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Review of the Literature: Scientific Argumentative Writing

Gabriela A. Mastro
Dominican University of California, gabriela.mastro@students.dominican.edu

RUNNING HEAD: Review of the Literature - Scientific Argumentative Writing

Abstract

In light of the essential science and engineering practices identified by the Next Generation Science Standards (NGSS), this study focuses on the specific science and engineering practice, "engage in argument from evidence," and how classroom practices can serve to strengthen this skill (National Research Council, 2012, p. 71). The NGSS focus on inquiry necessitates students' use of argument, particularly in writing, to communicate their knowledge and scientific findings and to develop an understanding of scientific practice. The contents of this literature review will link the practice of scientific inquiry to writing in the science curriculum, and how argumentative writing can support overall scientific literacy. This will benefit scientific educators by yielding information about how scientific argumentative writing can be most effectively implemented into the middle school classroom to yield the maximum benefit for literacy in the science curriculum.

Keywords: science, middle school, science and engineering practices, argumentative writing, Next Generation Science Standards

Introduction

Since California's adoption of the Common Core State Standards (CCSS) in August 2010 and the Next Generation Science Standards (NGSS) in September 2013, the face of science education has been changing drastically. These two sets of standards arose from concerns about the U.S. position in the global economy and the preparedness of its students to eventually be able to participate in an increasingly science- and technology-driven society. As such, the NGSS and CCSS place an increased emphasis on college and career readiness, as well as competence in science literacy and science and engineering practices.

Science education prior to NGSS, overall, consisted of "long lists of detailed and disconnected facts," leaving students with "just fragments of knowledge and little sense of the creative achievements of science, its inherent logic and consistency, and its universality" (NRC, 2012, p. 10). In response, the NGSS were intentionally developed in three dimensions: scientific and engineering practices, cross-cutting concepts that are applicable across scientific disciplines, and disciplinary core ideas. In comparison to several previous sets of state standards, the NGSS have led to an increased emphasis on scientific inquiry. Bowman and Govett (2015) stated that, as rapid progress is being made in all fields of science, the NGSS was created to be dynamic, emphasizing core ideas and skills, such as "technical reading, interpretation, critical thinking, and analysis," rather than mere simple facts (p. 55). In order for students to develop those skills, they need to continuously engage in scientific practice, and the NGSS encourage students' generation of models and evidence-based explanations as tools to meet this end.

Furthermore, the NGSS were specifically aligned with the CCSS in both math and English/language arts (ELA). This alignment was developed to address an increasing need for students to be able to communicate scientifically. Since much of scientific discourse consists of creating and defending evidence-based claims, the ability to "engage in argument with evidence" was included in the NGSS as a science and engineering practice, which is supported by several ELA anchors in the CCSS.

One challenge of incorporating the CCSS ELA standards with NGSS is that students are taught how to write argumentatively in language arts contexts, but those skills do not automatically transfer to science. One would assume that mastery of writing fundamentals would lead to success in writing tasks in all subject areas, but not all teachers and not all subject areas require students to engage in frequent writing exercises. Kiuhara, Graham, and Hawken (2009) surveyed high school science teachers, finding that there was a lower importance on the value of writing in science classes than in other subject areas, along with a lower overall writing frequency. Due to a general lack of support for writing in the science curriculum, even when cross-curricular scaffolds are used, students may struggle with writing tasks that are science-specific, including tasks that require students to supporting scientific claims by "arguing from evidence." It is clear that literacy skills taught in language arts classes are just one component of a student's capacity to write scientifically, which implies that science teachers need to draw on different techniques to explicitly teach literacy in the science curriculum (Norris & Phillips, 2003).

The world of science teaching is going through such major changes, and is in need of guidance for how to adapt curriculum to these changes. In light of this need, this literature review will inform future science instruction by providing research-based suggestions and practices for building students' scientific argumentative writing skills.

A review of the literature revealed the following themes: 1) The NGSS and the CCSS have drastically changed the way that inquiry and collaboration are implemented into the science curriculum, which, in turn, have an impact on the possibilities for teaching writing within the science curriculum. 2) Inquiry, as well as communication of its process and findings, can be used as a method for creating meaning of science concepts. 3) Inquiry practices and writing can combine, as students utilize scientific processes and evidence to develop and defend arguments. 4) Teachers' abilities to implement these practices into the science curriculum can be limited by their own self-efficacy, a perception that fundamental literacy instruction has no place in the science curriculum, inadequate professional development, lack of funding, and numerous other issues.

