Using an inquiry approach to teach science to secondary school science teachers

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Abstract

Leaders in science education have actively promoted inquiry science since the 1960s and continue to do so today. The US National Science Education Standards recommend that science instruction and learning should be well grounded in inquiry. In spite of these efforts, however, little has changed in the way science is taught. Teacher-talk and textbooks are still the primary providers of science information for students. The objective of this paper is to: (a) define inquiry as a strategy for teaching science, (b) review the history of inquiry science teaching, and (c) present the Physics by Inquiry model for in-servicing middle school science teachers in order to provide assistance for teachers to successfully implement an inquiry approach to teaching science.

Introduction

The Physics by Inquiry program for secondary science teachers was established in order to improve the quality of science teaching in secondary schools by helping secondary science teachers develop and implement inquiry teaching strategies in their classrooms. Teachers are taught inquiry teaching strategies by engaging in inquiry science activities and extending their understanding of the science concepts that they teach. As the teachers understand the process of science as inquiry, the teachers more eagerly teach the process to their students in much the same way as they learned the Physics by Inquiry program.

Inquiry is a process by which children actively investigate their world through questioning and seeking answers to their questions. This process is characterized by actions such as probing, searching, exploring and investigating (Martinello and Cook 2000). Inquiry as a way of learning about the world should be taught in the context of real-life scientific problems involving real science knowledge (Pugliese 1973). These problems should be relevant to the students. The students should initiate study of these problems as they probe, search and investigate problems and questions of interest to them. In fact, the US National Science Education Standards (National
Prior to the 1960s, the direction of science education in the United States had been centred on the teaching of facts, concepts and principles through didactic expository instruction rather than an inquiry-based approach (Pugliese 1973, Rakow 1986, Eltinge and Roberts 1993, Bianchini and Colburn 2000). Teacher-talk and textbooks were the primary sources of science information provided to students. Laboratory work was used in order to illustrate and confirm science concepts presented in textbooks.

This method of instruction was deemed to be inappropriate and ineffective by the science reformers in the United States who began their efforts early in the 1960s (Herron 1971, Tamir 1985, Welch et al 1981). Schwab (1962) recommended that students be taught to view science as ‘enquiry’ (a variation of the term ‘inquiry’) rather than a static body of information to be learned. He further recommended that students be taught the skills of inquiry and helped to apply them to conduct science investigations.

### Teaching science by inquiry

Teaching science by inquiry involves teaching students the science processes and skills used by scientists to learn about the world and helping the students apply these skills involved with learning science concepts. Students are helped to learn and apply these processes through conducting problem-centred investigations designed for learning specific science concepts. The teachers help students generate questions to guide these investigations.

This inquiry approach is often referred to as ‘guided discovery’. Teachers ‘guide students’ inquiry’ until the students ‘discover’ specific science concepts predetermined by the teachers. Pratt and Hackett (1998) suggest that, by learning science by inquiry, students develop deeper understandings of science concepts and also develop critical thinking skills. However, it is important to stress that learning science concepts by inquiry is much more time consuming than learning concepts by traditional methods.

The results of documenting science as an inquiry process add to the body of current science knowledge. When scientists engage in inquiry they generate new knowledge not created in a vacuum. Scientists reason from the information that they have. Newton expressed this idea when he stated that if he had seen farther than others, it was because he had stood on the shoulders of giants (Hewitt et al 1999).

Students can also be taught to utilize inquiry in order to add to the body of science knowledge that is understood. Students must be taught to reason from what they know and apply this reasoning in order to investigate phenomena observed in the world around them. Most importantly, students learn first hand through their own inquiry experiences the processes used by scientists to add to the current body of accepted science knowledge. Upon using Science as Inquiry strategies, teachers involve students in inquiry-based activities but do not predetermine science concepts for students to ‘discover’. Instead, teachers involve students in investigations such as (a) challenging the validity of currently accepted science concepts, (b) going beyond their present understanding of currently accepted science concepts and (c) investigating differing explanations for specific science phenomena (Schwab 1962).

