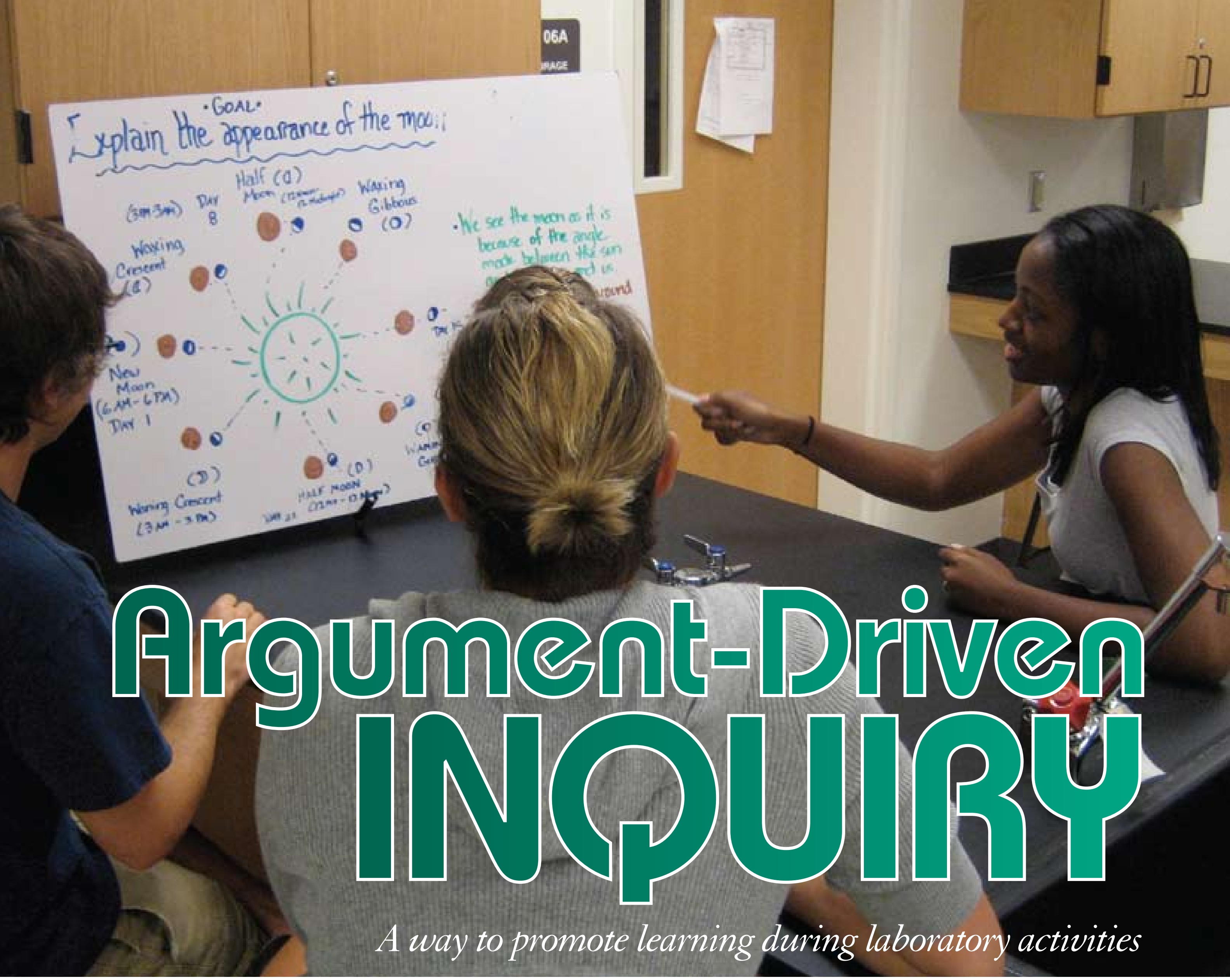


Argument-Driven INQUIRY

A way to promote learning during laboratory activities

Victor Sampson, Jonathon Grooms, and Joi Walker

In *America's Lab Report: Investigations in High School Science* (2005), the National Research Council (NRC) makes several suggestions for how laboratory activities can be changed to improve students' skills and understanding of science: First, laboratory activities need to be more inquiry-based so students can develop practical skills and an understanding of the ambiguity and complexity associated with empirical work in science. Second, students need opportunities to read, write, and engage in critical discussions as they work. Finally, it is important to encourage students to construct or critique arguments (i.e., an explanation supported by one or more reasons) and to embed diagnostic, formative, or educative assessment into the instruction sequence. The NRC describes laboratory-based instruction that fulfills these requirements as an integrated instructional unit.