Historical Context

On October 4, 1957, Soviet Russia launched the satellite *Sputnik*, indicating that the U.S. may have fallen behind in scientific research, technology, and engineering. This huge blow to national pride is seen as the catalyst for the development of modern science education. Following this event, policymakers recognized a need for educational reform, particularly in science and math, if the U.S. were to continue to be a competitive global force. Attention turned toward improving the quality of secondary science teachers, as well as the national science curriculum, as a whole. The hope was that in making science a rich, interesting subject area that encouraged the pursuit of further science education, the U.S. would emerge victorious in the "space race" with Soviet Russia.

As the Cold War continued, the fear of the U.S.'s loss of global dominance emerged with the publication of *A Nation at Risk: The Imperative for Educational Reform*. In this report, the National Commission on Excellence in Education put forth that the educational system of the U.S. was in such disrepair that the U.S. would continue to fall behind other nations in the areas of industry, science, technology, and commerce (1983). This report spurred a parade of science education reform initiatives that would occur over the next three decades.

In 1996, the National Research Council developed the National Science Education Standards. Their goal was to "spell out a vision of science education that will make science literacy for all a reality in the 21st century" (NRC, 1996, p. ix). These standards outlined what students needed to know, understand, and be able to do in order to achieve this goal, calling for a greater emphasis on inquiry-based science education.

Although the National Science Education Standards were a nationwide effort to improve science education, by the early 2000s, each state had its own set of standards and its own expectations for proficiency. Beginning in 2009, the Common Core State Standards (CCSS) began development as an effort to standardize education across the U.S., which would give the states more educational common ground. As of 2015, forty-two states, as well as several territories had adopted the CCSS for English/Language Arts (ELA) and mathematics. The CCSS emphasized several key shifts in ELA. Specifically, the CCSS highlighted the regular use of complex texts and academic language, communication with the use of evidence from literary and informational texts, and the use of nonfiction text to build knowledge.

In 2009, the Carnegie Foundation released a report entitled *The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy.* With echoes of *A Nation at Risk*, this report bemoaned the lagging achievements of students in science and mathematics and the U.S.'s reduced global economic power (*Opportunity Equation*, 2009). In response, the development of the NGSS began in 2011. The aim of these standards was to prepare students for careers in a society increasingly driven by science and technology and to increase the overall scientific and technological literacy of U.S. citizens to enable meaningful participation in this society (*Opportunity Equation,* 2009). The NGSS were released for adoption by states in May 2013, and was adopted in California in September 2013. California is currently in the implementation phase of NGSS, and science teachers are currently working to align curriculum, instruction, and assessments to the standards.

The NGSS were written specifically to align with the CCSS. In the area of literacy, the NGSS development team worked with the CCSS literacy team to "identify key literacy connections to the specific content demands outlined in the NGSS" (NGSS Lead States, p. 159). The final version of the NGSS drew specific connections to the CCSS for ELA, ensuring that the two sets of standards would be aligned. Appendix M of the NGSS release (2013) examined each SEP in the NGSS, identifying the aligned CCSS literacy anchor standards. The rationale was that "writing and presenting information orally are key means for students to assert and defend claims in science, demonstrate what they know about a concept, and convey what they have experienced, imagined, thought, and learned" (NGSS Lead States, p. 159). This deliberate alignment of NGSS with the CCSS ELA standards emphasize that the two sets of standards are intended to work together to build students' abilities to read and write scientifically, as they engage in inquiry-based scientific practice. As such, this literature review examined how the practice of scientific inquiry is connected to literacy within the science curriculum, and how that connects with an argument-based classroom culture.

