature about the drug on the nightly news
3. a research study conducted by outside researchers
4. information from a trusted friend who has been taking the drug for six months

A gene test shows promising results in providing early detection for colon cancer. However, 5% of all test results are falsely positive; that is, results indicate that cancer is present when the patient is, in fact, cancer-free. Given this false positive rate, how many people out of 10,000 would have a false positive result and be alarmed unnecessarily?

1. 5
2. 35
3. 50
4. 500

Why do researchers use statistics to draw conclusions about their data?

1. Researchers usually collect data (information) about everyone/everything in the population.
2. The public is easily persuaded by numbers and statistics.
3. The true answers to researchers’ questions can only be revealed through statistical analyses.
4. Researchers are making inferences about a population using estimates from a smaller sample.

A researcher hypothesizes that immunizations containing traces of mercury **do not** cause autism in children. Which of the following data provides the **strongest** test of this hypothesis?

1. a count of the number of children who were immunized and have autism
2. yearly screening data on autism symptoms for immunized and non-immunized children from birth to age 12
3. mean (average) rate of autism for children born in the United States
4. mean (average) blood mercury concentration in children with autism

You’ve been doing research to help your grandmother understand two new drugs for osteoporosis. One publication, Eurasian Journal of Bone and Joint Medicine, contains articles with data only showing the effectiveness of one of these new drugs. A pharmaceutical company funded the Eurasian Journal of Bone and Joint Medicine production and most advertisements in the journal are for this company’s products. In your searches, you find other articles that show the same drug has only limited effectiveness.

Pick the **best** answer that would help you decide about the credibility of the Eurasian Journal of Bone and Joint Medicine:

1. It is not a credible source of scientific research because there were advertisements within the journal.
2. It is a credible source of scientific research because the publication lists reviewers with appropriate credentials who evaluated the quality of the research articles prior to publication.
3. It is not a credible source of scientific research because only studies showing the effectiveness of the company’s drugs were included in the journal.

4. It is a credible source of scientific research because the studies published in the journal were later replicated by other researchers

Which of the following actions is a valid scientific course of action?

1. A scientific journal rejects a study because the results provide evidence against a widely accepted model.
2. The scientific journal, Science, retracts a published article after discovering that the researcher misrepresented the data.
3. A researcher distributes free samples of a new drug that she is developing to patients in need.
4. A senior scientist encourages his graduate student to publish a study containing ground-breaking findings that cannot be verified.

Researchers interested in the relation between River Shrimp (Macrobrachium) abundance and pool site elevation, presented the data in the graph below. Interestingly, the researchers also noted that water pools tended to be shallower at higher elevations.

Which of the following is a plausible hypothesis to explain the results presented in the graph?

1. There are more water pools at elevations above 340 meters because it rains more frequently in higher elevations.
2. River shrimp are more abundant in lower elevations because pools at these sites tend to be deeper.
3. This graph cannot be interpreted due to an outlying data point.
4. As elevation increases, shrimp abundance increases because they have fewer predators at higher elevations.

(Gormally et al., 2012).

Appendix B. Supplementary Tables.

Table 17. One-way ANCOVA results on scientific literacy skills within demographic groups.

Scientific Literacy Skills						
Group	**Source**	**SS**	**df**	**MS**	**F**	**Sig.**
Major						
	Pretest	2909.607	1	2909.607	151.601	< 0.001
	Group	27.793	1	27.793	1.448	0.230
	Error	3416.277	178	19.193		
	Total	74387.595	181			
Class standing						
	Pretest	2992.965	1	2992.965	154.711	< 0.001
	Group	0.556	1	0.556	0.029	0.866
	Error	3443.514	178	19.346		
	Total	74387.595	181			
Race/ethnicity						
	Pretest	2756.924	1	2756.924	143.075	< 0.001
	Group	14.185	1	14.185	0.736	0.392
	Error	3429.886	178	19.269		
	Total	74387.595	181			
Course						
	Pretest	2720.738	1	2720.738	142.917	< 0.001
	Group	74.479	2	37.240	1.956	0.144
	Error	3369.591	177	19.037		
	Total	74387.595	181			

SS sum of squares, df degrees of freedom, MS mean square

Table 18. One-way ANCOVA results on science identity within demographic groups.

Science Identity						
Group	**Source**	**SS**	**df**	**MS**	**F**	**Sig.**
Major						
	Pretest	333.797	1	333.797	243.579	< 0.001
	Group	2.132	1	2.132	1.556	0.214
	Error	243.929	178	1.370		
	Total	10420.000	181			
Class standing						
	Pretest	341.584	1	341.584	248.453	< 0.001
	Group	1.338	1	1.338	0.973	0.325
	Error	244.723	178	1.375		
	Total	10420.000	181			
Race/ethnicity						
	Pretest	342.580	1	342.580	248.669	< 0.001
	Group	0.838	1	0.838	0.608	0.437
	Error	245.223	178	1.378		
	Total	10420.000	181			
Course						
	Pretest	320.385	1	320.385	230.590	< 0.001
	Group	0.135	2	0.067	0.048	0.953
	Error	245.926	177	1.389		
	Total	10420.000	181			

SS sum of squares, df degrees of freedom, MS mean square

Table 19. One-way ANCOVA results on chemistry identity within demographic groups.

Chemistry Identity						
Group	**Source**	**SS**	**df**	**MS**	**F**	**Sig.**
Major						
	Pretest	599.100	1	599.100	326.356	< 0.001
	Group	0.737	1	0.737	0.402	0.527
	Error	326.759	178	1.836		
	Total	6068.000	181			
Class standing						
	Pretest	596.743	1	596.743	325.558	< 0.001
	Group	1.225	1	1.225	0.668	0.415
	Error	326.272	178	1.833		
	Total	6068.000	181			
Race/ethnicity						
	Pretest	604.359	1	604.359	328.621	< 0.001
	Group	0.141	1	0.141	0.077	0.782
	Error	327.356	178	1.839		
	Total	6068.000	181			
Course						
	Pretest	566.629	1	566.629	313.083	< 0.001
	Group	7.155	2	3.578	1.977	0.142
	Error	320.341	177	1.810		
	Total	6068.000	181			

SS sum of squares, df degrees of freedom, MS mean square

Table 20. Demographic groups by course.

Group		Sample Size
CHEM 161		47
Major	Science	29
	Non-science	18
Class standing	Freshmen	32
	Sophomore or higher	15
Race/ethnicity	BIPOC	11
	White	36
CHEM 162		111
Major	Science	76
	Non-science	35
Class standing	Freshmen	60
	Sophomore or higher	51
Race/ethnicity	BIPOC	31
	White	80
CHEM 163		23
Major	Science	18
	Non-Science	5
Class standing	Freshmen	13
	Sophomore or higher	10
Race/ethnicity	BIPOC	3
	White	20