Argument-Driven Inquiry (ADI) is an instructional model that enables science teachers to transform a traditional laboratory activity into a short integrated instructional unit. The model helps teachers meet the goals outlined by the NRC by providing opportunities for students to design their own investigations, gather and analyze data, communicate their ideas with others during structured and interactive argumentation sessions, write investigation reports to share and document their work, and engage in peer review during a laboratory investigation. Current research indicates that this type of instruction is a more effective way to enhance students' understanding of content and the development of scientific knowledge than traditional lab activities (NRC 2007). Integrated instructional units also appear to be an effective way to cultivate students' interest in science and help them develop reading, writing, and verbal communication skills.

The ADI instructional model

The ADI instructional model consists of the following steps:

- The *identification of a task* that creates a need for students to make sense of a phenomenon or solve a problem;
- the *generation and analysis of data* by small groups of students using a method of their own design;
- the *production of a tentative argument* by each group that articulates and justifies an explanation in a medium that can be shared with others;
- an *argumentation session* in which each group shares its argument and then critiques and refines its explanations;
- an *investigation report* written by individual students that explains the goal of the work and the method used, and provides a well-reasoned argument;
- a *double-blind peer review* of these reports to ensure quality and generate high-quality feedback for the individual authors;
- the subsequent *revision of the report* based on the results of the peer review; and
- an *explicit and reflective discussion* about the inquiry.

To illustrate how the ADI instructional model works, we describe an ADI lesson developed for a 10th-grade chemistry class. This example lesson was designed to help students understand the nature of chemical reactions (NRC 1996; Content Standard C, grades 9–12) and develop the abilities needed to do scientific inquiry (NRC 1996; Content Standard A, grades 9–12). The lesson also gives students an opportunity to improve their writing and verbal communication skills, their understanding of the writing process, and their ability to interpret evidence and reason in a scientific manner. In the following sections, we describe the purpose of each ADI step, the nature of classroom activity during each step, and how to support students as they work.

Identification of the task

For this first ADI step, teachers initiate the learning sequence and introduce the major topic to be studied. The primary purpose of this step is to capture students' attention, establish connections between past and present learning experiences, and highlight upcoming activities. At the end of this stage, students should be mentally engaged in the topic and should begin to think about how it relates to their previous class experiences.

We recommend using a handout that includes a brief introduction and a researchable question to answer, a problem to solve, or a task to complete. This handout can also include other important information that students can use during the second step of the instructional model (e.g., a list of materials that can be used in the lab or safety guidelines). Figure 1 includes the introduction and the problem we gave students at the beginning of the example lesson.

Generation and analysis of data

During this second step, students work in collaborative groups to develop and implement a method to address the problem. The intention is to provide students with an opportunity to "interact directly with the material world using the tools, data-collection techniques, models, and theories of science" (NRC 2005, p. 3). This type of practical work can be challenging for students, so it helps if teachers provide them with a list of materials that can be used during the investigation and some hints to help get them started. We usually include this information in the handout that we supply to students at the beginning of the investigation under the headings "Materials Available" and "Getting Started."

In our chemistry lab, for example, we told students they could use materials such as well plates, pH paper, test tubes, a list of solubility rules, and a polyatomic ion chart during their investigation. We also suggested that students first gather data about what happens when the reactants are mixed and then use the solubility rules and list of polyatomic ions to determine the products of the four reactions. We cautioned students about safety concerns, especially when handling acids.

Teachers can also require students to write out an investigation proposal that describes the method they intend to use, especially if the investigation is complex or

FIGURE 1

Information provided at the beginning of the example lesson.

Introduction: You have already seen many chemical reactions. You have also learned how to recognize the evidence of a chemical reaction. These include a color change, the formation of a solid, production of bubbles, or a change in pH or temperature. Chemists describe these reactions using chemical formulas. You have learned how to read chemical formulas and how to balance them. But if we mix two or more products together, how can we figure out what products are formed? In this investigation, you will need to figure out how to identify the products that are formed during a chemical reaction.

