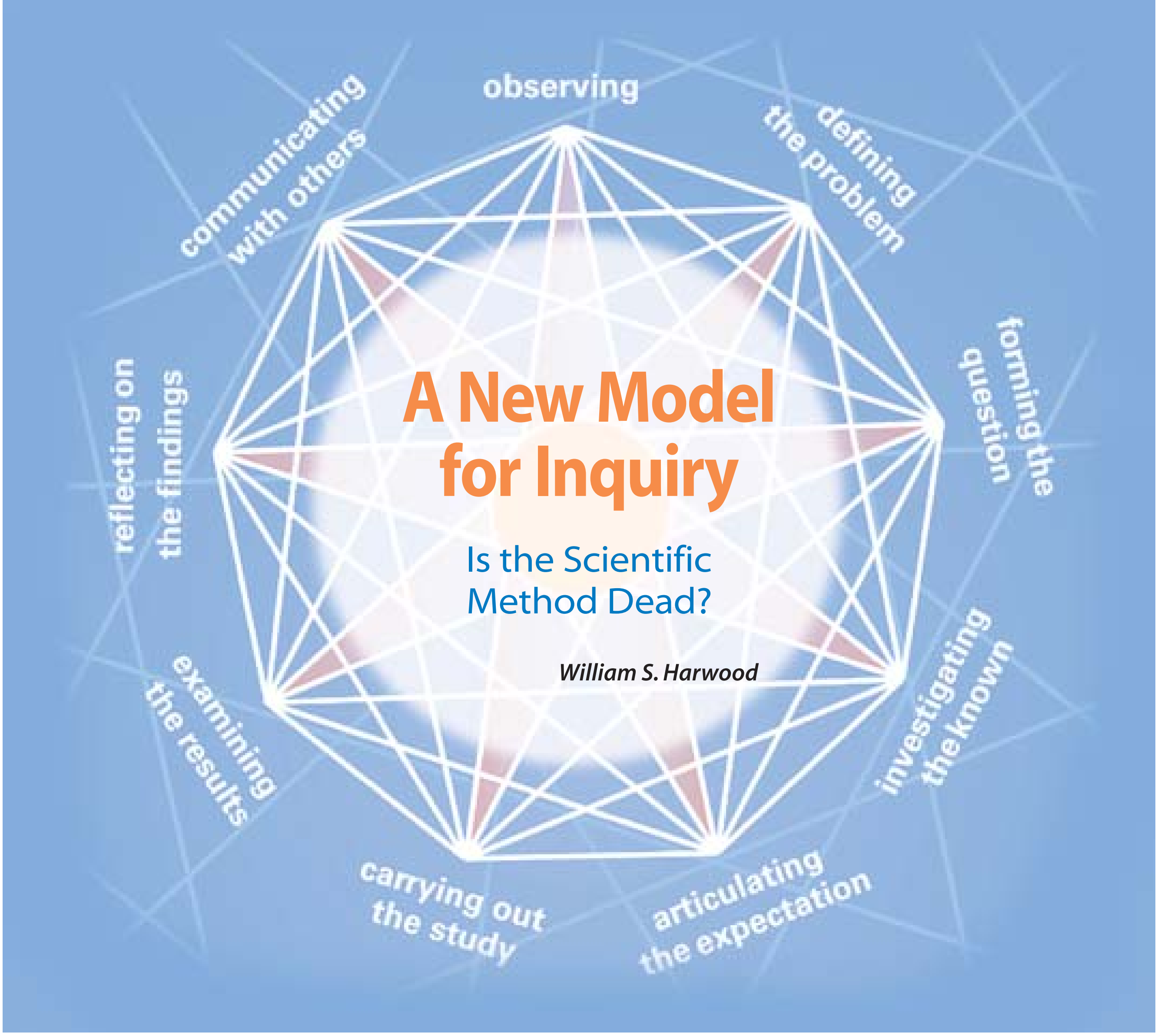
A New Model for Inquiry

Is the Scientific Method Dead?

William S. Harwood



William S. Harwood and Chris Miller

There has been renewed discussion of the scientific method, with many voices arguing that it presents a very limited or even wholly incorrect image of the way science is really done. At the same time, the idea of a scientific method is pervasive. This article identifies the scientific method as a simple model for the process of scientific inquiry. A more sophisticated model is briefly described and then used to analyze an inquiry-based exercise. The use of such new and empirically based models for the scientific inquiry process may assist instructors and developers of science learning materials.

