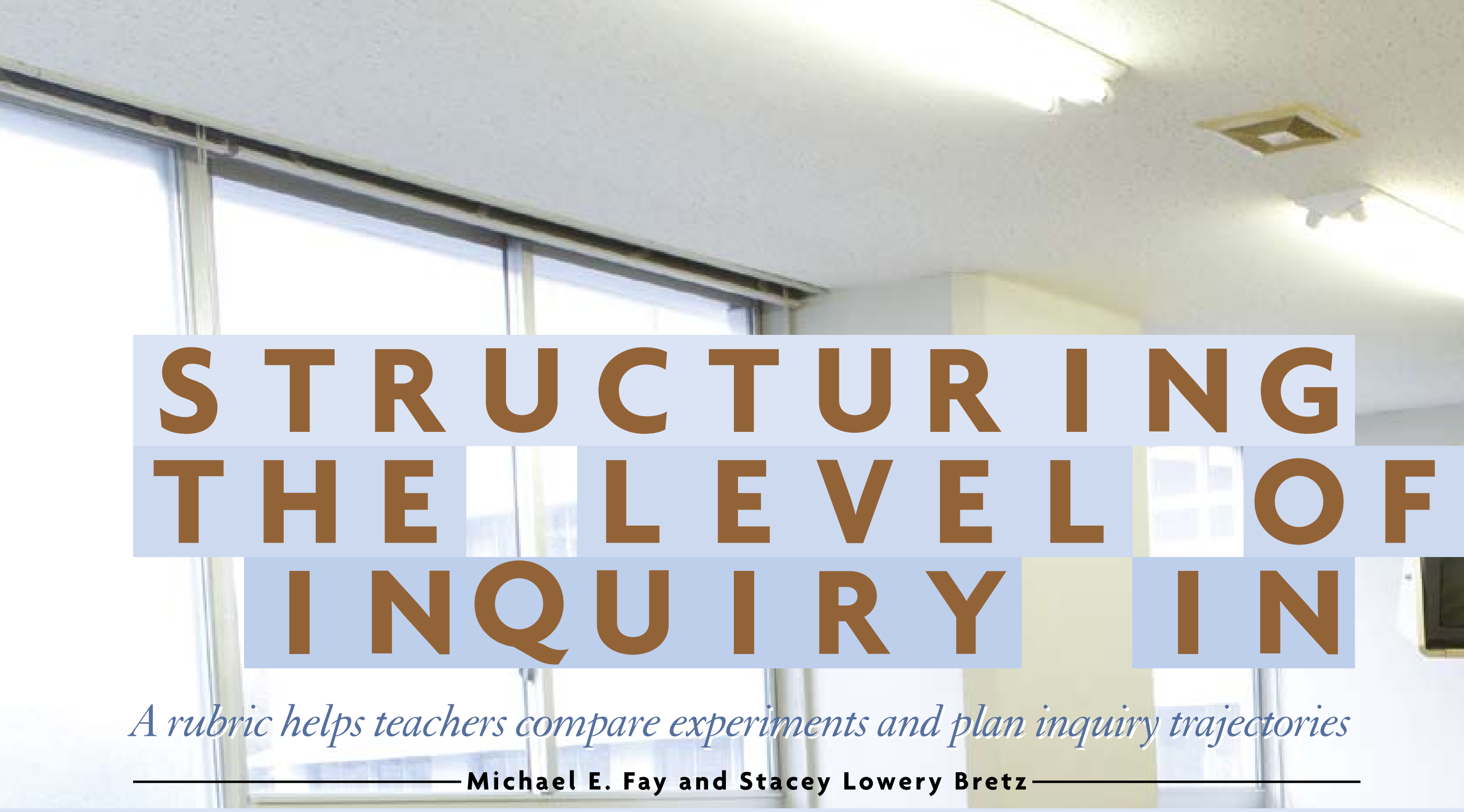

STRUCTURING THE LEVEL OF INQUIRY IN

A rubric helps teachers compare experiments and plan inquiry trajectories

Michael E. Fay and Stacey Lowery Bretz

As the upcoming school year approaches, many science teachers may be looking for new ways to incorporate inquiry in their classrooms. Fortunately, teachers have an array of inquiry activities at their fingertips. The scientific literature, for example, offers a variety of inquiry activities for teachers of all levels, as well as experiments designed to raise students' level of responsibility in the lab over the course of the year (Polacek and Keeling 2005; Reeve, Hammond, and Bradshaw 2004; Regassa and Morrison-Shetlar 2007). As a key feature of the *National Science Education Standards* (NRC 1996), all science teachers are urged to use inquiry in their teaching. But with so many resources available, how can a teacher make an educated decision about which experiments to incorporate into lesson plans? Are some forms of inquiry better than others, or just different? Does one activity exemplify inquiry better than another?

To help teachers select the most appropriate inquiry activities—which vary widely in the structure provided for students to conduct experiments—this article provides a rubric that can be used to compare experiments and suggests trajectories for structuring inquiry across the curriculum.

The trouble with inquiry

Despite the prevalence of worthwhile activities that offer students the chance to engage in scientific thinking, many teachers report that it is difficult to implement inquiry activities in their curriculum. Sundberg et al. cite issues such as limited resources and support as reasons for this difficulty; they also claim that it is hard to modify the entire curriculum to include such activities (2000). A factor that compounds the issue is the current state of science instruction, particularly in chemistry, at the preservice level. The undergraduate preparation of future high school chemistry teachers ranges from earning a bachelor's degree in chemistry to taking only general chemistry courses. In addition, these undergraduate chemistry courses often do not engage preservice teachers in inquiry. In particular, undergraduate chemistry laboratory courses typically require students to follow detailed instructions in order to verify facts or principles already known to scientists (Fay et al. 2007). The reality is that beginning science teachers who have not experienced inquiry as learners may find it difficult to implement such a curriculum in their own classrooms.