The problem: Determine the balanced chemical formula for the following reactions:

$HCl\ (aq) + Zn\ (s) \rightarrow$
$HCl\ (aq) + NaHCO_3\ (s) \rightarrow$
$Al\ (s) + H_2SO_4\ (aq) \rightarrow$
$CuCl_2\ (aq) + AgNO_3\ (aq) \rightarrow$

requires the use of potentially hazardous chemicals. A teacher can then quickly check group proposals to ensure that the student-designed investigations will be fruitful and safe. These types of strategies steer students in a productive direction and support them as they develop and implement their investigations.

It is important that the classroom teacher circulate from group to group to serve as a resource person for students as they work through this step of the model. Teachers need to ensure that students think about what they are doing and why they are doing it as they gather data. Teachers can ask probing questions such as, "How do you know that your data is reliable?" "What else do you need to figure out?" or "Do you have enough data to support your ideas?"

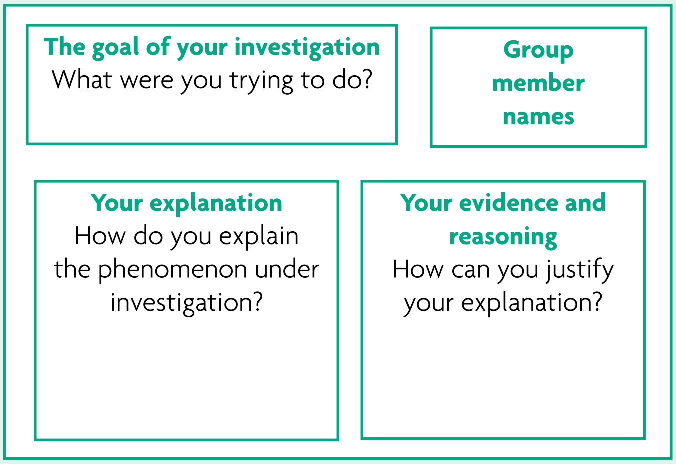
Production of a tentative argument

The next stage of ADI calls for students to create an argument that consists of an explanation, evidence, and reasoning in a medium that can be shared with others (e.g., a large whiteboard) (Figure 2).

FIGURE 2

Sample whiteboard for tentative arguments.

This type of medium helps students make their thinking and reasoning visible.



The explanation component of the argument is an answer to the research question that guides the investigation. Depending on the question, this explanation can offer a solution to a problem (e.g., the unknown powder is sodium chloride), articulate a descriptive relationship (e.g., as the temperature of a gas increases, so does its volume), or provide a causal mechanism (e.g., pressure is the result of the force exerted by gas molecules hitting the walls of a container).

The evidence component of the argument includes measurements or observations to support the validity of the explanation. This evidence can take on a number of forms ranging from traditional numerical data (e.g., mass, time, pH, or temperature) to qualitative observations (e.g., the color changed, or a gas evolved). However, for this information to be considered evidence, it should show a trend over time, a difference between groups, or a relationship among variables.

The reasoning component of the argument includes a rationalization that indicates why the evidence supports the claim and why the evidence provided should be counted as evidence. In our chemistry lesson, students produced an argument that included a balanced chemical equation for each reaction (their explanation), the evidence they were using to support their ideas (a precipitate formed or a gas evolved), and their reasoning (precipitates form as a result of a double-replacement reaction where at least one product is insoluble).

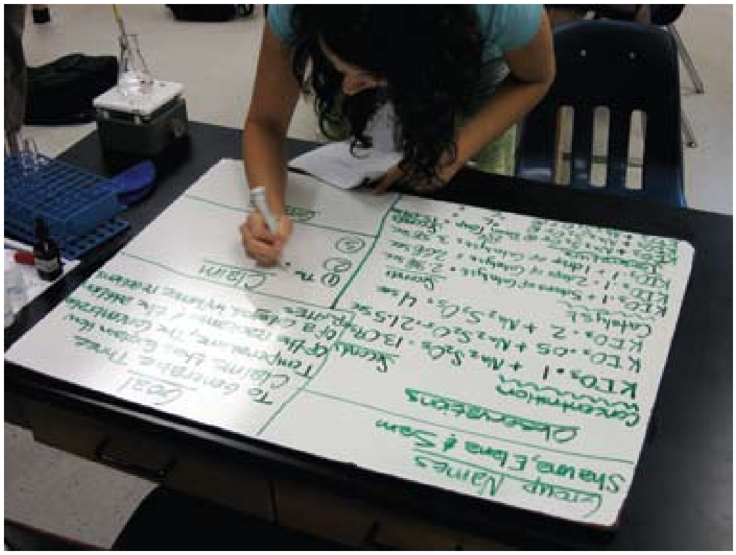
This step of the model is designed to focus students' attention on the importance of argument in science. Students need to understand that scientists must be able to support their explanations with evidence and reasoning. This step also helps students learn how to determine if available data are relevant, sufficient, and convincing enough to support their claims. More important, this step provides teachers and other students with a window into students' thinking by making their ideas, evidence, and reasoning visible. This in turn enables students to evaluate competing ideas and weed out explanations that are inaccurate or do not fit with the available data. This process helps students make sense of what they are doing and seeing.

