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Designing Inquiry-Oriented Science Lab Activities

Teachers can create inquiry-oriented science lab activities that make real-world connections.

***This We Believe* Characteristics**

- Meaningful Learning
- Challenging Curriculum
- Multiple Learning Approaches

*Denotes the corresponding characteristics from AMLE's position paper, *This We Believe*, for this article.

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Two veteran science teachers in a well-performing school district, Mr. Smith and Ms. D'Amico, arrive at school on an ordinary day, excited about the day's lesson. These teachers are well liked, motivated, and knowledgeable in their content area. Both teachers use weekly lab exercises and experiments as formative assessments. In their middle school classrooms, children are engaged and eager to learn. As students walk into Mr. Smith's classroom, a prescribed, step-by-step procedure of the day's experiment is found at each lab station. Only 60 feet down the hallway, students in Ms. D'Amico's class arrive to find only the materials for the day's experiment and a lab rubric at each lab table. In this classroom, students are expected to design their own experiment using materials they choose from the lab table.

Are middle level science classrooms in your school more like Mr. Smith's or Ms. D'Amico's? To what extent do teachers in your school use inquiry-oriented approaches in their science labs? In this article, I contrast the traditional approach to science lab activities that Mr. Smith uses with the inquiry-oriented approach Ms. D'Amico uses. I describe in detail the way Ms. D'Amico implements an inquiry-oriented lab in her classroom and illustrate how teachers can prepare students for standardized assessments while still creating meaningful lessons with real-world connections.

Inquiry as an instructional framework

The emphasis on inquiry today can be traced to the discovery learning movement of the 1960s. The main premise behind any inquiry program is that students learn by doing through the process of problem solving. By posing their own questions in scientific investigations, students are considered the creators of knowledge, whereas teachers are the facilitators of this knowledge creation process. As Bruner (1961) noted, "The practice of discovering for oneself teaches one to acquire information in a way that makes it more readily viable in problem solving" (p. 26).

Inquiry is defined in the National Science Education Standards (NSES) as a content area (National Research Council, 1996), and many state departments of education concur. Many science educators forget that inquiry is not merely a process or method of instruction. This strategy defines the teacher's job as assisting students in the

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process of discovering knowledge, not providing knowledge for them. "Asking theoretical questions, making observations, developing hypotheses, engaging in experimentation, collecting and analyzing data, drawing conclusions, making inferences, and formulating new questions are some of the exciting processes that are practiced through inquiry-based science" (Hammerman, 2006, xxii).

Inquiry allows students to take responsibility for the problems they create or discover. As Sternberg and Lubart (2007) suggested: "Students need to take more responsibility for the problems they choose to solve, and we need to take less. The students will make mistakes and attempt to solve inconsequential or even wrongly posed problems. But they learn from their mistakes" (p. 170). True inquiry revolves around developing student responsibility.

One way to implement an inquiry-based learning program at the middle level is to incorporate activities that relate to authentic, real-life experiences. Students should be encouraged to think like scientists. According to the NSES:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (National Research Council, 1996, p. 23)

Real-world connections to the curriculum enhance the use of inquiry learning in the classroom. Further thoughts and ideas arise when students share their findings and discuss their personal connections. These kinds of teachable moments stimulate inquiry and help students develop higher-order thinking skills as they create hypotheses, analyze and evaluate data, and compare and contrast results of their inquiry activities. Finally, such real-world inquiry learning may help increase student motivation (Renzulli, 1977, 2001).

A "cookbook lab" in Mr. Smith's classroom

Human heart rate is a topic related to the human circulatory system and linked to the NSES grades 5 to 8 life science content standard: "Structure and function in living systems" (NRC, 1996). Various state standards include similar descriptions of this content. Most middle grades life science teachers have incorporated some sort of heart rate experiment in their classrooms at one time or another.