How, then, can the scientific community guide teachers to better implement inquiry within their classroom activities? A first step toward answering this question is to enable teachers to evaluate the level of inquiry in their curriculum with user-friendly analytical tools. In this vein, several efforts to categorize inquiry in the classroom—using a rubric—have been proposed since the 1960s and refined or modified over the years. An early version of this rubric—generally attributed to Schwab (1964)—allowed for assessment of inquiry at varying levels. This version served as the building block for later modifications by Herron (1971), Chinn and Malhotra (2002), McComas (2005), and Fay et al. (2007).

The National Research Council (NRC) recently recognized a rubric (Lederman 2004) designed to help teachers and researchers quantitatively evaluate laboratory activities on a continuum of "levels of openness" for student independence. Levels of openness describe the degree to which students are free to make choices

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before, during, and after the laboratory experiment, as opposed to following prescribed directions. We modified this rubric to reflect the current understanding of learning (i.e., constructivism) and to indicate when an experiment allows students to construct their own learning and when it provides the information directly to students (Fay et al. 2007).

This body of scientific research has clearly established that not all inquiry-related laboratory activities are equivalent (Schwab [1964], Herron [1971], Chinn and Malhotra [2002], Lederman [2004], McComas [2005], and Fay et al. [2007]). Yet, given the importance of inquiry in science education, the word is frequently invoked without specifying its meaning. Our research has shown that many uses of the word *inquiry* do not necessarily imply or describe the same learning opportunity, or level of responsibility, for students (Fay et al. 2007).

