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Coordinating Scientific Argumentation and the Next Generation Science Standards through Argument Driven Inquiry

Abstract

Scientific argumentation is an essential activity for the development and refinement of scientific knowledge. Additionally, fostering argumentation related to scientific concepts can help students engage in a variety of essential scientific practices and enhance their science content knowledge. With the increasing prevalence and emphasis on argumentation skills within the current standards movement, i.e. Common Core State Standards and Next Generation Science Standards, teachers need access to productive approaches for engaging their students in this essential practice of science in order to promote students' development toward science proficiency. This article provides teachers with one possible instructional model, Argument-Driven Inquiry, that will allow them to structure their laboratory activities to support students' engagement in scientific argumentation while also emphasizing the disciplinary core ideas and cross cutting concepts of science.

Keywords: argumentation, instruction, standards, proficiency, science

What Is Scientific Argumentation and Why Is It important in Science?

Scientific argumentation "is a mode of logical discourse whose goal is to tease out the relationship between ideas and the evidence" (Duschl, Schweingruber and Shouse, 2007, p. 33). In many ways scientific argumentation is the process by which *science,* as a discipline, develops and refines knowledge. When scientists put forth arguments in support of new ideas, the claims, supporting evidence, and rationales or justifications of evidence, are critiqued and evaluated by other scientists. The cyclical process of critique, refinement, and evaluation then leads to scientific arguments that are robust and supported by sound evidence and scientific reasoning. Scientific argumentation is a key epistemic activity of the scientific community (Duschl, 2008), and is a characteristic that differentiates science from other bodies of knowledge. Given the importance of scientific argumentation within the scientific community, scientific argumentation should also play a prominent role in science education and science classrooms. The new framework for the Next Generation Science Standards (NGSS) (NRC, 2012) further supports the role of scientific argumentation as a bridge between the scientific community and the science classroom by suggesting that, "engaging in argumentation from evidence about an explanation supports students' understanding of the reasons and empirical evidence for that explanation, demonstrating that science is a body of knowledge rooted in evidence" (p. 44).

How Is Argumentation Addressed in the NGSS Framework?

The conceptual framework for the NGSS is intended to set the tone for the development of new national science standards as well as promote a renewed vision of science and engineering education. The NGSS framework provides an enhanced vision of science education that focuses on developing students' deeper understanding of the major crosscutting concepts and practices of science and engineering. Central to this new vision are "important practices, such as modeling, developing explanations, and engaging in critique and evaluation (argumentation), that have too often been underemphasized in the context of science education" (NRC, 2012, p. 44). Thus, these fundamental practices within science and engineering have been placed at the forefront of the new framework and identified as eight practices essential to the K12 science and engineering curriculum, which include:

1. Asking questions (for science) and defining problems (for engineering);
2. Developing and using models;
3. Planning and carrying out investigations;
4. Analyzing and interpreting data;
5. Using mathematics and computational thinking;
6. Constructing explanation (for science) and designing solutions (for engineering);
7. Engaging in argument from evidence; and,
8. Obtaining, evaluating, and communicating information (NRC, 2012, p. 49).

The NGSS framework further elaborates on the centrality of argumentation with respect to science and engineering. Figure 1 below shows how evaluation, i.e., argument, critique, and analysis, serve as a common practice between the investigative and solution or explanatory aspects of science and engineering.