To begin his heart rate lab lesson, Mr. Smith gave his students a question to investigate: How does exercise affect human heart rate? He expected his students to follow prescribed guidelines in a traditional manner, as depicted in Figure 1. In essence, students followed a script that did not encourage creativity and higher-order thinking. After collecting background information, Mr. Smith asked his students to make one prediction based on the teacher-designed question he gave them.

Figure 1
Comparing traditional vs. inquiry lab reports

After the first day of this lab activity, Mr. Smith's students completed a worksheet related to human heart rate. Even though this content had been included on state standardized tests, the expectations in Mr. Smith's traditional classroom led to traditional homework that lacked creativity and scientific thought. On day two, Mr. Smith gave his students a step-by-step checklist for the heart rate experiment (see Figure 1). All students followed this same, prescribed, cookbook procedure that required them to perform jumping jacks as the exercise in the investigation.

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After students conducted the experiment, Mr. Smith asked them to organize the results in data tables and a line graph. Finally, students completed a conclusion section in which they responded to a series of questions. Mr. Smith collected the lab reports at the end of the period, and there was no conversation about the findings or the conclusions.

An inquiry-oriented science lab in Ms. D'Amico's class

Teachers often follow rigidly scripted, cookbook lab exercises that ask students to simply follow instructions and regurgitate information that is already known (Windschitl, 2008). However, one of the most effective ways to assess learning associated with inquiry is through formative lab reports that require students to formulate their own problems, design their own experiments and investigations, and direct their own learning. By completing formative, inquiry-oriented lab reports, students in Ms. D'Amico's science class construct learning at a higher level and demonstrate their ability to form thoughtful hypotheses, develop and apply accurate procedures, and produce valid conclusions.

Step 1: Beginning an inquiry lab

In an inquiry-oriented lab, a teacher may use a guided- or open-inquiry approach. In guided inquiry, the teacher facilitates learning to some degree, providing support for students as they begin to develop testable questions for future investigation. In contrast, during open inquiry students make discoveries on their own, with little support from the teacher. (Editor's note: For a further discussion of these approaches, refer to C. A. Wilson's article in the November 2009 issue of *Middle School Journal*.)

Right from the start, Ms. D'Amico provided a rubric for students as they created their experiment and wrote a lab report (see Figure 2). Students in Ms. D'Amico's class were expected to create their own problem questions related to heart rate, which she eventually approved. Students brainstormed a list of problem questions that they would have liked to investigate, and then focused their investigation on one of these questions with limited guidance from the teacher.

Figure 2
Laboratory report rubric

Ms. D'Amico facilitated inquiry by walking around to all groups and listening to the ideas presented by the members; she then helped students form good research questions based on these ideas. This method of guided inquiry requires teachers to provide ample time for students to deliberate and to ensure that the questions posed come from the students and not the teacher. While this method of teaching obviously takes more time, the outcomes can be very beneficial. The questions produced by students in Ms. D'Amico's classroom included:

- How do sit-ups affect human heart rate compared to push-ups?
- How does the amount of rest between jumping jacks affect human heart rate?
- What are the effects of various exercises on heart rate?
- How does the amount of time one runs in place affect heart rate?
- What are the effects of lung capacity of seventh grade students on human heart rate?

Students who had difficulty forming problems or questions or classifying variables (i.e., dependent or independent) could consult www.sciencebuddies.com, a website designed to assist students with the scientific method process and lab report writing. For example, one student in Ms. D'Amico's class did not understand if time was an independent or dependent variable in an experiment. The student consulted this website for assistance and was asked to follow up with the teacher after this research was complete. The teacher facilitated learning by verifying if the student had correctly identified this variable.

Step 2: Forming hypotheses

Once students established research questions, they worked in cooperative groups to collect background information on the topic of human heart rate. Background information came from students' prior knowledge and experiences, allowing them to make real-world connections. Next, the students generated hypotheses. Ms. D'Amico asked students to develop multiple predictions based on the ideas of members of the cooperative group. By creating various hypotheses while in groups, students were thinking critically about each group member's prediction and, therefore, supporting inquiry learning through the process of metacognition.