Consider the following hypothetical experiments, which might be done in a freshman physical science course:

- *Experiment A*: Ms. Smith teaches at an urban high school. She does not have access to many resources for her laboratory activities, so she tries to do experiments that involve materials students can bring from home. One of these experiments requires popcorn kernels. Students bring popcorn to class and follow a detailed procedure that instructs them on proper methods for determining the percent-water content in the kernels. They are told what data to collect and how to calculate their final number. Ms. Smith tells her students how much water is usually in popcorn kernels, and students report how close their calculation comes to that value.
- *Experiment B*: Mr. Jones teaches physical science to freshmen, too. He has heard about Ms. Smith's ideas for experiments, but adds his own twist. Instead of telling students how to calculate the percent-water content, Mr. Jones only provides them with procedures for measuring the mass and popping the corn. He informs students that they must work with their lab partner to figure out how to find the amount of water in the average popcorn kernel. Students report their findings before being told the known percent water.
- *Experiment C*: Mrs. Lawrence is another physical science teacher at the same school. She has several lessons set aside each year that require her students to come up with their own experiments. One of these lessons is scheduled for the beginning of the school year, when she teaches about measurement. The assignment requires students to come up with an idea for their own experiment. Students have time in class to work with partners on their plan, and they must have it approved by Mrs. Lawrence ahead of time. One of the experiments devised by a pair of students is similar to the popcorn experiment Ms. Smith and Mr. Jones use. The two students take many more measurements than necessary because they are not sure what information they will need. However, in the end, they report that popcorn kernels lose a certain amount of mass, on average, after being popped. The students only speculate about

what happens to the mass, but Mrs. Lawrence is pleased to see that they do not assume that it was destroyed in the process of the experiment.

From these examples, it is easy to see that experiments—even those that use the same materials to explore the same science concepts—can provide opportunities for inquiry, yet offer varying degrees of freedom within student laboratory experiences. The following sections discuss the significance of these degrees of freedom as they pertain to high school science instruction.

A rubric for comparing laboratory activities

In order to distinguish among the degrees of inquiry exhibited in laboratory experiments, a rubric must facilitate a comparison of teacher responsibilities versus student responsibilities. Consider three high school chemistry laboratories that are reasonably equivalent in terms of the difficulty of the concepts involved:

- *Experiment D:* Students are required to perform a titration to determine the concentration of hydrochloric acid prepared in advance by the instructor. In the prelab section, an explanation of the underlying acid-base chemistry is described in detail. Students are told how to use a buret and Erlenmeyer flask, what measurements to take, and how to organize and analyze the data.
- *Experiment E:* Students must solve a problem similar to one an environmental chemist is likely to encounter. They are given a scenario and told that they must determine the level of magnesium ion in their water supply so that they can evaluate the "hardness" of the water. The teacher directs students to valuable resources available, but students are expected to develop their own methods of analysis and to decide what data to collect. Students are required to report their findings to the class.
- *Experiment F:* Students are assigned the task of analyzing household products. They are directed to explore the chemistry of soaps and detergents. Students must decide on a question to investigate, as well as develop both an appropriate experimental method and an analysis scheme (all approved by the teacher). Finally, they must reach a viable conclusion based on their data analysis.

How do these chemistry experiments differ from one another? Do any of them exemplify the construct of inquiry? Do all of them? The inquiry rubric in Figure 1 (Fay et al. 2007) can be used to differentiate among these experiments. The rubric is structured according to the following three parts of a laboratory activity:

- the problem or question under investigation;
- the procedure used by the student to collect data; and
- the solution or conclusion the student comes to in the end.

The rubric is based on the premise that there are distinguishable degrees of student freedom. As the four levels of inquiry progress from 0 to 3, they assign increasing responsibility to the student with decreasing direction from the teacher. A detailed description of each level can be found in Figure 2. According to this rubric, because *Experiment D* does not permit nor expect students to plan even one aspect of the experiment's execution, it is scored at Level 0. In *Experiment E*, the analytical procedure and conclusions are open to students' judgment; therefore it is scored at Level 2 per this rubric. Finally, the degree of freedom afforded students in *Experiment F*—allowing them to make decisions about the question, procedure, and conclusion—exemplifies the highest level of the rubric; therefore it is scored at Level 3.

Thus, these experiments do not provide equivalent student learning experiences with regard to inquiry because they are scored at different levels in the rubric—even though the difficulty of the concepts examined by these labs is similar. Educators who make it their goal to offer students the opportunity for inquiry should note that an experiment at Level 3 offers the highest degree of freedom to students. Encouraging the development of inquiry skills is consistent with Science Teaching Standard B in the National Science Education Standards (NRC 1996, p. 32).