Figure 1

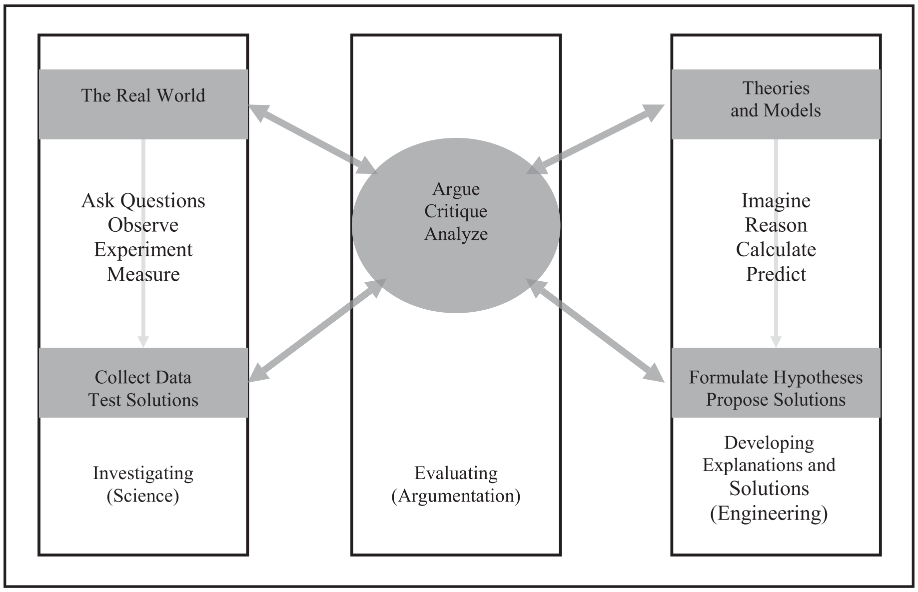

Figure 1. Evaluation is a central component of science and engineering [Figure reproduced from the NGSS framework (NRC, 2012, p. 45), originally figure 3-1]

Argumentation within the NGSS

Taking cues from the *Framework*, the Next Generation Science Standards (NGSS Lead States, 2013) operationalize the essential practices, disciplinary core ideas, and crosscutting concepts of science as a body of knowledge through the identification of student performance expectations. Many of the performance expectations can be tied to multiple essential practices given the unavoidable overlap between aspects of the essential practices. For example, *arguing from evidence* (essential practice #7) also entails *analyzing and interpreting data* (essential practice #4) – i.e. constructing the evidence from which to argue – those data were likely gathered as a result of *planning and carrying out an investigation* (essential practice #3), and engaging in argument from evidence is itself a form of *obtaining, evaluating, and communicating information* (essential practice #8).

Even though the essential practice of 'scientific argumentation' represents only one of the eight identified in the *framework* and the NGSS, it can serve a key role within learning contexts to foster students understanding of science content. Additionally, as shown in Figure 1 above, scientific argumentation is central to coordinating and bridging the work of scientists and engineers. Given the importance of argumentation within science, it is not surprising that the epistemic characteristic related to the development and refinement of scientific knowledge features prominently in the NGSS.

A review of performance objectives across multiple grade spans and disciplinary core ideas reveals several stems and phrases that demonstrate the abundance of objectives related to students' abilities to engage in scientific argumentation. The essential practice of *engage in argument from evidence* presents itself through the following phrases:

-evaluate the claims, evidence, and reasoning…
-construct an argument based on evidence…
-construct and present arguments using evidence…
-evaluate the validity and reliability of claims…
-analyze data to support a claim…
-evaluate the evidence…
-make and defend a claim based on evidence…
-evaluate the evidence supporting claims…
-use mathematical representations to support a claim…

The prevalence of these phrases throughout the NGSS further establishes the need to focus on implementing instruction involving argumentation in science classrooms.

The Role of Science Proficiency

In order to accomplish the goals described in the NGSS framework, it is likely that science curricula and classroom instruction will need to be enhanced to afford students the opportunity to engage in the practices and discourse of science (Duschl et al., 2007). Broadly speaking, science teaching and learning of this nature could be described as teaching for science proficiency, which is described in the National Research Council's (NRC) publication, *Taking Science to School* (TSTS) (Duschl et al., 2007). The TSTS report suggests that quality science teaching entails a focus on four strands of science proficiency, which also align with the vision of the conceptual framework for the NGSS. The four strands of science proficiency are:

1. Knowing, using, and interpreting scientific explanations of the natural world;
2. Generating and evaluating scientific evidence and explanations;
3. Understanding the nature and development of scientific knowledge; and,
4. Participating productively in scientific practices and discourse (Duschl et al., 2007; NRC, 2012, p. 251).

