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Developing Scientific Literacy to Promote 21st-Century Skills in Students

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DEVELOPING SCIENTIFIC LITERACY TO PROMOTE 21ST-CENTURY SKILLS IN STUDENTS

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Abstract

Scientific literacy and 21st-century skills are two skill sets that can equip students to handle the demands of the modern world. Scientific literacy is knowing the science content, understanding the methods and procedures scientists use, and being able to apply that knowledge to everyday life as citizens. This literature review examined methods to increase scientific literacy in the classroom through vocabulary instruction to increase content knowledge, scientific reading comprehension and writing skills, analyzing and interpreting data, engaging students in argumentation, and teaching through socio-scientific issues. Twenty-first-century skills are skills students need to gain to succeed in this technological age. This literature review also examined several strategies to promote 21st-century skills in a science classroom. Many of the strategies to increase scientific literacy also promote 21st-century skills. To prepare students to be part of an innovative society and workforce, one must incorporate both skill sets in the science classroom.

Keywords: Scientific literacy, 21st-century skills, vocabulary instruction, argumentation, graphing skills

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Chapter I: Introduction

Introduction

When entering a science content classroom, one is immersed in a new world filled with unique language, discourse, and visual representations of content. Scientific vocabulary is highly specialized, and it is vital that educators continuously strive to assist students in the acquisition and use of this unique language. Information is often presented visually through tables, charts, and specialized symbols and notions. This presentation can be very different from what students experience in other educational settings; therefore, teachers must help students interpret this information to understand the content better.

Having students know and understand the content before departing the science classroom has always been a goal of educators. However, there has been a shift in focus from content memorization to scientific literacy, where students use their scientific knowledge as a way of understanding and reasoning to support decision-making skills and roles in society (Dani, 2009). Scientific literacy plays a role in people's navigation and understanding of the world around them (NGSS, n.d.).

The term scientific literacy was first introduced in the 1950s by Paul Dehart Hurd (Hurd, 1958). Hurd pushed for changes to the science curriculum in the United States (US) for students to use scientific methods, apply them to their own life, and appreciate science's intellectual achievements and human endeavors (Hurd, 1958). Despite this call to action in the 1950s and the rapidly changing scientific landscape of the past six decades, scientific literacy has not been fully integrated into the general science curriculum. Instead, some individuals learn their scientific knowledge from uncredible sources that utilize poor scientific methods to obtain the desired results or from outdated and retracted studies. Scientific literacy must be a skill that educators expect of students as they step out of the classroom and into the real world to begin contributing to and participating in society.

The creation of the Next Generation Science Standards (NGSS) was in response to the need to broaden the expectations of students that exit a science classroom (NGSS, n.d.). These standards were rich in content and practice and supported students in becoming future innovators and leaders in this complex world (NGSS, n.d.). The NGSSs have three dimensions of science learning: crosscutting concepts across the different domains of science, the practice of scientists and engineering design, and disciplinary core ideas. Not all states have adopted the NGSSs, resulting in some states' standards not containing a link to scientific literacy. Even without scientific literacy being present in the standards, many instructional strategies to teach the content may also increase scientific literacy.

In addition to being scientifically literate, 21st-century skills have been identified and defined as a way to be successful in the modern world, where knowledge is quickly accessible through the internet (Stauffer, 2022). Stauffer (2022) has grouped 21st-century skills into three categories: learning, literacy, and life skills. The learning skills include critical thinking, creativity, collaboration, and communication. These skills help students understand the mental processes required by a modern work environment. Literacy skills help students with digital comprehension. Information literacy involves discerning fact from fiction, media literacy is understanding the media's role in how individuals receive information, and technology literacy is grasping the technology that continues to impact the world around them. Being technologically literate means the knowledge of the tools that run this world is in the student's hands. Finally, life skills aim to develop personal and professional qualities students need to embody. This last group of skills includes flexibility, leadership, initiative, productivity, and social skills.

Rationale

Research has found that scientifically literate students can better avoid misinformation and unwarranted beliefs, which is reason enough to teach scientific literacy in a classroom (Fasce & Picó, 2019; Howell & Brossard, 2021). Scientific literacy encompasses many skills and abilities and teachers must use various instructional strategies to teach these skills and abilities. These strategies should be looked at critically to ensure that the application and frequency are appropriate for the grade level and instructional goals.

First and foremost, being scientifically literate is rooted in knowing the content. Learning the content is hindered without a mastery of academic language; therefore, teachers must utilize varied and highly effective language acquisition techniques (Hayden et al., 2020). Although fundamental reading comprehension skills impact scientific literacy, teachers may need to implement different approaches to reading and writing within the scientific discipline (Shaffer et al., 2019). Graphs, charts, and tables frequently convey scientific information; however, the media can manipulate these visual representations to show a specific angle or promote a narrative. Therefore, students need tools to decode the information to enhance scientific literacy. Understanding that science is a way of thinking and processing information should come from engaging in the same methods scientists use, which can come from practicing argumentation (Chen, 2019). Scientific literacy is also knowing that science plays many roles in society and using a socio-scientific issue, such as climate change, can allow students to connect their scientific knowledge to larger social contexts (Ke et al., 2021). There must be further exploration of the teaching strategies that address these aspects of scientific literacy to ensure that students are equipped with the knowledge to be exceptional citizens.

Twenty-first-century skills help students keep up with and adapt to the quickly changing modern world and help them solve the problems of tomorrow. Many skills, such as collaboration, initiative, and flexibility, do not come naturally to students and must be taught in the classroom. Teachers will inevitably push students to step out of their comfort zones to obtain these skills. Students who graduate from the educational system become integral to the workforce. Companies need flexible workers willing to adapt when new methodologies and ideas arise in the industry. If a company falls behind because of a lack of adaptation or resistance to change, the company becomes obsolete (Stauffer, 2022). The future of the US economy depends on individuals having the technological knowledge and scientific skills needed to thrive in the 21st century. Finding ways to enhance 21st-century skills in the classroom is a must if the US wants to continue being an economic powerhouse in the future (Amadi, in press).

Scientific literacy and 21st-century skills aim to prepare students for the future, but it is unknown to what degree these skills overlap. This literature review examines the strategies implemented in a science classroom to increase the various aspects of scientific literacy and determine if those techniques also promote 21st-century skills. Strategies to promote 21st-century skills that can be implemented in a science classroom will also be examined. The ultimate goal of implementing these strategies is to prepare students to be innovative participants in this country's workforce and active citizens.

Definitions of Terms

Important terminology used in this paper is defined as follows:

Argumentation: An aspect of scientific discourse which can lead to new scientific understanding. Individuals use arguments to form reasons and justify claims with evidence, which can develop an understanding of content (Cavagnetto, 2010).

Critical thinking: The process of making a logical decision about the truth of a statement after the information is analyzed (Oxford English Dictionary, n.d.).

Discourse: The specific way that individuals in a discipline communicate using verbal and written language and visual representations to participate in knowledge construction (Lynch, 2013).

Instructional strategy: A technique that a teacher uses to help students learn the content with the goal of creating independent learners (Moore, 2019).

Scientific literacy: Knowing scientific facts, processes, ways of thinking, representations of knowledge, and how those can influence an individual's decision-making and participation in society (Dani, 2009).

Socio-scientific issue: A social issue with connection to science and technology. (Cavagnetto, 2010).

Statistical significance: The results from a given study are large enough to represent a meaningful difference and that the difference is not likely caused by chance (Mertler, 2019).

Twenty-first-century skills: The skills and abilities that students must acquire to be successful in the workforce during this century. Twelve skills fall into the learning skills, literacy skills, or life skills category (Stauffer, 2022).

Statement of the Question.

