# Constructing Inquiry-based Lessons in Teaching Science

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**Abstract**
With the publications of the National Science Education Standards (NSES), How People Learn (NRC, 2000), and How Students Learn Science (HSLS) (NRC, 2005), educators are developing inquiry strategies that are effective as well as engaging. Understanding the principles that are identified in these publications enables the science educator to be more effective and to help students improve their understanding of science. The key to being an effective science educator is to understand how students learn science. Knowledge of how students learn has raised the awareness to the forms of pedagogy that involves inquiry. Educators are learning from research in the areas of neuroscience and education to improve their skills in the classroom. Professional development at both the pre-service and in-service levels will enable educators to focus on student learning along with the pedagogy utilized.

**Keywords**
Inquiry, Pedagogy

## INTRODUCTION

With the publications of the National Science Education Standards (NSES), How People Learn (NRC, 2000), and How Students Learn Science (HSLS) (NRC, 2005), educators are developing inquiry strategies that are effective as well as engaging. Understanding the principles that are identified in these publications enables the science educator to be more effective and to help students improve their understanding of science. Professional development in the past has focused on how educators deliver the content instead of focusing on student learning. The key to being an effective science educator is to understand how students learn science. Educators must engage the prior understanding of students, provide experiences of "doing science" for deeper understanding of the content, and provide opportunities for students to assess their own learning (NRC, 2005). The most common strategy to help students to accomplish these principles is to do investigations using inquiry. Defining inquiry has resulted in many different variations that have confused science educators in how to approach it in their classrooms. The NSES (NRC, 1996) have provided science educators with the tools to assess their "inquiry" strategies and to implement effective inquiry strategies. With publications such as *Exemplary Science in Grades 9-12* from the NSTA Press, educators gain confidence that their efforts will be effective in improving achievement and interest in science.

## INQUIRY

The NSES provided a very formal definition of "inquiry" focusing on how scientists approach their research of the natural world and the use of evidence to provide explanations. This definition also applied to the science classroom to include the activities used by students to gain in their understanding of scientific ideas (NRC, 1996). Other perceptions regarding "inquiry" included the art and spirit of imagination as well as the wonderment of the investigation (Llwellyn, 2007; Hammerman, 2006). All perceptions regarding inquiry included the importance of the students' interests as well as what the teacher is trying to cover in the curriculum.

Is All Inquiry Equal?

Misconceptions about inquiry by science educators have resulted in them not recognizing that inquiry can take many forms. The NSES identified five features of inquiry to guide in the development of science classroom activities. The features were placed on a continuum to help the science teacher understand the amount of learner self-direction and the amount of direction from the teacher or material (Table 1). Table 1 serves as a tool for the teacher in determining the degree of inquiry associated with any classroom activity.

Educators can use the information in Table 1 to compare their use of inquiry found in classroom investigations. Bell, Smetana, and Binns (2005) also defined four levels of inquiry by focusing again on what is given to and expected by the student (Table 2).

*Table 1. Essential Features of Classroom Inquiry and Their Variations*

More -----------Amount of Learner Self-Direction -------------Less

Less -----Amount of Direction from Teacher or Material -----More

| Essential Feature | Variation | | | |
|---|---|---|---|---|
| Learner engages in scientifically oriented questions. | Learner poses a question. | Learner selects among questions, poses new questions. | Learner sharpens or clarifies question provided by teacher or other sources. | Learner engages in question provided by teacher, materials, or other source. |
| Learner gives priority to evidence in responding to questions. | Learner determines what constitutes evidence and collects it. | Learner directed to collect certain data. | Learner given data and asked to analyze. | Learner given data and told how to analyze. |
| Learner formulates explanations from evidence. | Learner formulates explanations after summarizing evidence. | Learner guided in process of formulating explanations from evidence. | Learner given possible ways to use evidence to formulate explanation. | Learner provided with evidence. |
| Learner connects explanations to scientific knowledge. | Learner independently examines other resources and forms the links to explanations. | Learner directed toward areas and sources of scientific knowledge. | Learner given possible connections. | |
| Learner communicates and justifies explanations | Learner forms reasonable and logical argument to communicate explanations. | Learner coached in development of communication | Learner provided broad guidelines to sharpen communication | Learner given steps and procedures for communication. |

NRC (2000)

*Table 2. Modified Version of the Four-level Model of Inquiry. How much information is given to the student? (Bell, Smetana & Binns, 2005)*