The scientific method is the common working model for the process of scientific inquiry. But, as with any other model, there are limiting boundaries beyond which it fails. There is a growing set of voices critical of the traditional version of the scientific method (Bauer 1992; McComas 1996; Lederman 1998; Giunta 2001). The two main complaints are that it emphasizes only a hypothetico-deductive mode for doing science and that it suggests that the process of science is dependent on following a proscribed set of steps. Regarding the first point, it is true that some science is conducted by formulating a rigorous hypothesis and then testing it. However, a great deal of good science is not conducted in this fashion. Moreover, even for science that follows a hypothetico-deductive process, the second complaint remains an issue.

Many national science organizations strongly reject the notion of science as a stepwise process (AAAS 1993; NRC 1996 and 2000; NSTA 2003). The Benchmarks and the Standards, and other documents created by national science organizations, portray the process of scientific inquiry as one fraught with unexpected twists and turns. Still, the scientific method model is so strongly present in our culture that students completing a summer research experience will articulate the scientific method as the way to do science, even when they did not fol-

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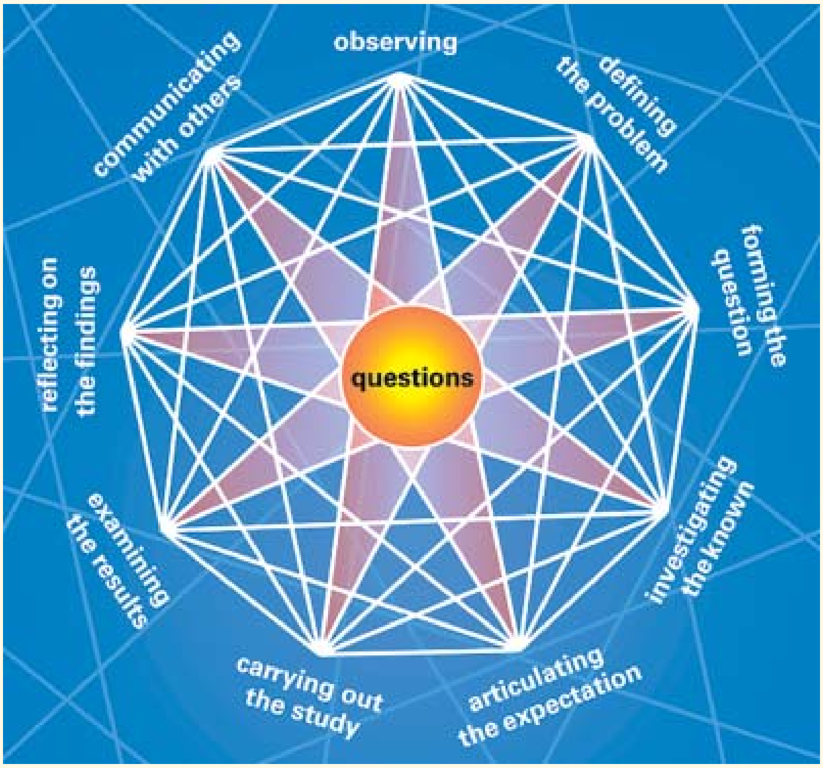
FIGURE 1

The activity model for the process of scientific inquiry.

This model identifies 10 activities. In the course of an inquiry, scientists move among these activities in unique paths and repeat activities as often as they find necessary.



low such a method during their research experience (Bell et al. 2003).

Fundamentally, the scientific method model is too simple to describe the process of scientific inquiry that many scientists use. Some educators suggest, therefore, that multiple methods should be used for scientific inquiry (Lederman 1998; McComas 1996). This is an unscientific response. Scientists explore complex systems with models (Gilbert, Boulter, and Elmer 2000), and the process of science should be amenable to the same approach. What we need, then, are some new models.

A New Model

What should we expect from a new model of the scientific inquiry process? An analogy can be made to models we use for acids and bases. In first-year chemistry, we teach the Arrhenius model of acids and bases, where any species producing hydrogen ions is defined as an acid and any species producing hydroxide ions is defined as a base. This simple model works well for the strong acids and bases, but fails with common bases such as ammonia. For a long time, scientists tried to make do with the Arrhenius model—as evidenced by ammonium hydroxide, a name given to a compound that does not exist. A more sophisticated model of acids and bases was needed, and this was provided by the Lowry-Brønsted model.