The guiding question of this literature review is: How can the development of scientific literacy skills promote 21st-century skills?

Chapter II: Literature Review

Incorporating methods to increase scientific literacy in the science classroom is part of a well-rounded curriculum. In this chapter, scientific literacy will be defined and methods to increase scientific literacy will be examined in the following categories: vocabulary instruction, reading and writing, analyzing and interpreting data, argumentation, and teaching through socio-scientific issues. Then, 21st-century skills will be defined along with a discussion of ways to increase and support the development of 21st-century skills in the classroom.

Scientific Literacy

Scientific literacy is crucial for making sense of an evolving, complex, and technology-based world (NGSS, n.d.). America's future ability to innovate and create jobs is rooted in science; therefore, scientific literacy should be a continuous focus in the classroom. Dani (2009) sought to define the many components and aspects of scientific literacy. While there must be a base level of knowledge about science facts, principles, and concepts, scientific literacy is also about putting into practice the investigative nature of science by using its unique processes and methods, including communicating through various means. Additionally, scientific literacy means understanding how science is a way of knowing, thinking, reasoning, and reflecting. All of these aspects contribute to the last part of scientific literacy, which is understanding the impact that science has on society including careers, science-related social issues, and using science in one's personal life to make decisions (Dani, 2009). A common theme that arises through various definitions of scientific literacy is "that students should be able to apply scientific concepts to analyze data and evaluate claims about the world around them" (Shaffer et al., 2019, p. 2).

Howell and Brossard (2021) sought to identify ways that scientific literacy could help battle misinformation. Howell and Brossard (2021) believed that being scientifically literate would help individuals feel empowered to find and use trustworthy scientific information to make informed decisions as citizens and in everyday life. Howell and Brossard (2021) identified three aspects of scientific literacy: civic science literacy, digital media science literacy, and cognitive science literacy. Civic science literacy involves knowing the procedures and processes of producing scientific knowledge. Digital media science literacy is being able to evaluate the media sources that one gets scientific information. Cognitive science literacy involves metacognition and being aware of one's own biases while evaluating scientific information and media.

Howell and Brossard (2021) listed potential outcomes of being a scientifically literate individual, utilizing the three aspects outlined above. Scientifically literate individuals should have an understanding of the bounds and potential of science. They will likely be able to avoid misinformation about a single study's power and understand what it means when retraction of a study occurs. Scientific literacy skills will help individuals understand how slowly science moves and that answers can evolve and change over time as scientists seek to find better and more accurate results. Scientifically literate individuals should understand the types of questions that science can answer. These outcomes show the importance of cultivating scientific literacy throughout a student's educational career. Teachers must teach students that science is a way of understanding the world and that there is a distinct way of acquiring knowledge (Howell & Brossard, 2021).

Being scientifically literate has far-reaching impacts in today's world. Fasce and Picó (2019) explored the relationship between scientific literacy and unwarranted beliefs to see if scientific knowledge and literacy could eradicate the unwarranted beliefs of paranormal, pseudoscience, and conspiracy theories. An unwarranted belief does not have a "set of reliable reasons to believe in it" and can negatively affect health, education, and public policies (Fasce & Picó, 2019, p. 111). Paranormal phenomena are believed to be outside the domain of science and the phenomena must be investigated using alternative methods. Pseudoscience is presented as scientific knowledge while containing non-scientific processes, a lack of evidence, and often uses deficient or out-of-date methods to come to conclusions. A conspiracy theory generally contains beliefs that some group concealed the actual cause of an event from the public.

Fasce and Picó (2019) recruited 199 female and 91 male undergraduate students in Spain. Religious and political affiliations were as follows: 123 students identified as religious, 167 were non-religious, 127 were right-wing voters, and 163 were left-wing voters. Once the data was collected, no significant differences between these three subgroups arose. Researchers used nine surveys along with pre-university and average university scores to determine if there was any relationship among any of these variables. Unwarranted beliefs were measured using the Revised Paranormal Belief Scale, the Generic Conspiracy Ideation Scale, and the Pseudoscientific Belief Scale. A student’s domain knowledge, level of trust in science, critical thinking skills, and application of critical thinking were measured using surveys to determine scientific literacy. Other predictors of unwarranted beliefs, including faith in intuition and ontological confusion, were also measured.

Fasce and Picó (2019) found positive correlations among scientific knowledge, trust in science, and critical thinking. The survey that measured science domain knowledge was a good predictor for pseudoscience and the paranormal, indicating that increasing knowledge protects against these beliefs. Scientific knowledge did not interact with conspiracy theories, but trust in science did. However, one cannot determine from this study if those that believe in conspiracy theories have a specific mistrust of science or if it is a general mistrust (Fasce & Picó, 2019). Overall, scientific literacy negatively predicted pseudoscientific and paranormal beliefs. Fasce and Picó (2019) used this study to call on educators to implement research-based methods in the classroom to cultivate more trust in science and other scientific habits to protect students from unwarranted beliefs. Since scientific literacy is crucial the following five methods will be discussed to build scientific literacy: vocabulary instruction, reading and writing, analyzing and interpreting data, argumentation, and teaching socio-scientific issues.

Building Scientific Literacy through Vocabulary Instruction

Harper's (2018) study examined and evaluated vocabulary instructional strategies within a middle school science classroom to determine the most effective strategy and the role reflective teaching has on a student's metacognition in science vocabulary comprehension. Harper selected three sixth-grade students to participate in this study, with one student at grade-level, one below, and one above grade-level reading. The Star Reading assessment determined the grade-level reading status.

Vocabulary instructional strategies included the four-square model (a modified version of the Frayer Model), diagrams, and word sorts. Harper collected pre- and post-vocabulary assessments, exit cards, student interviews, and notes from a teacher-reflective journal to determine student growth. The data were evaluated for student growth to determine instructional strategy effectiveness and drive teaching points for the next lesson. Data analysis found these themes: the importance of using both written and visual ways to represent vocabulary, repetition, review, and manipulation (Harper, 2018). When students were engaging in written vocabulary instruction, students wrote in science journals, making it easier for them to reference later. Repetition and review in various formats were helpful in students' understanding of the vocabulary. Not only were vocabulary games used to increase student engagement while varying word exposure, but opportunities for students to write and verbally process the information were also incorporated. Lastly, infusing manipulation and demonstrations into the lessons allowed students to see why different terms were needed to describe the natural phenomenon, highlighting vocabulary's role in engaging in scientific discourse. These tactics proved effective as there was an increase in student growth.

Townsend et al. (2018) also studied vocabulary learning and included multimodal instruction to determine effective methods for supporting students in using and accessing scientific vocabulary. This study's 59 middle school students came from one teacher's classroom. Researchers chose this teacher’s class because of the difficulty of scientific vocabulary, the teacher’s favorability among the students, and that the class was a full academic year in length. Students took two tests, one in the fall and the one in the spring of the school year. The first test focused on 20 general academic words, while the second focused on how well students could use general and discipline-specific words (Townsend et al., 2018). Students were exposed to concepts repeatedly over the year through different approaches and modalities to gain a deeper conceptual understanding of the science. The teacher utilized repetition in the instruction, accountability, and guidance while ensuring a high level of engagement. These tactics resulted in statistically significant gains in the production of discipline-specific science words and in science writing from the fall to spring semesters.

Another approach to vocabulary instruction is combining the instruction with scientific discourse. The Hayden et al. (2020) study aimed to identify ways to facilitate science vocabulary learning through scientific discourse in a seventh-grade classroom. This study also examined improved methods to design and implement instruction and assessment to support scientific concepts and language. Two topics guided the research. The first was how a teacher selects science vocabulary and subsequent instructional activities. The second examined the usefulness of a pre-and post-assessment in determining science vocabulary learning through sentence writing (Hayden et al., 2020).