Therefore, a classroom environment that privileges science teaching and learning aligned with the constructs of science proficiency is more likely to move science education toward the vision supported by the NGSS framework. It is important to note that although the strands of science proficiency may seem distinct, "these strands are not independent or separable in the practice of science, nor in the teaching and learning of science. Rather, they are mutually supportive – students' advances in one strand tend to leverage or promote advances in other strands" (NRC, 2012, p. 252).

Scientific Argumentation and Science Proficiency within the Context of Argument-Driven Inquiry

Coordinating the vision of science teaching and learning described by the framework for the NGSS and other constructs such as science proficiency will likely require that teachers implement new instructional strategies which privilege the essential practices of science. To the greatest extent possible, teachers should choose instructional strategies that are evidence based and offer the greatest potential for their students to experience science instruction that is both authentic and educative. Additionally, teachers will need access to instructional models that offer efficient and effective approaches for addressing the myriad practices and standards that may not have held a prominent role in their classroom previously, but are now the emphasis of the new standards.

We propose that the Argument-Driven Inquiry (ADI) instructional model (Sampson, Grooms, & Walker, 2009; 2011) is one strategy that is designed to foster the development of the four key aspects of scientific proficiency and moves the essential practices of science, as described in the NGSS framework, and operationalized by the NGSS, to a more prominent position within the science classroom and laboratory investigations. Classroom activities structured according to the ADI model engage students in data collection and analysis, argument generation, group argumentation, scientific writing, and double blind peer review processes. The ADI instructional model aligns well with various aspects of the NGSS and scientific proficiency frameworks and provides a way for students to develop the knowledge and skills they need to be proficient in science while in school. The discussion that follows is a brief description of the ADI model and how it could be useful for teachers that wish to shift their instruction to be aligned with the practices identified in the NGSS and the strands of science proficiency.

The ADI instructional model can serve as a template for teachers to restructure laboratory investigations to allow for a more authentic and educative experience for students. Figure 2, shows the interconnections of the eight stages of the ADI instructional model. Laboratory activities aligned with the ADI model, center on a guiding question (Stage 1), such as: "How does the concentration of salt water influence the rate of osmosis?" or "How can you predict if a material will float or sink in water or in alcohol?" The identification of the task and guiding question for the lab is similar to other instructional models such as the *Science Writing Heuristic* (Wallace, Hand, & Yang, 2004) or the *5E Learning Cycle* (Bybee et al., 2006). Students, working in small groups, are then tasked with developing an investigation plan that will lead to the generation of data and evidence (Stage 2) that can then be used to craft a scientific argument, which provides a response to the initial guiding question (Stage 3). It is important to note that students are not left on their own in an open-inquiry or discovery learning situation when they are developing their investigation plan or collecting data. During these stages the teacher actively engages the student groups to ensure that the procedures they develop are productive, efficient (from a time and available materials perspective) and safe. As such, investigations aligned to the ADI model would be classified as guided inquiry activities, given that the teacher has proposed the question and the students generate the methods to answer the question (Bell, Smetana, & Binns, 2005).

When the students generate their scientific arguments during Stage 3 of the ADI model, a central piece of equipment is the group's personal whiteboard, approximately two feet by three feet in size. The students craft their scientific argument using the whiteboard template they are provided so their claim, evidence, and the justification of their evidence are clearly visible. Using a display medium