The Lowry-Brønsted acid-base model identifies acids as hydrogen ion donors and bases as hydrogen ion acceptors and describes a relationship between acids and their conjugate bases (and vice versa). This is more sophisticated than the Arrhenius model and does an excellent job of describing the acid-base chemistry that first-year students need to understand. It also fails, however. To describe the reactions of metal complexes and other species, we need a different model. The Lewis model provides this new level of sophistication. In the Lewis model, acids are described as electron pair acceptors and bases as electron pair donors. This abstract idea is grounded in other models.

Each of these three models of acids and bases, however, describes processes with increasingly abstract sophistication. Scientists tend to use the simplest one that will suit their needs (there are other acid-base models, of course). In the same way, science educators need to develop scientific inquiry models that are more sophisticated and more useful to the community (Songer, Lee, and McDonald 2003).

In earlier work, my research group developed an initial model that was based on interviews with academic research scientists from various disciplines (Reiff, Harwood, and Phillipson 2002). Using additional data from focus groups of academic research scientists from several midwestern institutions, I refined and renamed the model and improved the visual metaphor. One application of this new model is to describe the extent to which an inquiry-based exercise is aligned with authentic scientific inquiry.

The Activity Model

The activity model of the scientific inquiry process contains 10 activities in which scientists engage. In the perspective of this activity model, scientists engage in an activity as often as necessary and move among activities in a pattern dictated by their specific needs. This differs substantially from the stepwise process suggested by the scientific method model. In the activity model (see Figure 1), there is no set of steps that defines "good science." Rather, the following 10 activities must be done (and often more than once) to develop and carry out inquiry:

- Ask questions—This first activity is shown in the center because asking general and divergent questions is the central feature of any scientific inquiry.
- Define the problem—Limit the arena that you explore. This is a converging type of activity. For example, your general question might be, "What is the effect of global climate change?" And then you might define this issue by focusing on the effect of global climate change on the oceans or on plant diversity.
- Form the question—Develop a question that can drive a research study (a convergent process).
- Investigate the known—Consult books and articles that have been published regarding your area of interest. Scientists consult experts in the field (other scientists or people with specific expertise). The need to investigate the known comes up frequently throughout the course of a scientific inquiry.
- Articulate an expectation—Develop an expectation for your study. This sometimes may be a formal hypothesis. More likely, however, it will be a prediction or a simple expectation such as, "if a system is probed in a particular way, the resulting behavior will inform my inquiry."
- Carry out the study—Technically, this is the most involved activity. Choose the means to investigate your question, gather or create materials, and collect data. To resolve challenges and problems encountered in this activity, you will have to do various other activities.
- Examine the results—Data can be obtained in various forms, depending on the type of study. You must be certain that your data are valid. If you are uncertain, then you should repeat the study or engage in other activities to determine whether you can trust the study results.
- Reflect on the findings—Spend considerable time thinking about what your results mean. Ask yourself how your results connect with what is known and how you explain them to colleagues and other interested people.
- Communicate with others—Scientists rarely work in isolation, so you shouldn't either. Throughout the course of an inquiry, scientists communicate with peers in their lab and colleagues elsewhere. Many inquiries involve collaborative efforts of several scientists. Good communication among them is an essential feature of inquiry. When the study is completed, the last activity will be formal communication through oral or written presentations.
- Make observations—Scientists single out this activity as something they do at many different times in a scientific inquiry. Observations may be the starting point for some inquiries, but you also accomplish them when you carry out the study and investigate the known.

Applying the Activity Model

I examined a college biology class exercise through the lens of the activity model. The lab I chose was recently published by authors with whom I had no personal or professional interaction other than to have obtained their permission to discuss their work. I chose their laboratory exercise because it was specifically designed to help students explore the scientific method (Levri and Levri 2003). It is a good lab exercise, but does not follow the scientific method with its stepwise approach as the authors claim. Rather, their exercise is a good fit with the activity model.

Levri and Levri's students began their lab with a whole-class discussion of a broad question: What happens when you eat spicy food? Correspondence with the activity model was immediate.