The argumentation session

We use the term *argumentation session* to describe the fourth ADI step. In this step, students are given an opportunity to evaluate or revise the products, processes, and contexts of their investigations in a whole-class or small-group format. We include this step in the model because research indicates that students learn more when they are exposed to the ideas of others, respond to peers' questions and challenges, articulate more substantial warrants for their views, and evaluate the merits of competing ideas (NRC 2007). The step also provides an opportunity for teachers to assess student progress and thinking.

The argumentation sessions are designed to promote learning by taking advantage of the variation in student ideas and helping groups negotiate criteria for valid inferences. For example, Linn and Eylon suggest that students often have a repertoire of ideas about a given phenomenon that includes "ideas that are sound, contradictory, confused, idiosyncratic, arbitrary, and based on flimsy evidence" and that "most students lack criteria for distinguishing between these ideas" (2006, p. 8). Similarly, Kuhn and Reiser (2005) suggest that students tend to rely on criteria such as plausibility or the teacher's authority to determine which ideas to accept or reject during discussions and debates. Engaging students in argumentation sessions during a laboratory activity allows students to learn how to distinguish between ideas using rigorous scientific criteria and develop scientific habits of mind.

Supporting and promoting this type of interaction inside the classroom is often difficult because this type of activity is foreign to most students. This is one reason why students are required to generate their arguments in a medium that can be seen by others (e.g., a whiteboard), which provides a way for students to focus their attention on evaluating evidence and reasoning rather than attacking the source of the ideas. We also recommend that teachers use a round-robin format rather than a whole-class presentation format. In this format, one person stays at the group's work station to share its ideas, while the rest of the group members visit the other groups' work stations one at a time to listen to and critique the explanations developed by their classmates. This type of format ensures that all ideas are heard and more students are actively involved.



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A student creates a whiteboard.

The investigation report

ADI, as noted earlier, is designed to promote and support writing across the curriculum in a manner that enhances students' written communication skills and their understanding of science. We integrated opportunities to write into this instructional model because writing is an important part of *doing* science. Scientists must be able to read and understand the writing of others, evaluate its worth, and share the results of their own research through writing. Writing requires students to articulate their thinking in a clear and concise manner (i.e., learning to write), encourages metacognition, and improves student understanding of the content (i.e., writing to learn).

To encourage students to learn how to write in science and write to learn about science, we recommend a nontraditional lab report that is more persuasive than expository in nature. This format is designed to encourage students to think about what they know, how they know it, and why they believe it. Students produce an "investigation report" that answers three basic questions:

1. "What were you trying to do and why?"
2. "What did you do and why?" and
3. "What is your argument?"

The three questions target the same information included in traditional lab reports, but do so in a way that requires students to think about the content and the audience as they write.

Students are directed to write a two-page report that dedicates one section to each of these questions. Students are also instructed to include the data they gathered in tables or graphs (when possible) as evidence to support their explanation in the third section of the report ("What is your argument?").

Double-blind peer review

The next stage of this instructional model is a double-blind peer review. Once students complete their investigation reports, they should print out three copies (using only a number to identify the paper). The teacher then collects these reports and randomly distributes three or four reports to each lab group along with a peer-review sheet (Figure 3, p. 46), which includes a list of criteria that are used to evaluate the quality of an investigation report and space to provide the author with feedback. The review criteria include questions such as: "Did the author use appropriate terms (e.g., *experiment, observation,* or *interpretation*) to describe the nature of the investigation?" and "Did the author use reliable evidence to support his or her explanation?"

The lab groups review each report as a team and then decide if it can be accepted, or if it needs to be revised based on the criteria included on the peer-review sheet. Groups are also required to provide explicit feedback to the author about what needs to be done to improve the quality of the report.

This step provides students with educative feedback, encourages them to develop and use appropriate standards

FIGURE 3

Peer-review sheet used by students during the double-blind peer review.