The Next-Generation Science Standards and Inquiry-Based Learning

As the NGSS have been adopted in several states, teachers are contemplating how to best address them in their curricula. A study by Bowman and Govett (2015) compared the life science standards in the NGSS to the corresponding standards of the Tennessee Curriculum Standards for Science Education (TNCSSE). This comparison allowed them to conclude that as the field of science is rapidly changing and evolving, often too quickly for textbooks to reflect these new understandings, there is a clear need for students to develop a broad understanding of key science topics, in order to expand on any new science information that may come to light. The NGSS place a new focus on certain learning skills, "such as technical reading, interpretation, critical thinking, and analysis rather than factual learning" (Bowman & Govett, 2015, p. 55), in order to allow students to achieve content learning goals. The NGSS incorporate inquiry as part of the content standards, rather than communicating this focus as a set of separate standards. Bowman and Govett observed that, "simply teaching the standards as written requires an embedded inquiry that surpasses the TNCSSE standards" (p. 59). In light of this, an understanding of what, exactly, entails "inquiry" needs to be established.

When teaching through an inquiry lens, teachers make pedagogical decisions "to promote scientific practices such as asking testable questions, creating and carrying out investigations, analyzing and interpreting data, drawing warranted conclusions, and constructing explanations that promote a deep conceptual understanding of fundamental science ideas" (Wilcox, Kruse, & Clough, 2015, p. 62). The researchers (2015) offered several insights for how inquiry can be implemented successfully in a science classroom. Inquiry can range from guided activities to more open approaches, depending on the amount of student support needed. Inquiry-based activities can be useful for differentiating curriculum due to the amount of concrete engagement and teacher interaction that they may require. While inquiry-based activities can consist of hands-on experiences, the most important thing is that students are making meaning of whatever activity they are engaging in, through decision-making, exploring their own thinking, and engaging in abstract thinking. Although an inquiry-based approach has been recommended for science education for many years, Wilcox, Kruse, and Clough (2015) claim that inquiry is not yet a common aspect of science teaching. They hypothesize that there is widespread misunderstanding of what it actually entails to facilitate inquiry-based learning.

Bell, Smetana, and Binns (2005) tried to clarify the meaning of inquiry learning. According to these authors, the following two criteria must be met for an activity to be truly inquiry-based:

a) Students are answering a research question through data analysis.

b) Students must be involved in analyzing relevant data. These data do not necessarily need to be collected by the students, themselves, but they need to be actively involved in interpreting this data and drawing conclusions from it.

Bell, Smetana, and Binns (2005) also define four "levels" of inquiry for teachers to use as guidelines to adjust an inquiry-based lesson to the readiness level of their students.

1. In "Level 1" activities, sometimes referred to as "confirmation activities," students are provided with the question and procedure, and the expected results are known in advance.

2. "Level 2," or "structured inquiry" activities provide students with the question and the procedure, but not the expected results. According to Bell, Smetana, and Binns (2005), the difference between Level 1 and Level 2 can be a matter of presenting the activity before or after the target concept is taught.

3. "Level 3," or "guided inquiry" begins with a teacher-presented question, but leaves the methods and solutions up to students, which may promote engagement and ownership.

4. "Level 4," or "open inquiries" allow students to design methods to investigate a topic-related question of their choosing. Successful Level 4 inquiries require students to have experience with inquiry at Level 1-3.

In Irish secondary schools, students undertake Junior Certificate programs, in which they participate in both mandatory and optional coursework in order to earn these certificates. Science, an optional subject that is studied by 95% of students, follows two parts: Coursework A or Coursework B (Kennedy, 2014, p. 286). Coursework A follows a sequence of thirty experiments, mandated by the Irish government. In the third year of this sequence, Coursework B requires students to complete two investigations, of the "Level 4" variety proposed by Bell, Smetana, and Binns (2005). However, when surveyed about these methods, 68.7% of science teachers "disagreed" or "strongly disagreed with the statement, "Coursework B is an accurate indicator of students' ability to carry out science investigations" (Kennedy, 2014, p. 295). Teachers reported that students' scores on Coursework B were based on the final presentation of material, not the skills learned while carrying out the investigations, which may also be influenced by peers, parents, teachers, and others who may offer assistance. A student's inquiry skills may be difficult to assess. Considering this, and the fact that inquiry-based science education can be difficult to implement, Kennedy (2014) does not recommend this teaching method as the sole means through which science education is delivered. Referring to studies that highlight the effectiveness of direct instruction on student achievement, Kennedy (2014) suggests that inquiry-based science instruction be balanced with direct instruction to maximize the student benefits.