Asking broad questions (numbered as activity 1) is the central hub of Figure 1. I have identified 16 stages, or points in time, where Levri and Levri's students move from one activity to another. Figure 2, next page, shows how students—like scientists in an authentic inquiry—move back and forth through the activities, revisiting several activities more than once.

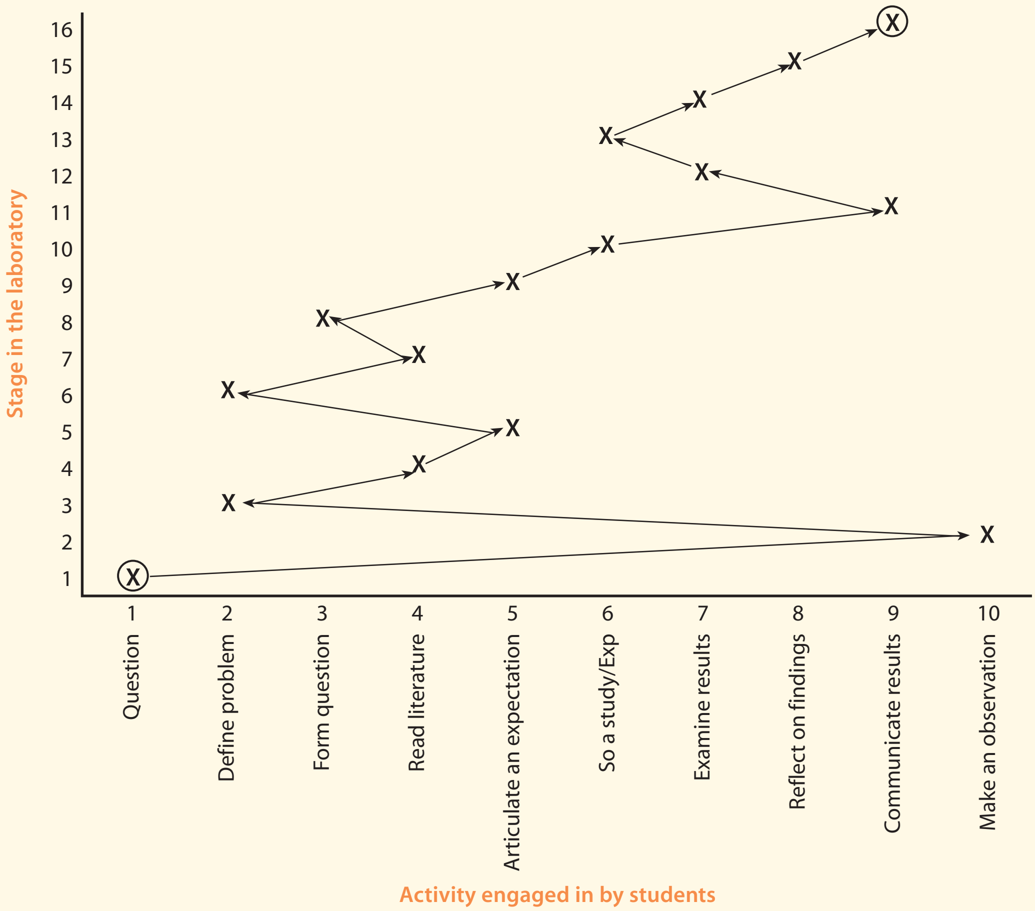
Levri and Levri report that students responded to the broad question (What happens when you eat spicy food?) by observing that they sweat when eating spicy food. This was part of making an observation (activity 10). Then, their discussion moved to wondering why people sweat when eating spicy food. This moved the process toward defining the problem (activity 2). Students' prior experience led them to suggest that sweating is a response to increased body temperature (investigating the known, activity 4). Accessing prior knowledge gained through reading, study, or experience is one way that scientists investigate what is known about a topic (activity 4). Other means of investigating the known include library research, web searches, and consulting experts on the topic. Based on this prior knowledge, students suggested that eating spicy food increases body temperature (articulating an expectation, activity 5).

The class discussion described in Levri and Levri guided their students in several activities that scientists use to define a problem and eventually identify a question that can drive an investigation. The

The activity model provides a more useful model to describe and explore scientific inquiry.