This is an abbreviated version of the peer-review sheet. The full worksheet is available online (see "On the web").

Criteria	No	Needs improvement	Good	Excellent
Goals				
Did the author introduce the phenomenon under investigation and the problem to be solved?	______	______	______	______
Did the author make the research question or goals of the investigation clear and explicit?	______	______	______	______
Did the author explain why the work was done and why this work is useful or needed?	______	______	______	______
Explain why your group gave any "Needs improvement" or "No" marks in the space below:				
Investigation				
Did the author describe how he or she went about the work?	______	______	______	______
Did the author explain why the work was done in this way?	______	______	______	______
Did the author use appropriate terms to describe the nature of the investigation (e.g., *experiment, systematic observation, interpretation of an existing data set*)?	______	______	______	______
Explain why your group gave any "Needs improvement" or "No" marks in the space below:				
Argument				
Did the author include a well-articulated explanation that provides a sufficient answer to the research question (i.e., does it explain every-thing that it should)?	______	______	______	______
Is the author's explanation coherent and free from contradictions?	______	______	______	______
Did the author use genuine evidence (trends over time, differences between groups, or relationships between variables) to support the explanation?	______	______	______	______
Explain why your group gave any "Needs improvement" or "No" marks in the space below:				
Writing				
Content: Did the author express his or her ideas clearly and provide the reader with valuable insight?	______	______	______	______
Organization: Does the writing have a sense of purpose and struc-ture?	______	______	______	______
Voice: Does the reader get a sense that someone real is there on the page?	______	______	______	______
Explain why your group gave any "Needs improvement" or "No" marks in the space below:				

Final decision: ______ Accept ________ Revise and resubmit for "what counts" as quality, and helps them be more metacognitive as they work. In addition, groups of students can discuss the validity of scientific claims and explain why a report is good or needs improvement. Students, as a result, begin to adopt more rigorous criteria to evaluate scientific claims and learn the value of peer review in science and in learning.

This type of focus provides a mechanism that can help students improve their ability to write in science. In addition, the review process is more effective because each group of students must reach a consensus about the score on each of the review criteria, which increases the likelihood that students will take the review seriously and improves the overall quality of feedback.

Revision of the report

The reports accepted by the reviewers are given credit (complete) by the teacher and then returned to the author, whereas reports that need to be revised are returned to the author without credit (incomplete). The reviewers accept very few reports, if any, at this stage. Therefore, most students, if not all, are required to revise their report based on the reviewers' feedback.

Revision is an important part of the learning process. Once the reports have been revised, they are then resubmitted to the classroom teacher for a second evaluation, along with the original version of the report and the peer-review sheet. If the revised report has reached an acceptable level of quality, the author is given full credit (complete). However, if it is still unacceptable, it is returned to the author for a second round of revisions. The goal is to encourage students to improve their writing based on educative feedback without imposing a grade-related penalty. Students also become engaged in a writing process that involves construction of a draft, evaluation of the draft, and revision to produce a final product.

Explicit and reflective discussion

Teachers should lead an explicit and reflective discussion about the investigation, which provides an avenue for students to talk about what they have learned regarding the investigation topic, after the peer review is complete. For the example chemistry lesson, students can be asked to explain what they learned about chemical reactions—and if a teacher finds that misconceptions persist, he or she can help students make sense of what they have observed. The teacher can also ask questions about the various tenets of the nature of science, such as how students' work reflects the durable but tentative nature of scientific knowledge or the theory-laden nature of science. These types of conversations help students develop a better understanding of how professional science works.

The teacher can also encourage students to talk about ways to improve the design of an investigation by asking them to evaluate what went well and what did not. The teacher and class can then work together to develop suggestions for future investigations. Our research (Sampson and Grooms 2008) suggests that it is important for teachers to highlight these types of issues, in an explicit manner, and then encourage students to reflect on what they have done and how they can improve investigations to promote student learning.

Benefits of ADI

ADI helps foster scientific literacy and allows students to develop scientific habits of mind, provide evidence for explanations, and think critically about suggested alternatives. This structure also enables teachers to promote reading and writing across the curriculum in a way that supports the learning of science *and* the learning of other school subjects. Overall, we believe this type of approach has great potential and will, over time, enable more students to develop a sophisticated understanding of both the science concepts under study and the process through which scientific concepts are developed, evaluated, and refined. ■

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On the web

Full peer-review sheet: *www.nsta.org/highschool/connections.aspx*

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