In summary, when students learn science by inquiry, the process of inquiry becomes the means by which the currently accepted science knowledge is better understood. Through learning science as inquiry, students also better understand how scientists developed the currently accepted body of science knowledge. Hence the students learn to apply these processes in order to go beyond the information needed to discover new knowledge. According to Schwab, teaching students the process of science as inquiry is more important than teaching science by inquiry (Eltinge and Roberts 1993).

There have been several advantages noted to utilizing inquiry-based science instruction in undergraduate education (Oates 2002). There have also been advents in utilizing web-based mechanisms in order to develop an inquiry-based science environment (Linn et al 2003). Inquiry-based science has also provided great benefits in diverse classrooms, wherein students are able to better respond to open-ended and multiple choice assignments (Songer et al 2003).

Some research exists that addresses the question of why inquiry-based science has not
become a prominent part of science teaching in state-funded schools. Eltinge and Roberts (1993) suggest three reasons why inquiry science has not been widely implemented (italics are added for emphasis):

1. Science teaching standards issued by state education agencies are generally more content-oriented than process-oriented. In other words, the focus is on the mastery of body of information. Little emphasis is placed on the process of inquiry as a method of learning science knowledge.

2. It is much easier to evaluate the effectiveness of student learning of science as a body of factual information than to evaluate the effectiveness of their science learning through inquiry. When students learn science through inquiry, they learn less factual science information, but achieve greater depth of understanding of that information. It is much easier to assess student learning of science facts than to measure their depth of understanding of science information.

3. Science textbooks tend to present science more as a body of information than as a method of inquiry, and science instruction continues to be textbook driven.

Welch et al (1981) offer the following suggestions as to why teachers do not use inquiry-based science instruction:

1. Lack of training.
2. Lack of time.
3. Lack of materials.
4. Lack of support.
5. Overemphasis on assessing content learning rather than process learning.
6. Inquiry approach is too difficult and much more time consuming.

Although science educators today continue to promote inquiry-based science, rapid implementation will not occur until the issues articulated by Eltinge and Roberts (1993) and Welch et al (1981) are implemented.

Physics by Inquiry program

The Physics by Inquiry program was designed in order to help middle and high school science teachers learn strategies for teaching science by inquiry and for teaching science as inquiry. Teachers in the program are recruited from middle and high schools located in the Rio Grande Valley of South Texas. The program is in its eighth year and many teachers have participated in the program thus far.

Teachers in the program spend approximately 45 hours of class time during the summer (2–3 weeks, 6 hour-long sessions every day), 24 hours during the fall semester, and an additional 30 hours during the spring semester (one monthly session of 6 hours each) in order to complete 99 hours of intensive training in physics concepts through discovery methods and hands-on activities. Teachers in the program also participate in one field trip funded by the program.

Teachers in the program attend Inquiry workshops held in a physics laboratory and the trainers (physics professors) lead the workshops. The workshops are designed to (a) increase teachers’ understanding of the science content taught through inquiry-based science activities, and (b) assist the teachers in developing the skills necessary in order to interact with students. The Physics by Inquiry program was designed to address these issues with science teachers through the establishment of inquiry-based science in their own classrooms.

Training teachers to teach science by inquiry

The initial program workshop sessions are designed to engage teachers in learning science content by inquiry. Through this process, the teachers experience the kind of learning that will provide for their own students, while being trained in the sessions. The inquiry model used to train the teachers is based on the following six steps:

1. Select science concepts/contents to teach the teachers.
2. Select a traditional science laboratory activity as used in state-funded schools with their students.
3. Discuss the laboratory activity with teachers. Draw questions about the activity, rather than having merely ‘cookbook’ activities as is customary with their own students when teaching laboratory activities that are usually called paper labs.
4. Engage teachers in the laboratory activity to seek answers for their questions.
5. Put the teachers in learning teams involving investigating together.
6. Cause the learning teams to interact with each other in order to discuss the results of their inquiry and finally confirm the results gathered during the modelled experiments.