Kennedy (2014) touches on the fact that several hurdles exist to the successful implementation of inquiry-based science education, on which Ramnarain (2016) further elaborates. Ramnarain’s (2016) study focused on teachers at a township school in South Africa, examining the implementation of inquiry-based learning and the various influential factors. Teachers completed a questionnaire and were interviewed. Results demonstrated that the teachers had an overall lack of perceived self-efficacy and desired further professional development to increase their repertoire of inquiry teaching strategies. Furthermore, teachers indicated that their school did not have adequate resources to engage in this type of teaching. The teachers also asserted that they did not have enough time to plan inquiry-based instruction and that the school did not recognize its importance in the curriculum. However, despite these other findings, teachers maintained a positive attitude about inquiry teaching. Limitations of this study included the fact that only one school was examined and that classroom observations were not conducted. Overall, Ramnarain (2016) concluded that the practice of inquiry teaching is highly context-dependent, and the results can be used to inform guidelines for professional development for teachers who use these methods.

As Ramnarain (2016) and Kennedy (2014) pointed out, there are several obstacles to implementing inquiry-based instruction as a regular teaching practice, and some of the benefits to student content knowledge are unclear. However, Otfinowsky and Silva-Opps (2015) conducted a study on undergraduate biology students that highlighted the effect that inquiry-based instruction can have on the development of scientific literacy. Undergraduates enrolled in

Vertebrate Zoology course at the University of Prince Edward Island, Canada, participated in a semester-long inquiry-based learning project. This project required students to create their own research questions and methods to present and discuss topics in vertebrate zoology. Students participating in this process engaged in regular reflective writing exercises to supplement their project work, and ultimately demonstrated more understanding of the role of scientific writing and communication. Despite all of the obstacles and hesitations that teachers may face in implementing inquiry-based education in science, student engagement in inquiry projects demonstrates the potential to build overall competence and confidence in scientific writing.

Implementing Literacy within the Science Curriculum

The concept of "scientific literacy" is broad, and consists of much more than the ability to read scientific literature and write in a way that conforms to the norms of the field. According to Fives, et al. (2014), scientific literacy is "knowledge of the nature of the field and its processes so that one can engage (in whatever form that takes for the individual) with science pragmatically and meaningfully in daily life" (Fives, et al., 2014, p. 551). In an attempt to create a working assessment of scientific literacy skills in middle school students, Fives, et al. (2014) defined six essential components of scientific literacy: 1) "The role of science," which encompasses the understanding of scientific questions, methods, and evidence. 2) "Scientific thinking and doing," which involves the actual observational and analytical processes needed to engage in science. 3) "Science and society," where students can identify scientific issues in society and the role of science in decision-making. 4) "Science media literacy," which is the ability to critique the media's representation of scientific findings and issues. 5) "Mathematics in science," where mathematical concepts can be used to engage in scientific processes. 6) "Science motivation and beliefs," which is the ability to draw upon scientific knowledge and skills in one's daily life.

Since scientific literacy encompasses a variety of scientific skills and attitudes, it is difficult to assess a student's scientific literacy, as a whole. What can be done, however, is to consider scientific literacy in terms of these smaller components, which can be assessed separately and targeted separately for further instruction. The focus of this research is the measure student ability to write scientifically, which encompasses a small component of scientific literacy. However, this study highlights the importance of not only teaching scientific concepts, but also giving students opportunities to develop beliefs and values about science in the world.

A study by Tomas and Ritchie (2015) demonstrated how incorporating writing into the science curriculum can be used as a tool for making meaning of science concepts. Tomas and Ritchie (2015) examined the use of "BioStories," a writing-to-learn strategy, where students created stories about biosecurity. This task was aimed at developing students' scientific inquiry skills, to evaluate to what extent this program developed students' scientific literacy – both in terms of scientific content knowledge and in the ability to understand how science relates to human affairs. Analysis of the writing tasks revealed an improvement in scientific literacy, which indicated that participation in the writing tasks yielded a positive impact on learning, with 19 of 24 students in the case study demonstrating deep levels of conceptual understanding. This study indicates that writing itself can assist students with acquisition of content knowledge. Writing does not necessarily need to be kept separate from scientific content knowledge, but can be used as a tool to build this knowledge.