FIGURE 1

Levels of inquiry rubric.

Level	Problem/Question	Procedure/Method	Solution
0	Provided to student	Provided to student	Provided to student
1	Provided to student	Provided to student	Constructed by student
2	Provided to student	Constructed by student	Constructed by student
3	Constructed by student	Constructed by student	Constructed by student

FAY ET AL. 2007 (ADAPTED FROM SCHAWB [1964], HERRON [1971], CHINN AND MALHOTRA [2002], LEDERMAN [2004], AND MCCOMAS [2005].)

Raising the level of inquiry through the year

With this rubric in mind, how should a teacher structure a course to help students learn through inquiry? Bell, Smetana, and Binns (2005) advise careful scaffolding of the curriculum to provide adequate support for students as they progress toward higher levels of inquiry. Figure 3 (p. 42) provides a graphical representation of several "inquiry trajectories." An inquiry trajectory provides a visual representation of when and how quickly to move from lower levels of inquiry to higher levels of inquiry. Using any of these trajectories will help move students toward greater independence in the laboratory. We have not collected evidence to suggest that one trajectory is better than another; pros and cons are listed for each tactic. (**Note:** Modifications to these trajectories are certainly possible; Figure 3 should not be considered an exhaustive set.)

Trajectory I represents a curriculum that begins at Level 0, which involves skill building and acquaintance with data-collection techniques. The level of inquiry increases slowly over the first half of the year, which allows students ample time to develop the manual dexterity needed to collect valuable data in the laboratory setting. Then, in the second half of the year, the curriculum gradually accelerates to Level 3 activities, which allows maximum student independence.

The benefit of remaining longer at lower levels of inquiry is significant because students have the chance to become familiar with the layout of the lab and the equipment. However, it is possible that this method does not challenge students soon enough to go beyond their comfort zone and to work at Level 1 and higher. Thus, teachers may encounter significant resistance from students who have grown accustomed to having each experimental step and all of the results spelled out for them ahead of time (Anderson and Helms 2001). Planning an inquiry curriculum to resemble Trajectory 1 may make it more difficult to expect students to function at higher levels of inquiry later in the year.

Trajectory II offers a strategy that may help to counter the difficulty proposed in Trajectory I. In this scheme, students still begin at Level 0, but experiments can quickly increase in the expected degree of student freedom. Soon after the start of the year, students are acquainted with the rules of the laboratory and may be better able to use prior content knowledge to devise investigations that pertain to the present subject matter. By challenging students to work at higher levels of inquiry early in the year, the teacher may avoid the undesirable situation in Trajectory I, in which students become frustrated by the change in effort they are required to put forth. A major downfall of Trajectory II, however, could be that students are brought up to Level 3 with a large portion of the school year remaining (possibly as much as half of the year). It may be difficult for high school students to maintain this level of independence as the curriculum carries them through changes in topics (Anderson and Helms 2001).

Trajectory III is a linear approach. Students progress through the levels more steadily than with either Trajectory I or Trajectory II. They could spend approximately one quarter of the year at each level, but such a timeline is not mandatory. This approach maintains a delicate balance between the extremes of the previous trajectories, and thus fewer problems may be encountered. By progressing slowly from highly teacher-centered activities to student-centered ones, students experience slow changes in the amount of effort required and do not have to work at the highest level for a longer period of time.

Finally, Trajectory IV, which resembles a sine wave, suggests another option for inquiry. This oscillating approach employs rapid fluctuation through the levels and avoids spending too much time at the highest level. Guided by this trajectory, students complete laboratory exercises in large conceptual units; each unit begins with an experiment that allows students to familiarize themselves with new techniques beneficial to investigating the current phenomena. Following this introductory experiment, a collection of successively higher-level activities are assigned, so that by the end of the unit, students are working on their own independently developed projects. When the next unit begins, students are once again at

FIGURE 2

Description of each level of inquiry.