The teacher's journals were analyzed, noting when the teacher wrote about word selection and the instructional strategies used. Thirty-six vocabulary terms from a unit and 10 focus words for the semester were selected. Instructional strategies were collaborative and authentic to develop personal ownership of a word and often took the focus away from perfect spelling. Pre- and post-assessments had four questions per vocabulary word and researchers used a grading scale to evaluate each question. During the assessments, students expressed a baseline understanding of a word, chose a one-word then a sentence length definition of the word, and wrote a sentence containing the word (Hayden et al., 2020). Statistically significant improvements in vocabulary word knowledge arose over the semester. The assessments provided students with multiple ways to exhibit word knowledge. According to Hayden et al. (2020), it is important to provide ways for students to "demonstrate incremental and multidimensional understandings" to help them acquire deeper learning and ownership of the content (Hayden et al., 2020, p. 27).

It is vital to build the foundation of vocabulary acquisition in elementary school so students have the necessary tools to understand and decode more challenging content in higher grades. The Kim et al. study (2021) was a replication and extension of a previous efficacy study that showed positive effects of a content area literacy intervention in elementary schools. This intervention took place for first and second graders across 30 elementary schools. The need for literacy interventions to help students understand nonfiction texts that require background scientific knowledge is high since less than five percent of first and second graders have this skill. There has also been an increase in the gap in reading levels between high-and low-performing students in fourth grade (Kim et al., 2021). Building future college readiness occurs through the implementation of interventions during the early elementary years.

Throughout this intervention, teachers utilized thematic lessons that provided a framework for students to build networks of related science and social studies vocabulary while also learning the content. Teachers also implemented concept mapping and read-alouds to support students' vocabulary networks. Students with an extensive network of content-specific vocabulary can more efficiently extend knowledge when reading and writing about new topics. Kim et al. (2021) looked at students' argumentative writing and group work to see how students transferred knowledge to new contexts.

Twenty lessons, with two sections each, were taught over five to ten weeks. Section one focused on building content knowledge through interactive read-alouds of informational texts followed by a discussion and concept mapping. The second section focused on group research using text features to gain more information about the topic during reading and writing activities and participating in academic discussions while incorporating newly acquired knowledge (Kim et al., 2021).

Kim et al. (2021) used various tests to determine the impact the intervention had on content area literacy. A semantic association task, composed of taught and untaught words, determined a student's vocabulary knowledge depth. The Measure of Academic Progress Primary Grade Reading test determined the intervention's impacts on reading comprehension. To determine the impact on argumentative writing skills, students read a short text that provided background information, then answered an open-ended question. Researchers then used a claim-evidence-conclusion based rubric to score a student's response regarding the text. The intervention impacted vocabulary knowledge depth (ES = 0.50) and argumentative writing (ES = 0.24) in science. The previous study did show an impact on reading comprehension, but the replication of those results did not appear in this study.

Teachers should tailor the instructional strategy to the group of students in the classroom and the specific goals of the group. Kruawong and Soontornwipst (2021) desired to find practices or exercises to help students recall and recognize science vocabulary and increase the student's motivation for learning in English. Students involved in this study were second-semester ninth grade English as a Foreign Language (EFL) students at a public secondary school in Bangkok, where English was the language of instruction. Students had all been part of a program that used English as the medium of instruction for three years and had varying degrees of English proficiency. The study used science vocabulary crossword puzzles (SVCP) to see if there was an increase in an EFL student's science vocabulary knowledge.

Kruawong and Soontornwipst (2021) had students take pre- and post-test assessments to determine how well a student acquired vocabulary knowledge using the SVCP practices. The student scores after SVCP were higher at a statistically significant level, showing that this was a way to enhance a student's vocabulary knowledge. This strategy is not complex to design and implement, as many free resources will assist one in creating a crossword puzzle.

Responses to open-ended questions surrounding using SVCP to learn vocabulary were collected. Students believed that the crossword puzzles would only help with rote memorization, and found it difficult to link the vocabulary learning with the science content. However, vocabulary is the basis for content learning. Fisher and Frey (2014) would suggest continuing to provide opportunities for students to use the vocabulary words once the meaning is known to move past rote memorization.

The Helman et al. study (2022) focused on improving the science vocabulary of secondary English learners with reading disabilities. These individuals tend to score the lowest on achievement tests that assess language, and more tools are necessary to support them to prepare them for life outside the classroom. A generative vocabulary strategy helps students learn to use both contextual and linguistic cues to determine the meaning of unknown words. CLUES was the generative strategy used to determine how it might benefit students to define unfamiliar biological terms. The five steps of CLUES are: "connect to the text, label two clues, use the clues to define the word parts, explain the word, and see if you are correct" (Helman et al., p. 24).

The Helman et al. study (2022) measured the accuracy of learning the new science words and how well the students used the probe to arrive at a definition of a word. During the intervention period, students made significant gains in both aspects. Utilizing multiple vocabulary approaches, including morphemes and cognates, explicit instruction for both contextual and morphemic analysis allowed the students to pick up the strategy quickly, and CLUES being a mnemonic device, all contributed to those gains. Mnemonic devices have proven to be beneficial for students with learning difficulties. Despite maintaining knowledge of the CLUES probe two and four weeks after the initial intervention, a decrease in accuracy was seen, suggesting that frequent practice and exposure to the strategy is a must.

Building Scientific Literacy through Reading and Writing

Shaffer et al.'s (2019) study utilized a previously constructed scientific literacy test to determine what role fundamental literacy plays in a student's scientific literacy. The Test of Scientific Literacy Skills (TOSLS) is a validated assessment tool that assesses "students' proficiency in using scientific literacy skills to solve scenarios in and beyond the undergraduate biology classroom" (Gormally et al., 2012, p. 364). The TOSLS is a multiple-choice 28-item assessment given to a range of students in eight undergraduate science courses within the first week of class. The strongest predictor of TOSLS scores was Scholastic Aptitude Test (SAT) reading scores, followed by SAT math scores. The SAT reading section measures a student's ability to find evidence in a text, use context clues to determine the meaning of a word, and perform scientific analysis. The SAT reading passage also includes tables, graphs, charts, and two passages of expository scientific texts (College Board, 2022). The fact that SAT reading scores were the best predictor of TOSLS scores shows the influence of fundamental literacy skills on scientific literacy. Impacting a student's overall literacy by increasing reading frequency and the variety of texts will also impact a student’s scientific literacy.

Reading and comprehending scientific texts require a unique set of skills due to the many text features included in those texts. Content-specific vocabulary, graphs, charts, and tables convey information. Scientific metaphors are frequently found in the text to convey concepts that are impossible to see happening with a naked eye. The scientific metaphor is a powerful tool that links the unknown with a student's prior knowledge, providing the framework for building new knowledge. Scientific metaphors can reach a wide range of students and teach associated vocabulary through gestures and visual aids, including illustrations (Barnes & Oliveira, 2017). If students can detect and interpret the metaphor, scientific metaphor can lead to deeper scientific understanding. The Barnes and Oliveira study (2017) suggested using a whole-class read-aloud to help build knowledge of scientific metaphors. A read-aloud has many benefits, including impacts on vocabulary instruction and developing the skills to think and read like scientists. Teachers can scaffold students' understanding and help them ponder the scientific content during this time. Through a read-aloud, teachers can help students interpret how the information is presented, ask questions, and find meaning like scientists do (Barnes & Oliveira, 2017).