Hand, Hohenshell, and Prain (2007) conducted a similar study on high school students. Students studying cells were asked to write a textbook explanation for seventh-graders, using a "Science Writing Heuristic" (SRH). The SRH provided scaffolding questions that incorporated inquiry and argumentation processes to assist students in formulating their explanations through evidence, constructing arguments from additional research sources, and reflecting on their ideas. In contrast to another group of students, who wrote a newspaper article about molecular biology concepts without using the SRH, students who used the SRH performed better on science content tests. Since there was such a clear contrast between the students who received scaffolding from the SRH and those that did not, this raises a question of how writing can be supported within the science curriculum so that it can be used as a tool for acquiring content understanding.

Strategies

Norris and Phillips (2003) contest that literacy in its fundamental sense, "reading and writing when the content is science" (p. 224), is essential for scientific literacy. In contrast, scientific literacy is often referred to in the derived sense, "being knowledgeable, learned, and educated in science" (p. 224). The authors posit that just because a student is able to read the words, this does not give the reader the ability to comprehend and follow arguments, and thus, to engage in scientific inquiry. For educational purposes, teachers need to focus on both the content and the different interpretations of a text. Science students must both be familiar with the science content within a text and be able to read those texts from a theoretical perspective. Norris and Phillips (2003) emphasize the necessity of making sure that all students have access to the content being addressed within a science text by ensuring that students have the fundamental skills to see both the content on the surface and the implications within a text. Teachers cannot assume that students can have the literacy skills to effectively analyze texts and construct arguments. These skills need to be explicitly taught.

In order to accomplish this, Farris, Werderich, and Haling (2016) supply several suggestions. They recommend incorporating literature into science content instruction, due to the inherent connection between reading and writing. In addition, visuals, such as videos, increase relevance to the topic at hand and to encourage students to share this information through writing. Finally, the author suggests that teachers provide note-taking scaffolds along with open-ended questions for students to respond to as they read and take notes. These suggestions, where students are provided with plenty of scientific resources in a variety of formats, are meant to connect the CCSS with the NGSS to not only enhance students' understanding of science, but to encourage them to communicate that information with others.

The qualitative results from the study by Hand, Hohenshell, and Prain (2007) demonstrated that when students were able to communicate their scientific knowledge by re-representing it for a different audience, this process allowed them the opportunity to clarify their own topic knowledge further. In addition, students reported that when they engaged in revision processes, they were able to clarify their own understanding. The use of the Science Writing Heuristic (SWH), and the fact that students who used it made more significant gains in content understanding than students who did not, demonstrated that students benefitted from the scaffolding that the SWH provided. In addition, students benefitted from communicating information with others, and they also benefitted from opportunities to revise their own work.

Towndrow, Tan, and Venthan (2008) followed a similar line of thought. Their argument maintained that science content learning lies within reflecting on experiences, and reflecting on how experiences connect to new situations. Therefore, they argue that reflection can promote scientific inquiry and a more robust understanding of content material. The use of science reflective journals was taught to a class of 7th grade girls in Singapore, and entries that were initially factual and superficial progressed into more multi-faceted, inquiring pieces of writing. The journals helped students view science learning as an ongoing process. Towndrow, Tan, and Venthan (2008) argued that, if students have opportunities to engage in continuous reflection on what they are learning, they will be more adept at developing questions and thinking beyond the surface level. Therefore, in order to encourage continuous, deep thought, the teacher needs to allow for continuous reflection on classroom material.

Wright, et al. (2016) recognized a growing importance of incorporating literacy practices within the science curriculum, and examined the body of research on the topic, thus far, in order to determine future directions. This study examined articles published in the *Journal of Adolescent and Adult Literacy* that were related to scientific literacy, in order to determine which literacy theories are used to recommend instructional strategies, and to compare the articles in this specific journal with those published in science education journals. 63% of articles focused on vocabulary development, which indicates the strong push to focus on vocabulary and background knowledge, but these approaches do not truly engage students in building their overall literacy skills within the science content area. This indicates a need for researchers to investigate more practices supporting literacy in science, as well as other content areas. The CCSS and NGSS make strong recommendations for incorporating literacy into science, but provide little direction for how to do so, and this may be because a clear path does not exist. Therefore, research is needed to elucidate some practices that educators can use to implement strategies into their classroom that specifically support literacy in the content areas.