Figure 2

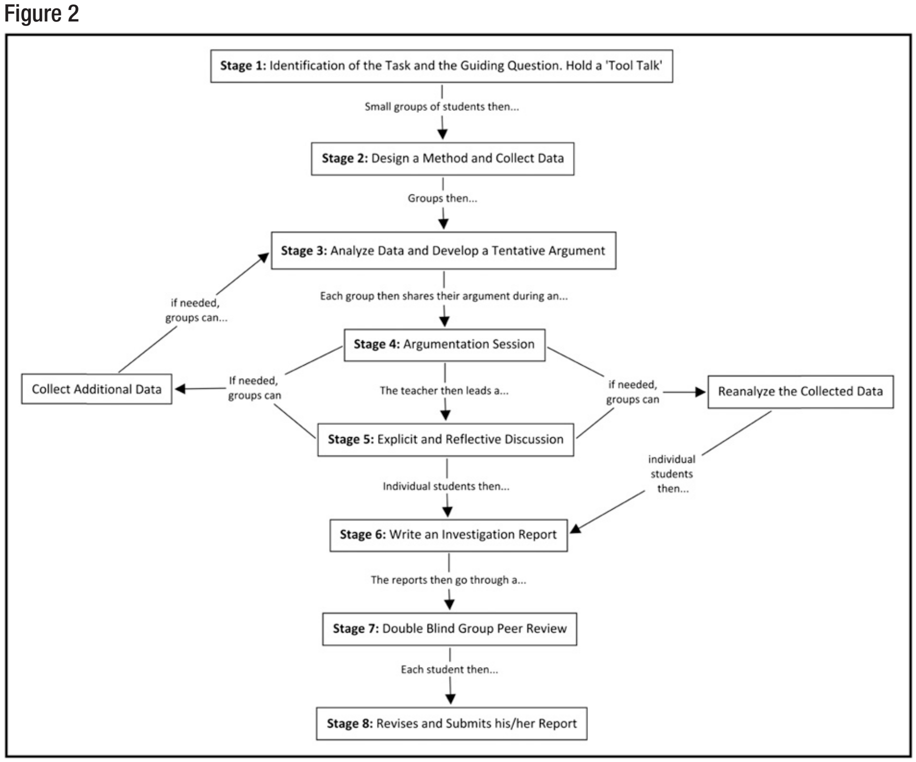

Figure 2. The eight stages of the Argument-Driven Inquiry instructional model [For a complete description of the various stages within the context of an activity see: Enderle et al., 2013 or Sampson & Gleim, 2009.]

such as the whiteboard allows the teacher to easily view the group's work and ask appropriate questions while the group attempts to coordinate the three aspects of their scientific argument.

Once the students have generated their data and evidence and developed their scientific argument each of the small groups shares their scientific argument during the argumentation session where other groups critique the validity and soundness of their classmates' arguments (Stage 4). The argumentation stage of the model is included because research suggests that learning is enhanced when students are exposed to the ideas of their peers and evaluate the merits of competing ideas (Duschl et al., 2007; Linn & Eylon, 2006). During the argumentation session members from each group rotate to other groups in a round-robin format so that they may view the whiteboards displaying that group's scientific argument. One member from each group remains at his or her own station to act as a presenter and shares the group's argument with the visiting audience. Pending the outcome of the argumentation session, the student groups may be compelled to collect additional data or reanalyze the data they collected if their argument is lacking in some way. Additionally, the teacher plays an active role in helping students negotiate potential differences between student groups (Stage 5) and ensures that student learning is consistent with accepted scientific concepts. It is not the intention of the ADI model to allow students' alternative scientific conceptions to go unchallenged.

Next, the students engage in writing an individual report (Stage 6) that presents the purpose and methods of their investigation, and their scientific argument. The process of writing the investigation report serves as an additional opportunity to help students learn and retain the target concepts associated with the investigation (Indrisano & Paratore, 2005). The student reports then undergo a double blind, group peer-review (Stage 7), which allows students an additional opportunity to critique their classmates' arguments, provide and receive feedback and negotiate the outcomes of the investigation. During the peer-review session, the students are provided rubrics that specify the important criteria for each section of the report. The students use those rubrics to provide feedback to their peers and identify strengths and weaknesses of their individual reports. Finally, the students are allowed to revise their investigation reports, based on the feedback from their peers and then submit their reports to the teacher (Stage 8).

When students participate in laboratory activities aligned with the ADI model, they are afforded several opportunities to engage in scientific argumentation and the critique and evaluation of evidence within and across small groups. Thus, each stage of the ADI model involves the students in the essential practices and discourse of the scientific community. Figure 3 further identifies how the various stages of the ADI instructional model allow for the incorporation of the essential practices described in the NGSS framework and the four strands of science proficiency, which are consistent with quality science teaching and learning.