Another way to increase a student's reading comprehension is using the Touch-Talk-Text framework that Carrier et al. (2021) designed. The Touch-Talk-Text framework engages students in hands-on learning experiences and scientific discourse before reading a piece of scientific text. Through scientific discourse and argumentation, students can gain a deeper understanding of the material by elaborating on their thinking or supporting it with evidence (Carrier et al., 2021). *Touch* is the first part of this framework so that students can engage in science practice and have concrete examples that will help them gain more meaning from the eventual reading of the text. *Talk* helps build familiarity and facilitates a more substantial mastery of the language.

If the content knowledge is built and the language has been introduced beforehand students were better prepared to comprehend a scientific text. Using this framework gives students more opportunities to use precise scientific language and prepares them for comprehension. This framework may increase motivation for reading scientific texts, contributing to students' scientific literacy.

There can be many factors that contribute to a student's level of reading comprehension. Hwang and Duke (2020) examined how science content knowledge, reading motivation, and decoding skills impacted third-grade English learner (EL) students' reading comprehension skills. Previous studies on reading comprehension controlled language status, but Hwang and Duke sought to evaluate the data of EL and monolingual students separately. The study utilized the 1998-1999 Early Childhood Longitudinal Study-Kindergarten cohort data as it was a nationally representative data set that allowed for the examination of reading comprehension on its own.

Content knowledge had the highest standardized probit regression coefficient on reading comprehension for monolingual and EL students. Overall, monolingual students scored statistically significantly higher than EL students. However, content knowledge played a more prominent role in an EL student's score. Hwang and Duke (2020) suggest that the differences between monolingual and EL students could arise from the schools. Some schools may provide more opportunities to students to gain science content knowledge alongside more extensive reading comprehension instruction. Additionally, EL students tend to be pulled into special education at higher rates and may only receive limited science instruction. This study shows the importance of keeping EL students in the content classroom and suggests that educators rethink the timing of pulling an EL student for basic reading and language instruction (Hwang & Duke, 2020).

Decoding skills had the second-highest coefficient. Students who had obtained decoding skills by first grade had better reading comprehension than those who did not. Reading motivation coefficient was the smallest of the variables looked at, and the coefficients were similar for monolingual and EL students. To foster reading comprehension, one can support a student's motivation for reading (Hwang & Duke, 2020).

Writing can impact scientific literacy in many ways. Writing can be used to communicate information or as a tool for learning. There are many ways to help develop students writing skills, including having devoted time for writing, using it as a tool to learn content, frequent opportunities to write and share with classmates, and allowing teacher feedback (Lopas et al., 2021). While these are great strategies, Lopas et al. (2021) knew that including writing accommodations for English language learners (ELLs) and native English speakers further supports them in language acquisition and scientific writing for science content learning.

Lopas et al. (2021) focused on using writing to learn, which is a tool that allows students to use writing to work through and comprehend the content. As students learn the content and use the terms, students practice the skills to engage in scientific discourse and argumentation (Lopas et al., 2021). Lopas et al. provided examples of appropriate scaffolding to a fifth-grade lesson on animal adaptations. Modifications and scaffolding occurred during each step, including reduced work.

During the engage step, graphic organizers with sentence frames or prefilled bubbles were used to activate a student's prior knowledge. Before the explore step, the teacher modeled the creation of a quality written response while thinking aloud. The writing framework provided in the explain step can help a student create a topic sentence, use supporting evidence, and create a concluding sentence, ensuring that the necessary parts are included. English language learners utilized a writer's checklist to stay on topic, remain organized, and ensure that all expectations of the task were met. ELL students received a rubric that contained the assignment modifications. Having a rubric helps students understand what the teachers are evaluating them on. Writing accommodations ensure a more equitable learning environment for all students by providing a pathway to scientific literacy and learning while understanding the science concepts (Lopas et al., 2021).

When it comes to reading and writing scientific literature, students should be able to understand the specific aspects involved in creating the literature. Two crucial aspects include the peer review process and the use of references. Geithner and Pollastro (2016) defined peer review as a process that involves the evaluation of research findings based on quality, significance, and originality, done by experts in the field, and is necessary for progress in science. Scientific literacy can be enhanced through peer review as it engages students in science practices that revolve around reading and writing.

The Geithner and Pollastro study (2016) looked at peer review as a way to increase student perceptions of their abilities to read and understand literature through a critical lens, incorporate feedback from others into their work, and their sense of belonging to the scientific community. The study consisted of 51 undergraduate human physiology majors enrolled in a scientific writing course. Assignments for each topic covered in the course included one or more writing assignments and a peer review. Peer reviews included reading a published scientific article and other students' work. The final project was to peer review an entire article and then collaborate in a group to conclude whether or not the article should be recommended to an editor based on the strengths and weaknesses of the article.

Geithner and Pollastro (2016) had students evaluate their perceptions of their writing and scientific literacy skills using a survey that had a rating scale of one to five. The survey was given at the beginning and end of the course to determine whether the peer review process impacted student perceptions. There was a statistically significant improvement in the survey questions that asked about the abilities impacted by peer review. The survey item that saw the most remarkable change in student perception was a student's ability to read scientific literature critically. Through engaging in the peer review process, students' perceptions about their ability to work collaboratively increased along with their sense of belonging to the greater scientific community. This study took place at the undergraduate level. Therefore, adaptation for secondary-level education would be necessary, but the results are promising for peer review and writing to increase a student's scientific literacy.

An aspect of scientific literacy that must come into play when reading scientific literature is distinguishing between credible and non-credible sources (Rehorek & Dafoe, 2018). Rehorek and Dafoe (2018) looked into referencing as a way of teaching students to evaluate the validity of a piece of writing. A valid piece of writing contains correct references to previously published work. Teaching students about referencing is a relatively quick and straightforward way to teach about the validity of a piece of work that does not involve having to teach or understand the factual content of the paper (Rehorek & Dafoe, 2018).

Rehorek and Dafoe (2018) had 36 undergraduate students in an introductory biology course participate in the study. The study aimed to develop a methodology for teaching referencing and scientific literacy skills and to show that these skills could support student success. Students completed a two-part written assignment as part of the study. The first part involved them finding scientific works based on a vague title and keywords, then correctly referencing the work. The teacher taught about the differences between primary and secondary literature and the peer-review process before moving on to the second part. For the second part, students were given a secondary source of information and asked to find a related primary source and database article. Students then answered questions designed to help guide students in evaluating the credibility of the three sources. After completing that assignment, students wrote a scientific paper based on an in-class experiment and a literature review. The peer-review process was mimicked by having students submit drafts for feedback along the way.

Rehorek and Dafoe (2018) found statistically significant differences between pre-and post-test answers relating to formatting and peer review but did not find significant increases in scientific literacy. Students also answered questions about their confidence level on these topics using a ranking scale of one to five. Student confidence levels rose statistically significantly, even when statistically significant gains in knowledge were not seen.

Building Scientific Literacy through Analyzing and Interpreting Data

Another essential aspect of scientific literacy is graphing, analyzing, and interpreting data. These skills help students identify patterns, make predictions, use models, and ask questions. Graphing is a skill that does need to be explicitly taught and practiced to help students reach proficiency. To start, students should be comfortable with graph creation. The acronym

SULTAN (Scale, Unites, Labels, Title, Accuracy, Neatness) can help students remember the components of a graph to include (Riley & Biernat, 2018). Students can begin to analyze and interpret the data presented in the graph after reaching proficiency with graph creation.

Riley and Biernat (2018) utilized the Identify and Interpret Strategy from BSCS Science Learning (2012) to analyze and interpret a graph that compared the velocities of two cars. During the Identify step, students started with the sentence stem of "what I see" to make observations and note any changes or trends within the graph. For the process to seem less overwhelming, the teacher can break the graph down into sections and use guiding questions to have students slow down. When it comes to the Interpret step, students wrote a "what it means" statement for each "what I see" statement written in the previous step. Here teachers can scaffold questions to reach a wide range of learners. The last step of this framework was creating a caption for the graph, allowing students to summarize the observations made. Riley and Biernat (2018) also recommend guiding students to connect the independent and dependent variables within the caption. This framework can be applied to students' design work and allows them to provide evidence to explain phenomena.