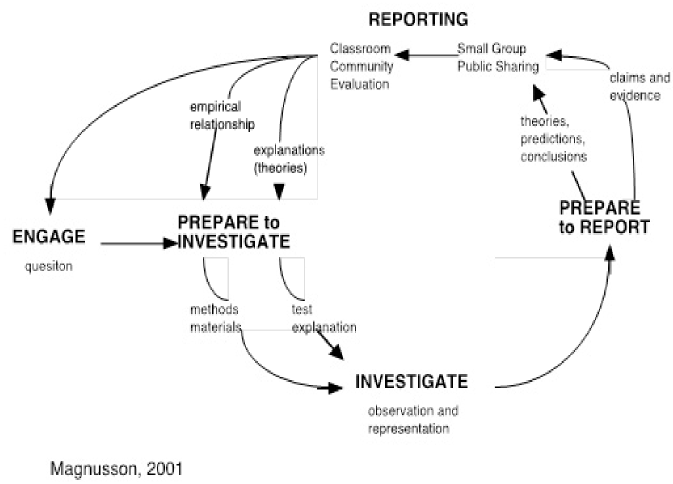
| Level of Inquiry | Question? | Methods? | Solutions? |
|---|---|---|---|
| Confirmed | X | X | X |
| Structured | X | X | |
| Guided | X | | |
| Open | | | |

These levels of inquiry can be further defined as:

- Confirmed Inquiry: Students confirm a science principle through an activity in which the results are known in advance.
- Structured Inquiry: Students investigate a teacher-presented question through a prescribed procedure.
- Guided Inquiry: Students investigate a teacher-presented question using student-designed or student-selected procedures.
- Open Inquiry: Students investigate topic-related questions that are student formulated through student-designed or student-selected procedures.

Understanding the different levels of inquiry as well as the NSES inquiry features table guides science educators in developing a curriculum through which students are more actively involved in the inquiry process. Educators can assess their classroom activities by comparing them to both the NSES essential features table and the table of the four levels of inquiry. From my experience as a high school biology teacher, using guided inquiry can provide many opportunities for students to be actively involved in inquiry. Figure 1 is an example of how guided inquiry can be utilized in a science classroom. Students are involved in the many steps that lead to more questions and more inquiry.

*Figure 1. A Heuristic for Teaching and Learning Science through Guided Inquiry (How Students Learn, 2005)*




**Inquiry Classroom Pedagogy**

My experience in incorporating the different levels of inquiry has included using the 5E Learning Cycle, laboratory modifications, questioning techniques, and assessment and metacognition for students.

*5E Learning Cycle*

The 5E Learning Cycle (Bybee, 2002) includes engagement, exploration, explanation, extension, and evaluation. These stages are directly related to the five features of inquiry as presented by the NSES. In my biology classroom, I developed activities that focused on a problem that was related to the biology content and to the interests of the students. The students were able to use their creativity to design different approaches in solving the problems presented. As a result, the students were able to ask questions of me but also of their peers. They were able to compare their results with others to determine the effectiveness of their evidence. Throughout the process, I was able to ascertain what knowledge students brought to the activity, to provide them with an avenue to "do science," and to provide them the opportunity to reflect on what they discovered and learned about the biology content.

*Laboratory Modification*
Many laboratory manuals that are associated with a science textbook utilize investigations that confirm science content. Students are provided with the exact equipment and material needed, specific instructions, and a worksheet that outlines what data should be collected. These laboratories, when performed by students, may not always turn out the way they should. The effective science educator will turn these aberrations into teachable moments. Having the students reflect on their steps, as well as the materials used, provides a means to study the science content.

Approaches to modifying the laboratories can be selected to help the students be better skilled in the inquiry features as presented in the NSES. It is important when doing the modifications to select an activity with goals other than teaching specific skills. For example, if you want students to make decisions on what questions to investigate, remove the introductory questions from the laboratory handout. Instead, provide a discrepant event and let the students decide on the question/s to investigate. If you want students to think about what procedures should be used to investigate a given question, remove the student procedures all together. Just provide what materials would be available for the experiment. If you want students to learn how to select appropriate data and how to organize the data, remove any data charts that appear on the laboratory hand out. This step provides for a variety of data tables as well as increases communication among the students.

These modifications will require students to discuss their prior knowledge, ask questions that spark ideas, reduce student frustration, make students responsible for communicating their lab work in a clear manner, and structure an experience so students must be mentally engaged in the lab when students cannot invent laboratory procedures.

*Inquiry Questions*
Science educators may find with focused practice how the type of question used can impact how students think. Selecting a different type of question can push the student to think at a higher level of inquiry. Llewellyn (2007) identified four types of questions that science educators can utilize to help the student become an independent thinker instead of relying solely on their science teacher for information. These questions include:

- Clarifying Questions: Ask the student to be more specific about a response given to the teacher or why the data presented is important to the question.
- Focusing Questions: Ask the student to provide an example to a response to another question.
- Probing Questions: Ask the student what might happen is she tried to modify an element in an investigation.
- Prompting Questions: Ask the student what might happen to a new suggestion provided by the teacher. This also serves as a guiding question.