While teachers are conducting their investigations for seeking answers to their questions, their instructors monitor their activities and provide direction as needed. Guidance is provided without giving answers. Questions are used in order to stimulate thinking, and guidance as needed until answers are derived from the original questions. Thus, inquiry is used as an important way to help teachers learn science content.

The inquiry model is taught to teachers at the beginning of the workshop through the working of a whole class in order to investigate science concepts using traditional science laboratory experiments. Project instructors model the science process skills shown in Chiappetta (1997) as the investigations are conducted. Teachers are provided with assistance in order to generate questions that (a) challenge currently accepted science concepts, (b) extend their understanding of currently accepted science concepts and (c) investigate differing interpretations and explanations of science phenomena.

**Challenging currently accepted science concepts**

Another example of how to help students challenge currently accepted science concepts can be given from the Law of Levers. To assist the students, a grouping is implemented and each group is provided with a 12 inch (30 cm) wooden ruler, a wooden pencil with flat sides to use as a fulcrum, two 3 ounce (85 g) paper cups, masking tape, an eye dropper or pipette, water and a 50 ml graduated cylinder for measuring water. The students construct a lever with the fulcrum at the 6-inch mark as shown in figure 1. Masking tape is used in order to tape the pencil to the table so that the pencil will not move during the experiments.

Students’ understanding of the Law of Levers can be extended by continuing their investigations, but this time changing the fulcrum from 6 inches to 4 inches as shown in figure 2. In addition, the students should add 20 ml of water to the cup nearest the fulcrum. Subsequently, the students should predict how much water would need to be added to the second cup (8 inches from the fulcrum) in order to lift the first cup. The students will generally predict that 10 ml of water will be added because the cup is twice as far from the fulcrum as is the cup containing the water. The students will likely be surprised to see that less than 10 ml of water is required. In fact, the students may need to use the eyedropper or pipette while putting water into the second cup in order to balance.

The students should be provided with additional materials in order to allow for the devising of their own investigations. If needed, inquiry should be stimulated by drawing questions out of the students such as: (1) Is there any effect due to shifting the fulcrum from the centre of the ruler? (2) Is there any effect due to the position of the weights on the ruler? (3) Is there any effect due to the mass of the effort arm and the mass of the resistance arm?

Examples exist in current science textbooks and other science literature that offer different interpretations and explanations for observed science phenomena. For example, what is the source of lift on an airplane’s wing that enables the plane to fly? Some textbooks and encyclopedias give different explanations. Instructors can present the following sequence of information to the teachers.
1. *Exploring Physical Science* (Maton et al. 1997): “An airplane wing is designed so that air passing over the wing travels faster than air passing beneath it. According to Bernoulli’s principle, the fluid that is flowing faster than the other fluid exerts less pressure. How does this explain the flight of the airplane?”

2. *Microsoft Encarta Online Encyclopedia* (2000): “Bernoulli’s principle is sometimes mistakenly used to explain the net force in a system that includes a moving fluid, such as lift on an airplane wing. . . . An airplane flies because its wings push down on the air flowing past them, and in reaction, the air pushes upon the wings . . . The third law of motion formulated by English physicist Isaac Newton states that every action produces an equal and opposite reaction. This causes lift, the upward force on the plane. Lift is often explained using Bernoulli’s principle . . . but this is an effect of lift, not its cause.”

3. *Modern Physics* (Trinklein 1992): “An airplane wing also utilizes Bernoulli’s principle. A moving airplane wing receives an upward force because of the motion of the air over it. Though you might think that the air deflected downward by the bottom of the wing does the lifting, it actually accounts for only about 15 percent of the force required to lift an airplane. Most of the force needed to lift an airplane is produced by the movement of the air across the upper surface of the wings” (Bernoulli’s principle).

The first and third sources are from high school science textbooks. The second is from an online encyclopedia.