The McHugh et al. study (2021) evaluated the effects of using the Math Infusion into Science Project (MiSP) on science knowledge and skills and student attitudes towards mathematics concerning science over an academic year. These mathematical skills of representing and interpreting data are foundational to scientific literacy. Additionally, infusing mathematics into a science curriculum can allow students to see how different subjects work together. Interdisciplinary work represents how problems get solved in the real world (McHugh et al., 2021).

The MiSP curriculum included a teacher's guide, introduction, lab activities, and assessments. Graphing, slope, and linear equations were the math concepts fused into the units (Burghardt, 2012). Twenty-eight middle school science teachers were involved in the study, each receiving 87 hours of professional development on the topic. Half of the teachers were assigned to use the MiSP model in six science units across an academic year and the other half served as a comparison. The study involved 672 infusion and 463 comparison eighth-grade students over two years. McHugh et al. (2021) created a science assessment to measure growth in mathematics-infused science principles and skills. Each question on the assessment fell into either the knowledge, application, or reasoning categories. Student attitudes toward mathematics, its role in science, and their confidence level with mathematical skills were measured using a ranking scale. Students took the assessment at the beginning and end of the school year.

The McHugh et al. study (2021) showed that students in the infusion group had more significant growth than the comparison group with content knowledge and process skills. Certain attitudes of the infusion group of mathematics in the context of science also saw more significant growth. Increased performance on the reasoning and application questions showed improved higher-order scientific process skills for the treatment group. The infusion group also had higher proficiency in applying mathematical concepts within a science context. Across both groups, there was no significant change in attitude regarding interest in mathematics or feelings of mathematical self-efficacy. There tends to be a decline in interest in mathematics among middle school students and these results suggested that MiSP does not mitigate this general decline (McHugh et al., 2021). Implementing mathematics in science through the MiSP is an excellent model for improving science content knowledge and process skills.

The Harsh and Schmitt-Harsh study (2016) sought to see the impacts that specific instructional strategies had on developing graphing skills in a science classroom at the college level. Previous evidence showed that most learners have difficulty displaying and interpreting visual data despite age and expertise level. Harsh and Schmitt-Harsh (2016) dove into the literature and found five instructional strategies to include in an inquiry-oriented stream-ecology unit in a general science course. Those strategies include collecting data through authentic scientific practice, exposure to complex and messy data that reflects actual scientific practice, a two-step data analysis approach that has students graph by hand before utilizing technology, explicit graphing instruction, and collaborative graphing practices.

The Harsh and Schmitt-Harsh study (2016) used two sections composed of 40 first- or second-year students. Before the unit began, researchers administered a 10-item test to assess a student's baseline graphing skills and students' self-reported attitudes about graphing. The post-test assessment had similar questions to the pre-test, and the researcher graded all graphs using a rubric. Students also had the option to anonymously answer questions regarding levels of satisfaction with the unit and how it helped them the development of graphing skills on a scale of one to four.

Across the 37 students who took both the pre-and post-tests, significant gains in graphing skills were seen across the unit. For graph construction, students had gains in the accuracy of plotting data, labeling, and understanding of graph design. Students only rated the usefulness of the unit in developing graphing skills as three out of four despite having significant gains in understanding big picture patterns. Students continued to have difficulty interpreting graphs that utilized mathematical functions as a means of interpretation. Students were highly satisfied with the unit; most indicated that data collection helped them develop graphing skills.

Harsh and Schmitt-Harsh (2016) saw substantial gains in student graphing ability, despite it being a small study on a short unit. However, alarmingly low pre-test scores surprised the researchers. A student's graphing ability should never be assumed based solely on a student's academic standing, and explicit graphing instruction should be incorporated to increase scientific literacy at all levels (Harsh & Schmitt-Harsh 2016).

Building Scientific Literacy Through Argumentation

Scientific literacy encompasses more than just knowing scientific facts; it also includes being able to participate in scientific discourse. Argumentation is an aspect of scientific discourse that can develop critical thinking and communication skills. Argumentation can lead to a better understanding of science's nature and practice, further enhancing scientific literacy. Argumentation is brought into the science classroom to promote scientific literacy. However, the forms should be evaluated as not all "foster a robust understanding of scientific culture and practice" (Cavagnetto, 2010, p. 337).

Songstil et al. (2019) sought an approach that supported Thai students to develop argumentation skills that promoted an ability to reason and critique information to make decisions about problems the students may face in society. Songsil et al. (2019) adapted an argument-driven inquiry model created by Sampson et al. (2011). The original model strengthened a student's ability to make rational claims supported by evidence. The model was adapted to a tenth-grade Thai classroom to fit within time constraints and to promote more teacher feedback. The new model was called the revised argument-driven inquiry (rADI) model.

The rADI approach started with the teacher introducing content related to a major topic and a current controversial socio-scientific issue (SSI), allowed students time to gather data and research within a group, and allowed time for discussion and an exchange of scientific findings. The teacher then presented the specific SSI, allowed for further data gathering, and had students create a claim about the SSI within the group. As a class, groups would then engage in argumentation. Eventually, students worked in groups and created a peer-reviewed written investigation.

Pre- and post-tests determined the impact of the rADI model on a student's argumentation skills. The test consisted of a section of background information on an SSI followed by four questions that measure the aspects of argumentation, including claim, warrant, evidence, counterargument, and supporting argument (Songsil et al., 2019). Researchers graded answers using a rubric with a one to four grading scale. Students that received instruction with the rADI model had statistically significant improvements in argumentation skills across most aspects compared to the control group. However, in both groups, students still struggled with the supportive argument element.

While this model does seem to have the potential to increase a student's argumentation skills, one must keep in mind the cultural context of this study. Within Thai culture, students do not generally express opposing viewpoints to teachers, and researchers had to revise the model to handle this cultural constraint (Songsil et al., 2019). Expressing and engaging with opposing viewpoints is a crucial aspect of scientific argumentation. Therefore, any model may have increased a Thai student's argumentation skills and it is hard to say if this model would be effective across all classrooms.

In 2019, Chen sought to provide teachers with an approach to building scientific literacy through argumentation within an elementary classroom. Chen (2019) developed the Science Talk-Writing Heuristic (STWH) approach, based on the Science Writing Heuristic approach developed by Keys et al. in 1999. Chen's (2019) approach emphasized writing and talking as literary tools to enhance argumentation in a science classroom and engage in the same methods scientists use. A good approach would foster students' ability to apply scientific knowledge and engage in scientific discourse. Students need to practice utilizing the language of science. Chen (2019) outlined four principles to include when creating a STWH lesson. The first included creating a private and public landscape for students to engage in argumentation. A private landscape includes personal understanding, while a public landscape is when students talk through things with others who might have opposing views. Engaging in arguments in these spaces helped students reach a consensus. The second is using argument as an epistemic tool where a big idea guides a question and the scientific argument composed of claims and evidence seeks to answer the question. Thirdly, using talk and writing as a synergistic literacy tool. Writing before talking activates prior knowledge; talking before writing allows students to practice working with the language. When used simultaneously, writing and talking helped a student's argument and helped them challenge other students when used as visual support or representation. The last aspect is to build uncertainties through scientific inquiry, which creates a space for student discussion and allows further gathering of evidence to settle the uncertainty.