Using verbs such as "does," "how can," "how come," and "what if" allow for more possibilities in responses than questions that start with "why." These types of questions are open-ended, allowing the student to not worry about the correct answer. Using this strategy provides the educator a method of determining how the student is processing the science content.

*Assessment and Metacognition of Student Learning*
Assessment of inquiry is found within both formative and summative assessment. Formative assessment can be either planned (a quiz or written assignment) or through interactive assessment (using questions in a student discussion). Using concept mapping or minute papers, for example, provide both the educator and student information on what was learned from an activity. The development of rubrics provides the scoring on the expected outcomes of students. Table 3 provides an example of a balanced scoring rubric.

## CONCLUSION

Why use inquiry? Using the NSES inquiry features chart and principles of how students learn science has impacted two areas: student achievement and attitudes toward science.

*Table 3. Example of a Balanced Scoring Rubric.* Science as Inquiry in the Secondary Setting *(NSTA Press, 2008, p. 114)*

← **Higher Levels of Performance**

| Weight | Task | 3 | 2 | 1 |
|---|---|---|---|---|
| 40% | Design, conduct, and evaluate the results of an investigation to answer the focus question. | Exhibits detailed ongoing progress of design process by documenting the development of procedures, the responses to peer feedback, and the generation of conclusions in notebook. | Documents and exhibits an understanding of the final design only, not ideas and drafts of ongoing design development. | Records data from investigation with little reference to ongoing procedural adjustments and developing interpretations of data. |
| 30% | Take individual multiple-choice test regarding essential understandings about inquiry. | Selects between 81% and 100% of the multiple-choice answers correctly. | Selects between 61% and 80% of the multiple-choice answers correctly. | Selects between 0% and 60% of the multiple-choice answers correctly. |
| 30% | Create a concept map, demonstrating a rigorous review and analysis of an article about the essential understandings of inquiry. | Designs, generates, and explains a concept map containing key ideas related to understandings of inquiry, which reflect article's conceptual hierarchy, connectedness, and application. | Constructs concept map with key concept terms, but does not show and explain the hierarchy, connectedness, or application among those terms from the article. | Produces a physical arrangement of terms from the article that has little discernible rationale and does not reflect hierarchy, connectedness, or application of the key understandings of inquiry. |

*Note:* The balanced scoring rubric weights each task sufficiently to communicate the importance of all outcomes to students.

Using the guided inquiry approach in an honors biology class has resulted in improvement of student achievement. A statistical analysis of the quantitative data assessing lessons using the 5E Learning Cycle resulted in a significant difference when comparing didactic approaches to the inquiry approach. In addition, the qualitative data illustrated that students preferred to work in groups, to see and touch materials, and to have the opportunities to communicate student ideas (Hayes, 2005). Hayes (2005) conducted a study on the relationship of the NSES to middle school girls' attitudes toward science. Those middle school girls who were engaged in inquiry strategies demonstrated increased student-student interactions, increased student-teacher interactions, more interest in science, and positive attitudes toward science. Other positive results from the utilization of inquiry are presented in the NSTA publication *Exemplary Science in Grades 9-12: Standards-Based Success Stories* (edited by Robert E. Yager). Science teachers can learn from these successful models to build upon their inquiry pedagogy and improve student skills.

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## REFERENCES

Bell, R.L., Smetana, L., & Binns, L. (2005, October). Simplifying inquiry instruction. *The Science Teacher*.

Bybee, R. (2002). *Scientific Inquiry Student Learning and the Science Curriculum: Learning Science and the Science of Learning.* NSTA Press: Washington, DC.

Hammerman, E. (2006). 8 Essentials of Inquiry-based Science, K-8. Corwin Press: Thousand Oaks, CA..

Hayes, C. (2005, June). *The effects of the National Science Education Standards on the attitude toward science in middle school females*. Indiana University, Bloomington, IN.

Hayes, C. (2005). Inquiring minds want to know about enzymes. *Exemplary Science in Grades 9-12* (pp. 25-32). NSTA Press: Arlington, VA.

Hayes, C. (2003). The story of enzymes. *The Hoosier Science Teacher*, *28*(4), 102-111.

Llewellyn, D. (2007). *Inquire Within.* Corwin Press: Thousand Oaks, CA.

Luft, J., Ell, R.L., & Gess Newsome, J. (2008). *Science as Inquiry in the Secondary Setting.* NSTA Press: Washington, DC.

National Research Council. (2005). *How Students Learn: Science in the Classroom.* National Academy Press: Washington, DC.

National Research Council. (2000). *Inquiry and the National Science Education Standards*. National Academy Press: Washington, DC.

National Research Council. (1999). *How People Learn*. National Academy Press: Washington, DC.

National Research Council. (1996). *National Science Education Standards*. National Academy Press: Washington, DC.