Implementing Argument within the Classroom Culture

Through a review of the literature, Cavagnetto (2010) concludes that argument within the science classroom is essential for students to transfer an understanding of scientific practice. Through argument, a student's overall scientific literacy can be supported as this understanding of scientific practice and norms merges with content knowledge. In practice, however, the practice of argument requires students to be able to construct an argument while utilizing appropriate evidence and science processes. At a more fundamental level, the process of argumentation builds overall literacy in the science content area as it develops skills such as metacognition and critical reasoning, and as students are immersed in the overall culture of science. Science cannot be possible without communication, both in writing and discussion. As a means of building these communication skills and familiarizing students with scientific practices, argument-based communication may serve as a useful part of the culture in science classrooms.

More specifically, Erduran and Jimenez-Aleixandre (2007, p. 5) proposed five research-based potential benefits of implementing argument into the science classroom: 1) Supporting cognitive and metacognitive processes and making those processes public through communication. 2) Allowing students to build competence in communication and critical thinking. 3) Empowering students to talk and write about science, and thus, build scientific literacy. 4) Immersing students in the scientific culture. 5) Supporting the development of reasoning skills.

Jimenez-Aleixandre and Rodriguez (2000) proposed that argumentation is a natural process that students engage in while collaborating with other students. They drew a distinction between "doing school" and "doing science," and their research goal was to move science education away from “doing school” to “doing science.” The difference is that “doing science” involves engaging in scientific dialogue or argumentation, because scientific reasoning “involves making arguments to defend choices” (Jimenez-Aleixandre and Rodriguez, 2000, p. 759). Jimenez-Aleixandre and Rodriguez aimed to identify instances of “doing science” in the classroom, which argumentative operations were used in this process, and students’ use of epistemic operations related to knowledge construction. One class of Spanish high school students were observed and videotaped to identify instances of argumentation. The researchers noted that “doing science” is related to the learning environment, and that in working collaboratively, students engage in natural argumentation. One goal of science education is to develop learners’ “capacities to understand how we have come to know and why we believe what we know” (Jimenez-Aleixandre and Rodriguez, 2000, p. 758), and in doing so, they need to be able to communicate their cognitive and metacognitive processes behind those understandings. Since argumentation naturally occurs when students work in groups, this natural collaboration can be utilized to build a classroom culture centered on argumentation, which can be harnessed through writing.

Kelly and Bazerman (2003) examined high-scoring argumentative essays in an undergraduate oceanography class, with the aim of identifying “what constitutes successful performance” (Kelly and Bazerman, 2003, p. 37). They considered the student’s rhetorical moves, the level of generality of claim, and the coherence of arguments. Successful arguments showed a hierarchical structure, multiple cohesive lengths, sentences at the boundaries of sections and subsections that served as links with the other sections, and often-repeated terms that build up cohesion and saliency throughout the paper. This analysis provides science teachers with a model of what high-quality arguments should look like, and allows for reflection and choice-making. Kelly and Bazerman (2003) recommend explicit instruction on scientific discourse, which focuses on students becoming adept with making claims, linking them coherently, and tying those claims to specific data and evidence. Furthermore, they suggest that teachers make the structures of an argument visible and explicit.

Not only is argumentation and communication a goal of science classrooms, but also the NGSS and CCSS have recommended that science teachers integrate literacy into their subject area, and to build on ELA teachers' practice. Like in ELA, students are expected to critique and evaluate evidence to build arguments to support claims. The research by Kelly and Bazerman (2003) provides specific elements of what a "successful" argumentative paper looks like, as well as guidance on how to help students achieve that. These results and discussion can be used to formulate learning experiences that address argumentative writing conventions. With a newfound importance on scientific discourse in the classroom, teachers need to develop strategies to support English Language Learners (ELLs), along with struggling students and the class as a whole, with expressing themselves either in English or in their native language.