The freedom to create their own hypotheses allowed Ms. D'Amico's students to explore what was meaningful to them. For example, one student stated, "If push-ups look more difficult to complete and appear to use more energy, then students [who do push-ups] will have a higher heart rate than those who do sit-ups." Another student stated, "If students have a higher lung capacity (e.g., 3.0 liters of air per breath or above), then their heart rate will be lower than those with a lower lung capacity (e.g., lower than 3.0 liters of air per breath). It is predicted that students will have a lower pulse rate due to their increased lung capacity, which is related to their level of fitness."

Step 3: Reconstructing knowledge with blogging and reflective writing

After the first day of designing an experiment, Ms. D'Amico's students were asked to participate in a blog. She simply posted a guiding question to which the students responded for homework. She posted, for example, "Discuss the initial design of your heart rate experimental problem question and hypothesis. Also, comment on at least two other student problem questions or hypotheses." Ms. D'Amico's students took part in this blog, discussing the problem questions they were investigating and the hypotheses they had created.

Whether a teacher uses a class blog or assigns a reflective writing piece, students engage in metacognition as they reflect on their learning and make real-world connections. The blog or reflective writing piece should be supported with a rubric that gives clear expectations, including requirements for providing clear *explanations and evidence*. The NSES embrace explanation and evidence as components of the "unifying concepts and processes" standard (NRC, 1996), and a rubric should include these components as well as authenticity and connection to the real-world (see Figure 3).

Figure 3
Sample rubric for online blog entries or reflective writing pieces

Students in Ms. D'Amico's class developed critical thinking skills not only by responding to guided questions posted by the teacher but also by dialoguing with other students. Blogs offer numerous opportunities for students to share knowledge, so true inquiry learning takes place as students construct their own learning based on their prior knowledge and based on the knowledge of other students. Consequently, they may actually find new problems that need to be solved.

Step 4: Who needs a checklist? Creating procedures in the inquiry classroom

As the experiment entered day two, Ms. D'Amico's students were creating their own procedures with limited assistance from the teacher. These students used higher-order thinking skills and took ownership of their work by designing their own procedures. By collaborating in cooperative groups, the students could share ideas about their designs in the same way as with an online blog.

It is important that the teacher provides support in an inquiry lesson by facilitating the learning. By asking students to create a draft first, the teacher can assess student progress at that point and provide formative feedback on how students can improve the methods of the investigation. The teacher can also elicit responses from students that point to the crucial elements of an efficient procedural design, such as including multiple trials and keeping variables constant. Through this course of action, students are guided into developing an effective, detailed procedure and will be prepared for these types of questions commonly found on standardized assessments.

Step 5: Collecting data and drawing conclusions

By conducting the experiment, students measured heart rate based on the variables they had originally defined. The NSES include measurement as one of the unifying concepts and processes in science (NRC, 1996). After students conducted their experiments, they collected results and organized data in tables. Ms. D'Amico asked her students to choose the best type of graph for the data presented in the lab report. This allowed her students to think critically about an appropriate graph for the data, whereas the traditional approach used in Mr. Smith's class spoon-fed this information to the students. Inquiry classrooms like Ms. D'Amico's empower students to draw conclusions and describe what was learned from an investigation by using supporting evidence from the data and by making real-world connections. Since many state science assessments include questions related to analyzing data, choosing appropriate graphs, and drawing conclusions, this practice prepares students for these standardized tests.

Step 6: Extending the inquiry

The inquiry does not end when the lab report is complete; students should communicate their findings as real scientists do. Ms. D'Amico's students did this by giving oral presentations in class and by using another blog to share their findings. An example portion of a blog thread is shown in Figure 4. Ms. D'Amico also incorporated a follow-up homework assignment, asking students to share their data with family members. Ideas generated from this discussion were documented and submitted the next day in class and posted online as part of a blog response. These types of follow-up activities help students develop the ability to think metacognitively.