The alignment between the ADI instructional model and the NGSS framework is a compelling reason for incorporating ADI-based activities into the science classroom. However, it is important to note, that the ADI model is only one strategy that may prove useful in addressing the new science standards and promoting quality science teaching and learning. Furthermore, the ADI model is intended to provide a structure for laboratory investigations, thus it is not appropriate for all teaching that takes place within a science course. In order for teachers to move their instructional practices toward the vision of science teaching and learning supported by the new standards they must incorporate a variety of instructional approaches that provide their students with multiple opportunities and multiple contexts for learning and applying the essential practices of science. The ADI model is shared here simply as a useful strategy for teachers to add to their teaching 'tool box.' It is not intended to be a 'magic pill,' capable of addressing all of the challenges in science education.

Figure 3

Elements of Quality Science Teaching and Learning		Stages of the ADI Instructional Model: Identification of the task and guiding question	Design a method and collect data	Analyze data and develop a tentative argument	Argumentation session	Explicit and reflective discussion	Write an investigation report	Double blind peer review	Revise and resubmit investigation report
Essential Practices	Ask questions (science) and define problems (engineering)	●							
	Develop and use models			●		●			
	Plan and carry out investigations		●						
	Analyze and interpret data			●	●				
	Use mathematics and computational thinking			●					
	Construct explanations (science) and design solutions (engineering)			●			●		
	Engage in argument from evidence			●	●			●	
	Obtain, evaluate, and communicate information		●	●	●		●	●	●
Science Proficiency	Know, use, and interpret scientific explanations			●	●				
	Generate and evaluate scientific evidence and explanations		●	●	●				
	Understand the nature and development of scientific knowledge					●			
	Participate productively in scientific practices and discourse		●	●	●		●	●	●

Figure 3. Alignment of ADI, essential practices of science, and the aspects of science proficiency

Table 1 Description of assessments used in a comparison study of the ADI instructional model

Assessment	Nature of the Task	Description of the Task	Time Allotted
Content Knowledge	Extended response items aligned to content area "big ideas"	Questions required students to describe a scientific phenomena then apply their understanding to explain a related scenario	50 minutes
Scientific Writing	Essay, interpretation of data and responding to a prompt	Students analyze a data table, critique a flawed argument and provide an alternative argument	50 minutes
Performance Task	Lab practical and extend response	Students develop and conduct an investigation to identify an unknown and provide an argument in response to the guiding question	50 minutes

Additional Evidence for ADI

The ADI instructional model has been implemented and researched in a variety of contexts from secondary school to post-secondary science classrooms (Enderle et al., 2012; Grooms et al., 2012; Sampson et al., 2013; Walker & Sampson, 2013). One recent, small-scale study compared the learning gains of high school chemistry students who completed a course where ADI investigations were used during laboratory activities to students who did not experience ADI in their chemistry course. The two schools were located within the same school district and consisted of similar student demographics. As part of this study, students completed several pre- and post-assessments (developed by the researchers), which were designed to measure their abilities with respect to science content knowledge, scientific writing, and conducting a scientific investigation or a performance task. These assessments are briefly described in Table 1. Each assessment was scored by members of the research team using a rubric that was generated from an expert response to each content assessment item, writing prompt, or performance task. In order to ensure consistent scoring, the rating teams scored a similar set of assessments (representing 20% of the sample) and an inter-rater reliability was calculated in the form of an intraclass correlation (ICC). An ICC above 0.6 is considered substantial agreement between raters (Landis & Koch, 1977). The ICC values for each instrument used in this study are as follows: content assessment, 0.90; writing assessment, 0.62; and performance task, 0.79.