A STWH lesson is composed of five phases. Students design the test and observations needed for gathering data after generating an inquiry question. Students engaged in a discussion that debated claims and evidence, followed by reading to compare their arguments with experts

Finally, students reflected through argumentative writing. The STWH approach fostered students' ability to negotiate ideas through both a sequential and simultaneous use of writing and talk, leading to increased scientific literacy if continuously used over time (Chen, 2019).

Building Scientific Literacy Through Teaching Socio-Scientific Issues

Models can be used to explain scientific phenomena, and constructing, using, and evaluating models builds content knowledge. It is important to include multiple models as each model has its limitations and scientific works are better exemplified in the classroom when more models are used (Ke et al., 2021). Scientific models that can be combined and used include the following: mechanistic models show "how and why phenomena occur," system models show the components and interactions of a system, and mathematical models are derived from empirical data (Ke et al., 2021, p 595). Socio-scientific models bring social factors to scientific modeling to help explain and predict multifaceted socio-scientific issues (SSI).

Utilizing socio-scientific models and SSI learning ultimately promotes scientific literacy. Students must evaluate the various phenomena or systems in the science at the root of an SSI; therefore, students must utilize multiple models simultaneously. Using different models deepens students' scientific understanding at the core of an SSI. Presenting students an opportunity to develop and use these socio-scientific models allows students to connect scientific knowledge to larger social contexts, leading to more informed decision-making on future encounters with an SSI.

In Ke et al.'s (2021) study, multiple scientific and socio-scientific models were used to teach the science of the COVID-19 pandemic and how to respond to the pandemic as globally responsive citizens. Scientific models included a mechanistic model of viral cell entry, computer modeling to show the impacts of social distancing, and a mathematical model that showed exponential growth to model the virus's contagiousness. The socio-scientific model was used to help students understand how COVID-19 impacts different sectors of society and how personal decisions impact the system.

Many socio-scientific models do not contain much scientific information; therefore, many practicing science teachers do not believe those models belong in the classroom (Ke et al., 2021). However, Ke et al. (2021) argued that this model helped students transfer scientific knowledge of COVID-19 to this complex social issue. For example, when building the socio-scientific model, a student linked "conservative political views" to "face masks" and "infection rates" while also including the relationship between "social distancing" and "infection rates" that was shown by the computer model. Utilizing the socio-scientific model allows students to link scientific ideas to other aspects relevant to an issue and this link may provide a reason for students to explore a scientific topic further.

Science education should give students scientific knowledge to engage in and contribute to discussions about SSIs. Students should reach a level of scientific literacy to make informed decisions as citizens. It is vital to know science, both the content and how it works, to take a stance on an issue, state one's claim, and critically evaluate others' claims. When engaging in discussions about an SSI, students can use science to clarify a position, combine science with the social dimensions of an argument, and use it to convince those with differing views. However, when students state an argument without explicitly stating the science that backs up an argument, the reasoning may seem unscientific due to the lack of specific scientific concepts being said (Ottander & Simon, 2021).

The Ottander and Simon (2021) study sought to understand how students in upper secondary school used science and how democratic participation was constructed in a group of students when discussing an SSI. One group focused on the world's energy supply and the other on the world's food supply. The discussions were analyzed and students actively used science to raise questions, evaluate claims, add authority to arguments, and make the issue more understandable (Ottander & Simon, 2021). Students experienced democratic participation through "deliberative conversations and critical reflection of the SSIs" and when students experienced ideological dilemmas (Ottander & Simon, 2021, p.1916). However, it frequently seemed that students tended to avoid ideological dilemmas. Students passed off the responsibility of an issue by stating things like "they (scientists) will find something out" (Ottander & Simon, 2021, p.1911). When students avoid engaging in these challenging positions, it can take away the feeling of democratic participation. If utilized and set up correctly, having students engage in conversations around an SSI allows them to use scientific knowledge and gain feelings of democratic participation.

Teaching scientific literacy through argumentation while looking at an SSI is powerful as it can provide a realistic context for students to learn science. It is an essential realization that scientists participate in social debates because science intersects with social issues. When engaging in an argument concerning an SSI, social aspects play a much more significant role than science. Scientists may ditch specific scientific discourse in this social realm for a watered-down version of science talk. If students are not using scientific discourse properly, it is a less effective way of teaching scientific literacy (Cavagnetto, 2010).

Twenty-first Century Skills

The necessary skills and abilities to succeed in the 21st century differ from those in the past. There are 12 skills, grouped into three areas, that have been identified for students to master to succeed in today's information age. *Learning skills* include critical thinking, creativity, collaboration, and communication. Flexibility, leadership, initiative, productivity, and social skills fall into the *life skills* category. *Literacy skills* include information, media, and technology literacy. Information literacy encompasses understanding facts, figures, statistics, and data (Stauffer, 2022). Initially, scientific literacy may seem like it only falls into the information literacy category because it involves the knowledge and understanding of facts. However, teaching scientific literacy can impact many 21st-century skills including various learning and social skills.

Developing 21st-Century Skills

There is a growing need for people to take on careers in the science, technology, engineering, and/or math (STEM) fields; however, the recruitment of people, especially girls, is lacking. Previous studies have shown the effects of various activities like science centers and museums on cultivating STEM interest but have lacked the aspect of developing 21st-century skills, which is a growing focus (Walan, 2021). The Walan (2021) study focused on using drama and activities in a makerspace to increase interest in STEM and develop 21st-century skills among young girls. A makerspace allows students to work creatively and collaboratively utilizing different tools and technologies. Ten girls aged 7-11 from a town in Sweden participated in the study. Additionally, there was a project leader, the drama teacher, and three female engineering students that participated in the project as support to the girls.

Researchers collected data through interviews and observations. During the initial interview, researchers gathered information about the girl's background and baseline interest level in STEM and acting. Additional data collected were the girls' props' drawings and the final products created in the makerspace. Initially, none of the girls had any interest in STEM, and most volunteered for the project because of an interest in acting and drama.

Interviews with the drama teacher indicated that the activities throughout the project had increased the girl's engagement and that the makerspace environment had helped the girls gain an "I can fix this" attitude (Walan, 2021, p. 33). The girls in the study looked up to the female engineering students and wanted to be like them when they grew up. The creation of a drama production fostered the girl's creativity and problem-solving skills, all while working together cooperatively. This study confirmed that drama could be used as a mediating artifact in increasing interest in STEM. Although the sample size of 10 girls was small, the findings of this study were positive for combining makerspace activities with drama to promote 21st-century skills and an interest in STEM.

Higher-order thinking skills (HOTS) are 21st-century skills. Teachers equipped with practical strategies that are easy to implement in a content area classroom can successfully teach HOTS. Higher-order thinking skills are critical to 21st-century skills and allow students to succeed in a content classroom. The Tajudin et al. study (2019) aimed to develop a Thinking-Based Learning (TBL) module for use within a middle school mathematics classroom to enhance HOTS. Thinking-Based Learning is a way of combining teaching a specific thinking skill with the teaching of content matter. When built correctly, a TBL module provides the structural framework for a specific type of thinking. The framework and procedures allow the thinking to occur efficiently and effectively (Tajudin et al., 2019).

Implementation of a TBL is critical to its success. Steps include connecting the thinking skills to everyday life, using a habit of mind, using content learning to guide students in efficient thinking, and pushing students to use metacognition (Tajudin et al., 2019). The TBL module utilized a student-centered approach that contains an introduction, engagement, reflection, and transfer phase (IRET). The IRET model guided learners in defining their thinking, engaged them in a thought-provoking process, and allowed them to relate prior knowledge with what students learned through exploration (Tajudin et al., 2019). The TBL module that Tajudin et al. (2019) developed was successful for the middle school mathematics classroom and had satisfactory validity. Thinking-Based Learning helps meet the need to teach students 21st-century skills and can be integrated into content teaching. Teaching students HOTS prepares them to be problem-solvers for the next generation.