Figure 4
Sample portion of a student reflective blog thread

Ms. D'Amico scored the lab reports according to the criteria in the rubric (Figure 2) and gave her students appropriate feedback to make the most of the inquiry experience. Two days later, while students worked on an independent assignment, Ms. D'Amico conferenced with each student one-on-one to review the graded lab report and provide feedback. This enabled her to focus on specific student strengths and weaknesses to support differentiation.

Inquiry outcomes

One week after the human heart rate lab, Mr. Smith and Ms. D'Amico convened during their grade-level common planning time. The school district designed these meetings to collect and analyze data to make informed decisions that would improve overall student learning. The teachers shared their instructional methods, assessments, and observations of students from the heart rate activities.

Although Mr. Smith and Ms. D'Amico presented similar student achievement data, Ms. D'Amico reported that her students displayed a high level of motivation to complete the task and exhibited curiosity about the topic several days after the activity was completed. Conversely, Mr. Smith shared that his students groaned when they found out that a lab report was required and complained about not being able to do push-ups or sit-ups. A correlation to standardized achievement scores cannot be made from the results of just one lesson, but there is research suggesting that inquiry methods designed to stimulate the scientific process improve student achievement (Beaumont-Walters & Soyibo, 2001; Bybee, 2000; Chang & Mao, 1999). Such research may help to explain why Ms. D'Amico's students were better prepared for other activities later in the year, including the science fair project.

A disclaimer for inquiry teaching

Instructional approaches that look exceptional on paper are often very difficult to implement in real classrooms with students who have diverse learning styles and special needs. Inquiry instruction takes time to develop, and students cannot simply delve into an inquiry learning program if they have not practiced it often. Various books and websites provide teachers sound examples of inquiry for professional development, and the appendix lists recommended resources to help teachers get started. While these resources can be very helpful, teachers best learn how to do inquiry when they actually try it out and reflect on their teaching afterwards.

Teachers must be mindful of the variety of learners in an inquiry-oriented classroom and use the necessary scaffolding to assist students as they work toward their potential (Vygotsky, 1978). For example, providing a checklist like the one shown in Figure 1 can give some needed structure to students who struggle with the inquiry learning process. Also, teachers can strategically design cooperative inquiry groups to match strong students with those who struggle with inquiry. This arrangement allows for students to share knowledge and be leaders.

For example, some students may need the teacher to provide the problem question for the lab investigation to help them get started. By using a teacher-created checklist similar to the traditional example found in Figure 1, some students who need more structure will be able to learn and avoid roadblocks to their own inquiry. When differentiating for diverse learners, it is important for teachers to use flexible cooperative groupings. Such arrangements may benefit English language learners, who can be supported by their peers while the teacher is assisting other students. Finally, guided-inquiry settings that include additional resources, such as visual aids, may help English language learners and students with a variety of special needs thrive as they make connections to their cultures and interests.

A call for inquiry classrooms

As they prepare students for high-stakes state assessments, science teachers are faced with a dilemma: Should they remain complacent and use step-by-step procedures and "cookbook" labs on a regular basis, or should they invest the time and resources needed to create meaningful, inquiry-oriented learning experiences for their students? By using an inquiry approach, educators can spark students' curiosity, increase levels of motivation, inspire creativity, and bring authenticity to learning through real-world lessons. Teachers who implement inquiry learning in this way help to develop lifelong learners. Moreover, because inquiry is central to the NSES and is an important component of most states' science standards, this type of instruction helps students prepare for high-stakes standardized assessments.

Extensions
The author describes a six-step process for developing inquiry lessons in science. How can this process be adapted to other content areas?

Use the six steps outlined in the article as a guide to create an inquiry-oriented lesson. Be sure to adjust the lesson design based on the characteristics of your classroom and your students' learning preferences.

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Appendix
Strategies and resources for implementing inquiry-based science

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