González-Howard, McNeill, and Ruttan (2015) described actual lessons from a sheltered English immersion classroom to demonstrate how teachers can help ELLs "engage in argument through evidence." Three strategies were highlighted as follows: "Discussing the meaning of the word or phrase related to argumentation," "Doing a think-aloud to model appropriate language to use during a task," and "Simplifying a complex claim by identifying key concepts in it." These strategies need not only apply to English learner students, but can be used to support all students in general education science classrooms to achieve this specific SEP.

Cheuk (2016) identifies four mechanisms for argumentation in the classroom: content knowledge, facility with the components of an argument, scaffolds, and group-worthy tasks. All of these components need to be considered in designing whole-class instruction, as well as instruction for ELL students, so that students can bring discourse into the classroom through their personal experiences, and feel supported while doing so. In addition, teachers need to consider classroom climate and culture, as well as how collaboration is structured. Cheuk (2016) describes several areas for future research, including an understanding of the "pedagogical content knowledge that teachers need to support this type of learning in our science classrooms" and the design of "instructional tasks that facilitate communicative opportunities that foster generative knowledge among ELLs and mainstream students who engage in argumentation in K-12s science classrooms. (Cheuk, 2006, p. 105) What might be helpful for these future directions, especially in middle school science classrooms, is to identify models of instruction that support this practice, and to evaluate the implementation of these models. With this, a better understanding of argumentative discourse within the science classroom can be gained, and future directions of research and recommendations for teaching practice can be developed.

The Argument-Driven Inquiry (ADI) model, developed by Sampson, Grooms, and Walker (2011), gives students an opportunity to both engage in scientific practices and build their scientific writing skills and content knowledge, as well as their overall scientific literacy. The goals of ADI are for students to learn how to write scientifically by engaging in a realistic writing task and engaging in scientific practices, to provide students with opportunities to read good examples of these tasks that are written with the same goal in mind, to provide them with information about their own content understanding and writing quality, and to give students opportunities to revise their work (Sampson, et al., 2013).

The ADI model, as written, consists of eight steps: 1) identification of the task and research question; 2) collect and analyze data; 3) develop a tentative argument; 4) argumentation session; 5) write an investigation report; 6) double blind group peer review; 7) revise and submit the report; and 8) explicit and reflective discussion (Sampson, et al., 2013).

Cavagnetto (2010), in a study of various orientations to teaching scientific argumentation, noted that immersion in scientific practices was the most effective, suggesting that simply knowing the structure of an argument is not enough for students to be able to argumentatively. He suggests that the goal of argumentation instruction is to transfer an understanding of scientific practice, rather than just argument skills. With this understanding in mind, the ADI model gives students explicit instruction in both argument construction and scientific practice, by allowing students to construct arguments using their own data from their own investigations.

Sampson, et al. (2013) conducted a study to evaluate the effectiveness of the ADI model in science classrooms. Their study was conducted in four high school classrooms and two middle school classrooms, and the researchers assisted teachers with developing a total of sixteen labs in the ADI style and measured the gains students made in their content knowledge and their argumentative writing skills. They collected data through argumentative writing assessments and science content assessments, both graded on rubrics. Researchers found that students' ability to write scientifically and to understand science content showed a significantly large improvement when implemented consistently.

Taking this research further, Grooms, Enderle, and Sampson (2015) conducted a small-scale study that examined two high school chemistry classes in the same district, with similar demographics. One school's students participated in ADI, while the other did not. Pre- and postassessments indicated that students in the ADI class made significant gains in their science content knowledge, scientific writing, and performance tasks, while the non-ADI class only made gains in their science content knowledge.

One issue with this model was that it is fairly extensive, and one major line of research was to determine which aspects of ADI are "nonnegotiable" to produce meaningful student learning results (Sampson, et al., 2013). Therefore, more research on the ADI model is required to determine which features of the ADI model can be modified or shortened, while still yielding meaningful benefits to students' content knowledge and argumentative writing skills.

