The Scientific Method: From Socrates to String

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Overview

In all disciplines of science, educators have been trained to teach the scientific method as a step-by-step approach that will guide students in gaining understanding of a variety of science concepts, whether they are general or specific. This method seems universal in its structure and is consequently multidisciplinary. As such, science teachers have a common instructional language when referring to the scientific method. It has been my experience that most teachers do not question this process, as it seems intuitively sound as a procedure for investigation. Traditionally, science textbooks also reinforce this process as an accepted practice that will lead to scientific meaning for the learner. Is this process, as it is structured, the best practice for teachers to promote? Does it allow for creativity or independent thinking that is 'out of the box'? Is the scientific method in itself an acceptable foundation to guide students to the higher ability of being able to logically reason? The aim of this unit is to demonstrate that understanding the history of thought behind the scientific method informs science educators of best practices for their science instruction.

Rationale

The History of the Scientific Method

The history of the scientific method is deeply rooted in the philosophical development of thought and how the world is viewed in such a framework. Early traces of the scientific method are credited to Imhotep (c.2600 BC), the Egyptian architect and doctor who is believed to have written the Edwin Smith papyrus. (1) In these papers Imhotep systematically outlines cures, diagnoses, treatments, detailed anatomical observations, and prognoses. In ancient Greece, Plato deals with abstract thinking as he mentions the teaching of arithmetic, astronomy, and geometry in schools. (2) Aristotle, in the second book of his *Physica* (Physics), talks about investigating the cause of each thing in order to seek what is most precise. (3) He states, "*Generic effects should be assigned generic causes, particular effects to particular causes*. (4) In reference to discovering the inherent nature of objects, Aristotle writes "*the question What is it? recurs in other fields, it might be supposed that there was some single method of inquiry to ascertain (as there is for derived properties the single method of demonstration); in that case what we should have to seek for would be this unique method."(5) Although* Aristotle did not create a system for inquiry, his writing seems to lean toward a more empirical system of discovery.

The next major advancement of the scientific method emerged from Roger Bacon, a Franciscan friar who lived during the thirteenth century. Bacon was known to perform and describe a variety of experiments. The method that he advanced was a repeating cycle of observation, hypothesis, experimentation, and the need for independent verification. (6) He recorded his experimentation with great precision so that others could reproduce and validate his results. Bacon studied many areas of science including the precursors to the microscope, spectacles, flying machines, and hydraulics.

In the seventeenth century the philosophical arena was saturated with strong intellects such as Descartes, Locke, Berkeley, and Hume. Descartes was recognized as a speculative thinker and much of his work deals more with abstract reasoning rather than with the ideas of scientific methodology. However, Descartes influence did lead the empiricists of his time to further their notions of how to best understand the world. John Locke is best remembered for his view that the human mind is a "blank tablet". On this tablet is written the experiences that are derived from the senses. (7) The consequence of this position is that humans can only have knowledge *a posteriori*, or based upon experiences. George Berkeley responded to Locke's position by proposing that things only exist as a result of their being perceived, or in light of the fact they are the entity doing the perceiving. (8) David Hume, the Scottish philosopher, divided the realm of knowledge into two categories. One category involves mathematical propositions and is called *relations of ideas*. The second category is entitled *matters of fact* and includes ideas that are derived from observation of some worldly phenomenon. (9)

Galileo Galilei showed that experimentation was required to logically demonstrate differences in scientific opinions. He used mathematics as a way to prove his ideas to others. Sir Isaac Newton, in his *Philosophiae Naturalis Principia Mathematica*, outlines his four "rules of reasoning", which would become a model for other sciences to emulate. (10) One of the priciples can be summarized as a statement of hypothesis testing in that Newton suggests that ideas formed by induction are to be held true but open to further investigation.

A more recent contributor to the formulation of the scientific method was Karl Popper. He is credited for supporting the hypothetico-deductive model. (11) This model suggests that science investigation is forwarded by a hypothesis that is intended to explain some observed phenomena. Experiments are done to see if the predicted explanation is upheld or falsified. Recent work on the scientific method has been done by Paul Feyerabend. He argued for the position that there are no particular rules that govern scientific investigation that need be used at all times. He objected to any single prescriptive scientific method on the grounds that any such method would limit the activities of scientists and thereby impeed scientific progress. (12)

It is critical to explore the efforts and work of the past so that it can inform our thoughts and actions in the present. The scientific method evolved through a series of sometimes extreme beliefs and lines of thought. As its course approached our current time, there seems to be more of an integrated approach or balance of ideas that no longer hold extreme positons. This movement towards integration should tell us of how we may also approach science instruction and investigation in our classroom environments.