Critical thinking skills are another 21-st century skill that can be taught in the classroom. The Rubini et al. (2018) study aimed to understand the impact an interactive problem-based module (IPBM) had on student achievement and critical thinking skills at the seventh-grade level. The study used a previously developed IPBM for an environmental pollution lesson and expanded it to include population density. Students encountered these problems daily, stimulating thinking and increasing the connection to finding solutions to the problems (Rubini et al., 2018). Rubini et al. explained that the IPBM consisted of an introductory video, a presentation of facts, and a list of questions for the students to think through. Students created a mind map, then worked through the questions using an understanding of the concept to arrive at a solution. The closing section contained the critical thinking questions. The IPBM can be used as a self-guided module as it is user-friendly and contains images and videos that help support the content.

Analysis of pre- and post-tests showed only a moderate gain in critical thinking skills and student achievement. The research assumed that the impact in both categories is due to the IPBM. However, using problems that students encounter daily as a topic for a lesson helps students solve problems and understand the concepts, which naturally lend themselves to critical thinking skills (Rubini et al., 2018). So, was it the chosen topic or did the IPBM use lead to the moderate gain seen?

Rubini et al. (2018) also surveyed students on personal opinions of the IPBM; almost all students enjoyed using it and many enjoyed its interactive nature. Students also noted the topic's role in the favorability of the module. The topic related to problems that the students experienced which was a driving factor in finding solutions. Even though the gains in student achievement and critical thinking were only moderate, implementing a tool that students have a positive attitude towards could go a long way.

Generic science skills are an essential part of biology learning, and these skills are similar to 21-st century skills, with the primary skill of thinking found in both (Haviz et al., 2018). The purpose of the Haviz et al. study (2018) was to describe and observe the generic science skills of students conducting biological experiments. If one can promote generic science skills in the classroom, it will also help students gain 21st-century skills without employing any additional teaching strategies.

The primary 21st-century skills that Haviz et al. (2018)evaluated were thinking skills, including creativity, critical thinking, problem-solving, and metacognition. These 21st-century skills fit with generic thinking skills like reasoning and critical and creative thinking (Haviz et al. 2018). The generic problem-solving skill encompasses analyzing, decision making, applying, and verifying. The science skills correlated to these generic and 21st-century skills were direct observation, awareness of scale, logical framework, cause and effect, modeling, and inference. Researchers observed generic science skills using observation sheets. At the same time, students conducted experiments on the *Mimosa pudica* plant and varying stimuli and while students used the body structure and mass of an animal to analyze animal motion. Of 295 eighth-grade students, researchers selected a sample population of 32 students for the study.

Researchers split the 32 students into six groups for the experiment and then averaged the scores for each generic science skill category. The highest percentage score average was modeling at 87.49%, and the lowest was awareness of scale at 71.17%, which still put it in the sufficient category for learning. Students took a motion of living organisms assessment after the experiment. All 32 students had a score greater than 75%, indicating that mastery of the topic was reached. Haviz et al. (2018) concluded that educators must continue to revisit generic science skills to help students obtain the 21st-century skills that students will need to perform well in the future.

While teaching and promoting 21st-century skills in the classroom is essential, students will never implement those skills without teachers fostering a student’s self-efficacy toward those skills. The Semilarski et al. study (2020) evaluated using everyday life scenarios in science lessons to promote a student's perceived self-efficacy toward 21st-century skills. Semilarski et al.

(2020) discuss previous research that has shown that using everyday life scenarios can increase the relevance of science learning for students while helping them develop interdisciplinary core ideas. Having students engage in real-world skills and active learning opportunities can be a way to promote perceived self-efficacy.

The Semilarski et al. study (2020) took place over a year and a half and followed students from tenth-grade to eleventh-grade. The experimental group had 209 students, while the non-experimental group had 162 students. Scientific core ideas were genetic variation, models, chemical reactions, land surface change, heredity and DNA, motions and waves, characteristics of substance, energy conversion, weather and climate, and systems. Everyday-life scenarios used to teach these core ideas included debate, role-play, argumentation, and other active learning opportunities. The 21st-century skills that these scenarios promoted were cognitive and problem-solving skills, mindset for scientific research, critical thinking skills, the changeability of scientific knowledge, and responsible citizenship. Students completed pre-and post-surveys that measured their perceived self-efficacy towards 21st-century skills.

After the intervention, the experimental group saw statistically significant increases in cognitive and problem-solving skills, mindset for scientific research, and critical thinking skills. Non-statistically significant differences arose in the changeability of scientific knowledge and responsible citizenship aspects. The results from the non-experimental group show that the intervention did increase perceived self-efficacy towards most of the skills. When science learning is based on real-life situations and includes active learning opportunities while purposely linked to developing 21st-century skills, students' self-efficacy toward those skills can improve (Semilarski et al., 2020).

Amadi (in press) understood the significance of incorporating 21st-century skills into the classroom to ensure that future generations can continue to provide innovation and growth to a country. During the study, Amadi looked at public school science curricula in the United States (US) and Canada to determine how integrated 21st-century skills are. Amadi (in press) analyzed the 4th and 8th grade Common Framework of Science Learning Outcomes in Canada and the 4th and 8th grade Next Generation Science Standards in the US.

Amadi (in press) utilized the 21st-century skills outlined by Applied Educational Systems (AES). The 21st-century skills "were used in coding the expected skills to be developed by grade 4 and grade 8 students in Canada and the USA" (Amadi, in press, p.7). Amadi (in press) identified the skills in the curricula, and the degree of integration of these skills was determined. Canada had a higher integration rate than the USA. 4th-grade science standards contained 100% of the 21st-century skills, and the 8th-grade standards had 83% of the skills. The USA has a 33% integration rate in 4th grade and 17% in 8th grade. The most common 21st-century skill included in the science curriculum was critical thinking. However, critical thinking will not take students very far without being accompanied by the other 11 skills. As a student moves through the education system, more skills are gained. However, both countries saw a decline in the number of 21st-century skills in the curricula from 4th to 8th grade.

Amadi (in press) expresses grave concern over the lack of 21st-century skills in Canadian and United States education because of science and technology's many roles in our lives. Wealth creation is impossible without scientific knowledge, and science and technology enhance basic requirements for life. An evaluation of the standards only finds the desired goals to be met, so a future investigation should focus on student assessment to see if students have the ability to demonstrate 21st-century skills.

Chapter III: Discussion and Conclusion

Summary of Literature

The literature review was broken into two sections, one discussing ways to increase scientific literacy and the other discussing 21st-century skills. However, these two topics are very much intertwined. When one is scientifically literate, the facts are known, there is an understanding of the ways of thinking and reasoning, and one comprehends the impact that science has on society. This definition means having information literacy about the facts and critical thinking skills, which are both 21st-century skills. A scientifically literate population will ensure the US's future ability to innovate and help the population battle misinformation and avoid unwarranted beliefs (Fasce & Picó, 2019; Howell & Brossard, 2021).

Students can better comprehend the content and gain the ability to engage in scientific discourse if the scientific vocabulary is known. Therefore, scientific literacy can be built through vocabulary instruction. Townsend et al. (2018) and Harper (2018) found that repetition was critical in increasing a student's scientific vocabulary. Harper successfully used written and visual ways to represent vocabulary and review and manipulation to increase vocabulary knowledge. Teacher support, guidance, and accountability impact vocabulary acquisition (Townsend et al., 2018). Thematic lessons, concept mapping, and read-alouds supported a student's vocabulary network (Kim et al., 2021). Science vocabulary crossword puzzles can help students acquire the meaning of a word and scientific discourse allows them to use the word to gain ownership (Hayden et al., 2020; Kruawong & Soontornwipst, 2021).