Problems and Challenges with Implementation

Although argumentative writing may yield many potential benefits to students, there are several obstacles to successful implementation of these practices within the science curriculum. According to Bar, Brosh, and Sneider (2016), the NGSS have established clear targets for assessment, but not a clear pathway to reach the ideals set forth in these standards. Although the authors of this paper focused on the development of "threshold concepts," related to science content, that allow students a foundation for meeting the standards. The same can be argued for every area of science, including the ability to write scientifically. Bar, Brosh, and Sneider (2016) suggest that, in every area of science, teachers must work across grade levels to define these concepts and use a variety of methods to develop these concepts, knowing that they are the foundation for further science understanding. However, for many essential skills taught in science classes, this is much easier said than done.

Kiuhara, et al. (2009), in an effort to inform high school writing reform, examined writing practices used by teachers, evaluated the preparation that teachers received to teach writing, and asked questions to teachers about the importance of writing beyond high school and their students' writing attainment. Overall, the researchers found that science teachers did not require their students to do much writing, and provided very little explicit instruction on writing. They also viewed writing as less important than social studies and language arts teachers did. Potential hypotheses for this phenomenon is that science teachers may not view teaching writing as their responsibility, or that they believe that students already possess needed writing skills (Bar, Brosh, and Sneider, 2016).

This study took place before the adoption of the NGSS, and some improvements may have taken place since then in accordance with these standards. However, the statistics regarding science writing is alarming, and this may contribute to the overall issues with scientific literacy presented in the classroom. This study demonstrates why it is important for science teachers to incorporate scientific literacy within the classroom, starting at the elementary level, because it is imperative that, even if they go into a classroom later in their educations where scientific literacy is not explicitly taught, they will have some of the skills they will need to succeed in scientific writing in the future.

However, science teachers may not be emphasizing scientific literacy skills, including writing in the content area, because they might not feel qualified to do so. Demirel and Cayamaz (2015) conducted a study at Hacettepe University in Turkey aimed to examine teachers' self-efficacy in their ability to teach their students to be scientifically literate. The purpose of this study was to provide feedback to teacher training programs about potential directions for improvement in developing these self-efficacy beliefs within teachers. Responding to a "Self-Efficacy Scale in Scientific Literacy" questionnaire, prospective science and primary school teachers thought their scientific literacy abilities were on a “quite sufficient level,” with prospective science teachers rating their abilities significantly higher than prospective primary school teachers, females higher than males, and science teachers of upperclassman higher than science teachers of lowerclassmen. Demirel and Cayamaz (2015) suggest that in order to increase teacher self-efficacy in science literacy, teacher training programs should provide more direct experience and chances to practice. Without this experience and practice, teachers may be more hesitant to incorporate writing into the science curriculum.

May and Wright (2007) described the Language Across the Curriculum (LAC) movement, which aimed to integrate language as a central component of all content areas in secondary schools. This program was implemented in several countries, including New Zealand. However, this interest decreased as the interest in high-stakes testing grew. While this movement was well-grounded in theory, not all schools implemented these practices. One reason may be because financial resources were not adequately allocated to support this movement. Another reason may have been the lack of teacher buy-in, which may be an issue of professional development. Furthermore, school structures need to support these initiatives. The author claims that secondary teachers are less equipped to teach literacy practices than their elementary school counterparts, and to analyze data for informing instruction. This highlights a need for secondary teachers to continue engaging in professional development that will allow them the skills to continue helping students to build their literacy skills, and for the organizational structures to ensure that these initiatives will be supported.

Summary

The NGSS establish inquiry as an integral part of content standards. Therefore, these standards are pushing the U.S. science curriculum toward an increase in inquiry-based teaching and learning, and placing more emphasis on scientific literacy and writing. If teachers are able to overcome numerous obstacles to utilize the new focus on inquiry and collaborative practices to deliver instruction on scientific writing, The research demonstrates that students show improved content knowledge and improved ability to communicate scientifically through argumentative writing when teachers are able to successfully combine inquiry and collaboration with argumentative writing. Therefore, the use of inquiry-based activities, such as the ADI model, as a context for these argumentative writing practices would be a useful tool for science teachers to impart the skills that students are required to have under the NGSS and CCSS. However, teachers' ability to implement this kind of instruction would require schools and districts to address certain limitations, such as teacher self-efficacy, access to appropriate professional development, and the inherent educational bias against fundamental literacy instruction in the science curriculum.

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