FIGURE 2

Chronological map of activities students engaged in during the lab exercise.



movement between asking broad questions, making observations, articulating expectations, investigating the known, defining a problem, and framing a question to drive an investigation is not represented by the scientific method. There is not a set of steps to develop a hypothesis, prediction, or expected outcome from a study. Scientists have the option of going back and forth between activities until they feel they are ready to carry out a study.

In Levri and Levri's paper, students articulated a clear expectation that they could have used to design and carry out a study. However, the instructors understood that there was insufficient clarity at that point to allow students to move to that activity. The instructors asked for other ways to explain the sweating, and this led to more discussion that further defined the problem (activity 2). As experts, the instructors provided students with the additional information that people also sweat when they become nervous or stressed and that, under these conditions, there is no increase in body temperature (investigating the known, activity 4).

Then, they were able to refine the question (activity 3): Does your body temperature increase when you eat spicy food? The expectation (activity 5) was that measuring body temperature would provide valuable insight. They worded their expectations as follows: If body temperature increases, then spicy food increases body temperature and one sweats. If body temperature remains the same, then spicy food probably stresses the body, resulting in a sweat.

Students carried out the study (activity 6) by designing and implementing specific experimental procedures. In the class, this was handled by small-group discussion followed by whole-class discussion. The whole-class discussion allowed everyone to compare ideas and pick the best from well-thought-out plans and procedures. So, the students spent a lot of time at that point communicating with others (activity 9). Discussion resulted in an optimum procedure for the study, and then data were gathered. The data were analyzed, and students discovered that taking one's temperature orally resulted in wider variation than did taking one's temperature under the arm or in the ear (evaluating data, activity 7).

Once students understood this, they repeated the study (activity 6) using the agreed-upon measuring location (underarm or ear). They evaluated (activity 7) and plotted the new data using error bars. The results provided support for the idea that body temperature increases, although it appeared that body temperature increased slightly just from the activity of eating (reflecting on results, activity 8). There was a whole-class discussion regarding the meaning of the results and final lab reports wherein students responded to specific questions (communication with others, activity 9).

Implications

The idea of a single scientific method is pervasive in the literature used by educators. The simple model of the scientific method, however, is not able to fully describe the activities that scientists engage in during a scientific inquiry. It also limits our ability to describe exciting inquiry-based laboratory instruction.

The activity model provides a richer description of the process of scientific inquiry, but continues to describe a single approach to doing science. I believe that this model will help science teachers and science teacher educators in framing inquiry teaching and learning. Students and teachers of science may wrongly assume that doing experiments is the only time when they are "doing science."

The activity model, however, suggests that lessons focusing on developing a research question or improving information-gathering skills (such as webquests, library research, and talking with experts) are aspects of scientific inquiry. That is, such lessons are part of doing science. Moreover, the activity model suggests that working with others and discussing issues, ideas, and results of a study are activities (communication with others) that are part of doing science. Communication is not something that occurs only in a formal manner at the conclusion of a study.

This article demonstrates that it is possible to use the activity model as a means to examine and describe inquiry-based lessons and labs. It is less thorough and sophisticated than other curricular evaluation methods (Kesidou and Roseman 2002). This model has the benefit, however, of being easy to use for mapping the sequence of activities engaged in by students (see Figure 2).

A similar mapping of the stages of inquiry, but in tabular form, has been accomplished for descriptions of authentic scientific inquiry conducted by a geologist (Harwood 2004). Faculty and/or curriculum developers can use this model as a framework to determine whether they have accomplished their goals for setting up a given lesson or lab. To make this determination, they should ask themselves: Are students likely to engage in the desired set of activities? Do they have some freedom to move among activities as needed (unless restriction is a desired feature of the lesson)?

So, is the scientific method dead? I don't think so. It will persist for quite some time as a simple model and one that is often used as a guide for formal written scientific reporting. The activity model provides a more useful model to describe and explore scientific inquiry. It also provides an effective means to examine one's teaching and to explicitly discuss the real process of scientific inquiry with students. ■

Acknowledgments
I thank E. Levri and M. Levri for allowing me to analyze their work and for comments on the manuscript; IU graphic design student C. Miller for help creating the image of the activity model and clarifying the language used to describe the activities; and E. Zimmerman, Art Education, for advice regarding the image of the activity model.

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