The results presented in Figure 4 display the effect sizes for the gains the students showed in each course, based on a paired-samples t test comparing students' pre- and post-assessment scores. If a group of students does not demonstrate a significant learning gain (i.e., there is no difference between their pre- and post-assessment scores) then the associated effect size is zero. Alternatively, it is possible to have small changes in pre- to post-assessment scores that are considered statistically significant, but, practically speaking, those differences may not be very meaningful. Using effect sizes provides additional information about the practical relevance of the differences observed between pre- and post-assessment scores. To that end, effect sizes are interpreted using the following scale: small = 0.2, medium = 0.5, and large > 0.8 (Cohen, 1992). Over the span of the school year, the students in the course that incorporated ADI laboratory investigations made significant gains on all the assessments. The students in the non-ADI course only made significant gains in their science content knowledge. Additionally, the gains the students in the ADI course achieved are actually meaningful when measured by effect size. Applying the scale above, the gains in science content knowledge were very large for both groups, the gains on the performance task were only moderate and the gains on scientific writing were small, but these gains are more important given that the students in the non-ADI course did not show any gains in the areas of scientific writing or in their ability to design investigations. When taken together, these results suggest that using the ADI instructional model during laboratory investigations has the potential to produce greater learning gains in areas related to the essential practices and strands of science proficiency,

Figure 4

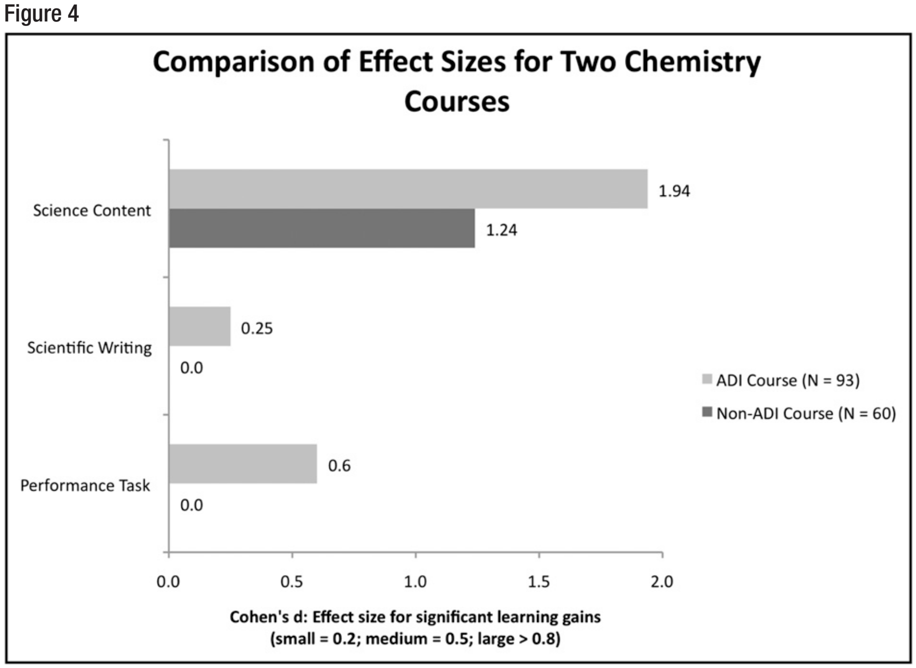

Figure 4. Comparison of learning gains by effect sizes for students in an ADI course and non-ADI course

which are supported within the framework for the NGSS.

Conclusions and Implications

The conceptual framework for the Next Generation Science Standards, and the standards themselves, present a vision for science teaching and learning that privileges science classrooms where students are given opportunities to generate, critique, and evaluate scientific evidence in an effort to develop scientific explanations and arguments. In order to achieve this vision of science teaching and learning, it is likely that classroom instruction will need to be restructured to align with these values and the essential practices of science identified within the framework and standards. We have presented one promising strategy, the Argument-Driven Inquiry instructional model, from a variety of approaches, which may be useful to science educators. Quality science teaching and learning will need to incorporate diverse modes of instruction in order to achieve the greatest benefits. By implementing the ADI model for laboratory investigations, teachers will be well on their way to developing the robust pedagogical tools necessary to realize the vision of science teaching and learning described within the NGSS framework.

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