Characteristic descriptors of each level are shown in bold.

Level of inquiry	Description
0	The *problem, procedure,* and *methods* to *solutions* are **provided** to the student. The student performs the experiment and **verifies** the results with the manual.
1	The *problem* and *procedure* are **provided** to the student. The student **interprets** the data in order to propose viable *solutions*.
2	The *problem* is **provided** to the student. The student **develops** a *procedure* for investigating the problem, **decides** what data to gather, and **interprets** the data in order to propose viable *solutions*.
3	A "raw" phenomenon is provided to the student. The student **chooses** (or constructs) the *problem* to explore, **develops** a *procedure* for investigating the problem, **decides** what data to gather, and **interprets** the data in order to propose viable *solutions*.

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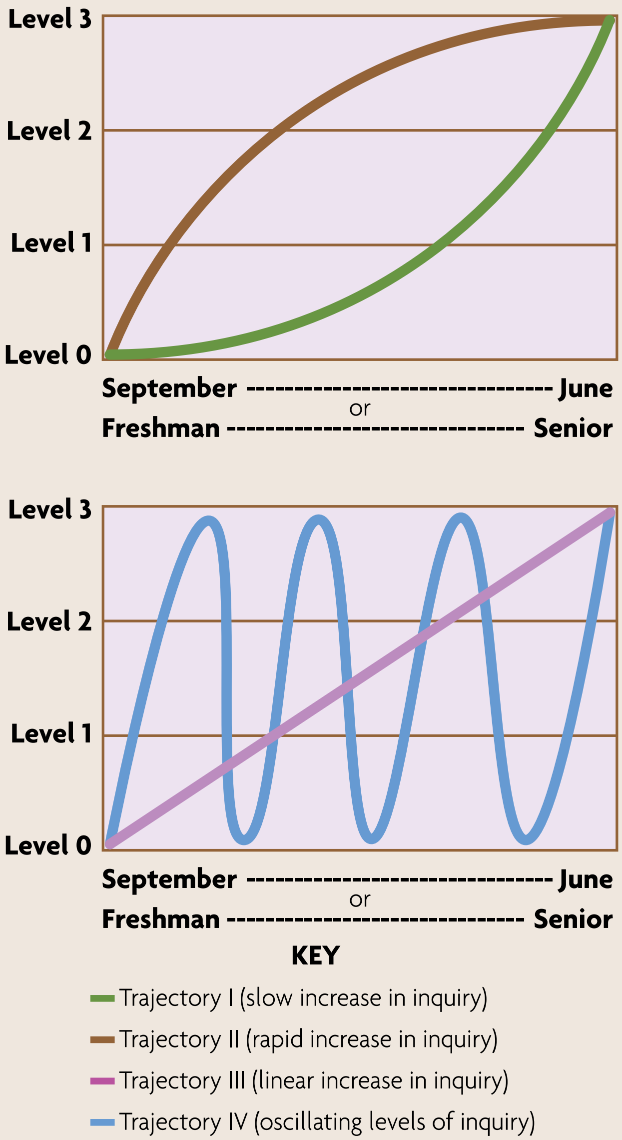
FIGURE 3

Four inquiry trajectories.



Level 0, getting used to new techniques. This trajectory is similar to a commercially available collection of college-level chemistry laboratory experiments (Wink, Fetzer-Gislason, and Kuehn 2005).

It is important to note that the trajectory descriptions and analyses included here are specific to a single academic year in high school. However, these trajectories can be applied across the entire high school science curriculum, from the beginning of freshman year to the end of senior year, as indicated in Figure 3.

Conclusion

Both the National Standards and a majority of state standards require the implementation of inquiry within the science curriculum. Since many teachers face challenges in incorporating inquiry activities into their lessons, supportive and practical help is needed. By providing a rubric for evaluating the level of inquiry and several trajectories to increase inquiry levels, we hope to instill confidence in teachers to develop higher levels of inquiry for their students. When the lines of inquiry are open to students, they have the opportunity to experience the processes of science. ■

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