This unit can be used in any secondary grade level science or social studies classroom. It is intended to be used as a way to demonstrate to teachers and students alike the significance of the development of the scientific method. This view of that historical process is hoped to reveal underlying reasons for the way science instruction has been delivered and continues to evolve in today's classroom.

Objectives

This unit is meant to for both teachers and students of science. For the professional educator, the unit will explain the history of thought that is the foundation of a basic science process. This topic has a rich past and is necessarily connected to the phiosophy of science. This unit also appplies across the sciences as the scientific method is a common language to the majority of science courses being taught at all levels. Students will be able to appreciate and explain that there are reasons for their work in science and scientisit of the past have relied on processes like the scientific method to discover and explain how the world works.

Strategies

Instructional Methods Utilized to Teach the Scientific Method

Over the past several decades, science educators have been trained to teach the scientific method as a structured and linear process from the hypothesis to the conclusions. This process was supported and reinforced in the science classroom as the delivery of science education was done mainly in a deductive, direct teaching style. This style of instruction can be broken down into four phases.(13) The first phase consist of the teacher presents and defines the concept, ties it to prevoius content learning , clarifies the terms involved, and states the learning objective. Key concepts are defined nextand by use of related examples and examples not related to the concept. The third step would be practice with the problem set or skill in order to master the concept. Classroom laboratory experiences are also very prerscribed in this scenario. The so called "cookbook labs" are done in a designated block of lab time. This description is not to imply that there is no use for a deductive method in science instruction. Depending on the educational objective, direct learning via a deductive approach can be the most efficient instructional technique to be implemented. One such time would be to experience a "proof of concept" activity for purposes of a specific quantitative study. i.e. How much of a reagent A is needed to produce a certain amount of a product B?

The deductive model does not stress thinking skills as readily as other models. (14) Although the learner is asked to compare examples and generalize from them, they do not look at a large body of data and actively search for patterns. The teacher chooses this form of instruction to satisfy specific educational or time related goals. One such educational goal may be to cover a certain body of content in the least amount of time possible. This choice of instruction will compromise the focus on thinking skills in favor of content emphasis. Students will be asked to learn more superficially or to just try to memorize the new information presented. One potential effect of this choice, which we as educators do choose often, is that the average student may not assimilate this new information to existing schema they have already created. The content may "stick" until the test but be lost from memory or replaced within a few short weeks. Teachers can try to subvert this problem by showing students relevance of new content and how it relates to prior knowledge. To do this though requires more instructional time than teachers may want to spend if they are trying to cover large amounts of content over a short period of time.

Another teacher motivation for employing a deductive approach could be that the teacher was trained in this style of instruction and that is what they consider to be the “right way” of doing things. In some cases, teachers do resist changes that evolve in pedagogy over time. Often the response is that “this too will pass” or “This is what I already do but they renamed it”. There are times that this rings true but not for every instance. The goal of professional development on a personal level should to be to incorporate new instructional ideas into what already works in your instructional repertoire.

Even after sound professional development, there still are many science educators who prefer to use the deductive model of instruction for the majority of their teaching. There is a sense of efficiency within this model. In a district or school that is supporting weighty traditional curriculums, this method of teaching could well be preferred over a more time intensive approach. These teachers are professionals who have adequate training and are generally well educated, know their content well, and actually deliver the material in a seemingly flawless manner. It misses the point to argue that their teaching is at fault, but rather it begs the question of there being additional valid instructional methods available that appeal to a range of learning styles and thereby maintain some instructional balance within classroom instruction and learning.

In terms of student motivation, the deductive model may also fall short as compared to the inductive or inquiry methods. Students will have less opportunity to interact at length with the content, not to mention that they are less concerned about responding with giving the “wrong” answer. In addition, deductive instruction is not inherently framed to support that learners have a sense of the unknown. As a result it is more difficult to regain the attention of a student who has become off task or temporarily distracted.

Another primary style of instruction is known as the inductive method. Common names for this approach are inquiry and discovery learning. In this case, knowledge is built from the learner’s experience and interactions with the phenomena being studied. The teacher presents a concrete example of a concept and the learner is to discover patterns, relationships, and to generalize from their observations. The concept is explored prior to it being named. The teacher plays the role of facilitator, intentionally guiding the learner with meaningful questions. An example of this process would be to present learners with a scenario and materials that follow with general instructions. i.e. Lift a car up an inclined plane of x degrees. Add varying weights to the car and record force needed to pull car up ramp. Students would then be asked to record and graph their experimental results. Inquiry is another example of a developed instructional strategy that experienced teachers sometimes care not to look at or feel that they already use it in their instruction.