Instructors discussed the discrepancies in these three explanations. The phenomenon of lift was investigated through the questions: (1) Will a wing produce lift if its lower surface is parallel to the airflow across it? If the reaction occurs, could any lift generated be attributed to the shape of the wind and explained by Bernoulli’s principle. (2) Will wind generate greater lift on the airplane wing if the leading edge is tilted upward so that the bottom edge of the wing is no longer parallel to the flow of air across the wing? In this situation, the lower surface of the wing will no longer be parallel to the flow of air across the wing. If additional lift is generated, this response could be attributed to the effect of Newton’s third law as the air flowing across the wing strikes the lower surface of the wing and is deflected downward, producing an action/reaction situation.

In order to investigate these two questions, instructors helped teachers design and construct an apparatus that allowed a wing to move upward as lift was generated and that could be tilted so that the bottom edge of the wing was not parallel to the flow of air across the wing. Mounting a wing on two wooden dowels accomplished this task. A hole was drilled in the tip of each wing and the dowel was inserted through the holes so that the wing could slide up and down on the dowels (figure 3). One group of teachers found that there was too much friction between the wooden dowels and the wing. After applying a lubricant, the friction was reduced and the wing started to glide upward with a fast flow of air. This upward glide occurred even when the bottom of the wing was parallel to the flow of air moving over the wing. Consequently, it can be seen that supporting evidence is provided for the lift generated by the effects of Bernoulli’s principle. When the angle of attack of the wing was increased by approximately $10^\circ$, the lift on the wing increased by about 5% to 10%, indicating that action/reaction was contributing to the lift on the wing.

Teachers were challenged to research the literature and investigate the discrepancies regarding
the source of lift on an airplane wing provided in the science textbooks and encyclopedias. Furthermore, teachers were encouraged to utilize sources such as science textbooks, in addition to appropriate university-level textbooks, trade books, research journals and Internet resources.1

Summary and conclusions
The quest for inquiry-based science has been at the centre of educational reform in the United States for the past 40 years; however, little progress has been made to achieve this goal. The Physics by Inquiry program was established to help train teachers in the strategies necessary for implementing an inquiry-based instructional program. A major strategy of the program has been to engage teachers in inquiry-based science during workshop sessions in such a way that teachers can take back to their classrooms many of the insights and implement the best ideas with their students.

The Physics by Inquiry program has been very successful with teachers. We are beginning to see the results of the program through the achievement of the science teachers’ students and the enthusiasm that the students have about learning science through inquiry-based science. In addition, these students now more often gain admission to the university and even more frequently select science as their major. Continued growth of the program is projected with respect to both the number of science teachers trained and the number of their students who come to the university and select areas of science as their major.

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References
Bianchini J A and Colburn A 2000 Teaching the nature of science through inquiry to prospective elementary teachers: A tale of two researchers J. Res. Sci. Teach. 177–209
Eltinge E M and Roberts C W 1993 Linguistic content analysis: A method to measure science as inquiry in textbooks J. Res. Sci. Teach. 30 (1) 65–83
Herron M D 1971 The nature of scientific enquiry Sch. Rev. 79 (2) 171–212
Microsoft Corporation 2000 Encarta 2000 Interactive Multimedia Encyclopedia
Oates K K 2002 Inquiry Science: case study in antibiotic prospecting Am. Biol. Teacher 64 (3) 184–7
Pugliese A C 1973 The meaning of inquiry, discovery, and investigative approaches to science teaching Sci. Teacher 24–7
Rakow S J 1986 Teaching Science as Inquiry Fastback (Monograph) no 246 (Bloomington, IN: Phi Delta Kappa Educational Foundation)
Tamir P 1985 Content analysis focusing on inquiry J. Curriculum Stud. 17 878–94
Trinklein F E 1992 Problem solving Modern Physics (Orlando, FL: Harcourt)

1 For further insight into how wings work see the article by Babinsky (2003) in this journal.