The "connect to the text, label two clues, use the clues to define the word parts, explain the word, and see if you are correct" (CLUES) generative strategy can provide students with a method to determine the meaning of an unknown scientific word without direct intervention from the teacher (Helman et al., 2020, p. 24).

Reading and writing activities can build scientific literacy. Shaffer et al. (2019) found that basic literacy skills were a good indicator of scientific literacy skills. Supporting reading comprehension in the science classroom further supports scientific literacy. Teaching students about scientific metaphor and using the Touch-Talk-Text framework supports reading comprehension (Barnes & Oliveira, 2017; Carrier et al., 2021). The Touch-Talk-Text framework could also support a student's motivation to read, which Hwang and Duke (2020) found to contribute to reading comprehension. Using a write-to-learn tactic in the classroom allows students to comprehend the content further and is a tool that can be scaffolded to meet the needs of a wide range of student capabilities. An essential part of the scientific writing process is peer review which ensures the credibility, originality, and significance of research findings. Being involved in the peer review process allowed students to gain skills that increased their ability to critically read scientific literature (Geithner and Pollastro, 2016). Another tool that can assist students in critically reading scientific literature is using the referencing strategy to determine credible from non-credible sources (Rehorek & Dafoe, 2018). Understanding how the peer review process and how the use of references leads to credible and valid sources contributes to a student's media literacy skills, which is another 21st-century skill.

Building scientific literacy through analyzing and interpreting graphs also contributes to media literacy. Understanding what a graph conveys can help students interpret how a media outlet might present the information to the public to meet a specific purpose. The Math Infusion into Science Project (MiSP) curriculum helped integrate graphing and interpreting data skills into the science classroom (McHugh et al., 2021). Riley and Biernat (2018) found it helpful to use the Identify and Interpret strategy to help students gain the ability to analyze and interpret data. A single strategy might be more flexible and accessible to integrate than an entire curriculum. Involving students in the data collection process contributed to the results and positive student attitudes in the Harsh and Schmitt-Harsh study (2016). Other strategies that Harsh and Schmitt-Harsh used included exposing students to complex and messy data, having students graph by hand before using technology, explicitly giving graphing instruction, and having students work collaboratively. Students practice 21st-century skills when working collaboratively.

Engaging in argumentation develops scientific literacy and the 21st-century skill of communication in students. Songsil et al. (2019) found that the revised argument-driven inquiry (rADI) model developed argumentation skills, and Chen (2019) used the Science-Talk Writing Heuristic (STWH) approach that focused on using writing and talking as literary tools to enhance argumentation. Students use scientific discourse and participate in the same methods scientists use when engaging in argumentation.

Bringing socio-scientific issues (SSIs) into the classroom and using them as part of a discussion can impact scientific literacy and many 21st-century skills, including communication, collaboration, leadership, flexibility, and social skills (Ke et al., 2021). Students can work collaboratively in a group and one of those members can practice leadership skills as a group leader. Throughout a discussion, students may need to go back to the literature as a conversation pivots, allowing students to practice flexibility. Ke et al. (2021) found that using an SSI helps students connect scientific knowledge to larger social contexts, which can help them see the benefit of working together, thus fostering social skills. Engaging in discussions around an SSI helps students' communication skills and can help students gain feelings of democratic participation (Ottander & Simon, 2021).

Haviz et al. (2018) found that when students had and used generic science skills, students also used many 21st-century skills. Beyond using approaches to increase scientific literacy to promote 21st-century skills, some strategies focused on 21st-century skills. Walan (2021) successfully used drama and a makerspace to promote 21st-century skills and foster girls' interest in science, technology, engineering, and math (STEM). Using a thinking-based learning (TBL) approach or an interactive problem-based module (IPBM) can also impact 21st-century skills (Rubini et al., 2018; Tajudin et al., 2019). Everyday-life scenarios to teach 21st-century skills can help foster students' self-efficacy toward these skills (Semilarski et al., 2020).

Professional Application

Research has shown that implementing methods to increase scientific literacy can help promote 21st-century skills in students and prepare them for life outside of the classroom in a professional setting and in a role as a citizen. Applications from this research could be implemented at the state, district, and teacher levels.

Amadi (in press) reviewed the standards in the United States (US) and Canada and found a decreasing integration rate of 21st-century skills in science curricula as students get closer to entering the workforce. At the state level, scientific literacy and 21st-century skills could be integrated into the standards to prepare students better to be members of society. Some aspects of scientific literacy to include in the standards are interdisciplinary work, specific science reading and writing skills, data analysis and creation, and technological aspects.

Districts should provide meaningful professional development opportunities to teachers as many teacher preparation programs do not include teaching strategies to address 21st-century skills (Sajidan et al., 2018). Additionally, the world and technology evolve quickly and the strategies teachers use to promote 21st-century skills should also evolve at the same rate (Sajidan et al., 2018). Frequent professional development in 21st-century skills provides teachers opportunities to learn about new strategies and ways to support students. In the McHugh et al. (2021) study, teachers received 87 hours of professional development over two years, which may have contributed to the success of MiSP.

At the individual teacher level, incorporating various teaching strategies to teach the content will also cover many aspects of scientific literacy, as discussed previously. Teachers must be willing to incorporate new strategies and evaluate the effectiveness of those strategies. Incorporating many strategies can reach more students and address more learning styles. Teachers can collaborate with other teachers to develop interdisciplinary lessons that can impact a student's 21st-century skills. An interdisciplinary lesson could be an intense graphing lesson or unit connecting math and science or connecting science and social studies by teaching about the social impacts of climate change or genetically modified crops.

Limitations of the Research

There are several limitations in this literature review. Most studies lasted one academic year or less except the Semilarski et al. (2021) and Hayden et al. (2020) studies. When fostering 21st-century skills, increasing the length of study would be beneficial as those skills are not confined to a one- or two-semester-long course.

The studies examined for this literature review were conducted in many places across the US and the world. Within the US, there are differences in the curriculum from state to state. If the starting curriculum is different, some states might see statistically significant improvements while others using the same intervention do not. When examining the studies conducted outside of the US, one must also consider the different cultural backgrounds and restraints that could contribute to the results.

Despite high school and college being the final stepping stone for many students before entering the workforce, only the Semilarski et al. (2021) study examined strategies to promote 21st-century skills at the high school level and none at the college level. Researchers should conduct further studies that address 21st-century skills at the high school or college level as it may not be enough to rely on science teaching to cover all the 21st-century skills as students approach graduation. Four studies examining ways to improve scientific literacy took place at the post-secondary level of education. College courses, instructional strategies, and classrooms are very different from primary and secondary school, so those studies will need to be adapted for use in primary and secondary school.

Implications for Future Research

The COVID-19 pandemic pushed technology into teacher and student lives without any transition. Students and teachers had to adapt quickly to the new learning environments and technology was utilized in a way that had never been done before. Some technological advancements from the pandemic will not leave the classroom anytime soon. Technology literacy is part of 21st-century skills and future research could include using technology to increase scientific literacy and 21st-century skills. Additionally, many schools are adopting a one to one technology device policy where each student has a mobile computing device. Future research should identify the differences, if any exist, in scientific literacy and 21st-century skills between schools with and without one to one technology devices.

Conclusion

Including varied approaches to teaching vocabulary, incorporating scientific reading and writing, providing students with opportunities to analyze and interpret data, using argumentation, and discussing socio-scientific issues helps teach science content, promotes scientific literacy, and promotes students' 21st-century skills. If students are scientifically literate and have 21st-century skills coming out of the education system, the system has prepared them well to be active participants in today's society.

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