Inquiry and the Scientific Method

There are as many definitions for inquiry as there are science teachers. How do we find some consistency in what is meant by this term? It is not a new concept in education but it does have implications for current science teaching and learning. Inquiry can be viewed as one of many "diverse" approaches to the teaching of science. Inquiry has distinguishing, multifaceted features but is not limited by any one definition.

The National Science Education Standards defines inquiry as: "the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of how scientists study the natural world." (NRC, 1996, p.28)

The standards are divided into two categories: 1.) *abilities* necessary to do scientific inquiry and 2.) *understandings* about scientific inquiry. As implied, the abilities to focus on certain skills and processes students need to perform a scientific investigation. Understandings reach for a deeper insight into the nature of inquiry. Abilities and understandings about inquiry become increasingly complex from K – 12, but there are certain themes that permeate all grade levels.

The abilities to do scientific inquiry encompass the cognitive skills that go beyond the process skills of science, such as observation, inference and experimentation. (15) The effect of applying such abilities is that students are taught to combine the abilities with content knowledge as they reason scientifically and develop critical thinking in order to understand specific science concepts. The abilities, as described by the National Science Education Standards, extend from the elementary to the high school level. They are meant to be increasingly more difficult as the grade level increases. This type of progression should allow for students to develop and mature within a consistent framework. One barrier to this goal has been that not all school districts have bought into the idea of inquiry as a model that they want to embrace and support. Usually, inductive instruction entails a high price tag in terns of staff development and curriculum materials. Another setback has appeared in that the curriculum writers have not been able to produce textbooks that are in line with the National Standards.

Students are being asked to identify questions and concepts, design and conduct scientific investigations, use technology, formulate and revise scientific explanations based on evidence, recognize and analyze alternative explanations, and communicate and defend a scientific argument. As written, these abilities when implemented appropriately, would teach students a valid way to understand their world in terms of science.

In addition to the abilities, the standards are also explained for the understandings of scientific inquiry. The understandings of scientific inquiry represent how and why scientific knowledge changes in response to new evidence, logical analysis, and modified explanations debated within a community of scientists. (16) The understandings about scientific inquiry, at the high school level, focus on there being a method that typifies how scientists think and act as they work. Explanations of theory and experiment are expected to be questioned, defended, and modified if necessary. Mathematics is stressed as an essential tool for scientific understanding. Scientist accept that there may be a variety of reasons for a researcher to investigate. The combination of the abilities and understandings of inquiry are deemed to provide the fundamentals in students learning to view science in a methodical manner.

The Roles of the Teacher and Student in Inquiry

During an inquiry experience, the teacher becomes a facilitator of events, instead of an orator of facts. The goal of the teacher is to consciously guide students through the inquiry experience via meaningful questions and engaging challenges. Increasing student independence may be a paradigm shift for teachers who are accustomed to having greater control over the activities, students, and lab materials in the classroom. Inquiry can vary as teachers determine the degree of guidance they want to provide or the instructional needs of the class as a whole. Inquiry is not the only appropriate instructional mode for the classroom. Some ideas are better conveyed through a lecture. Teachers need to be aware of the appropriate content standards surrounding inquiry as they prepare their activities and instruction within this approach. Each grade strand has its own guidelines as to what inquiry entails at that specific level.

Students are given additional responsibility for their learning. They may be asked to create or develop ideas that were traditionally given by the teacher. Students are encouraged to try alternative ideas and techniques to solve problems. Inferences and predictions based on experimental data may lead to new experimental ideas. Communication of ideas among peers, teachers, and others is encouraged and supported. This is similar how the scientific community discovers new and important information.

Key Components Underlying Inquiry-based Science

Inquiry, within the curriculum science framework, is seen as not only a "content" piece but as an underlying and continually evolving "process" critical for effective science education. The National Science Education Standards and the Pennsylvania Standards for Science and Technology both address this dual nature of inquiry as it relates to science education. Teachers should familiarize themselves with the inquiry standards by using the appropriate concept map for their teaching level. Teachers need to ask themselves which standards they feel they already teach. The National and PA standards are available online and can be downloaded. (www.nap.edu and www.pde.edu). Teachers should try to match evidence of their instruction to the inquiry standards. Upon reflection, teachers can then determine what standards they have not addressed in their classroom.

Effective science instruction will help students develop certain habits of mind as well as higher-level thinking skills. Research has shown that teaching methods and techniques are as important as the science being taught. Problem solving is intimately related to scientific investigation. Advances in medicine, communications, transportation, and industry are examples of progress in society due to citizens having essential scientific knowledge and skills. Today's world is linked via the media and sharing of information in many arenas. Science instruction, therefore, needs to include the processes that foster these skills that are critical to everyday living. The following curriculum designs each focus on an area that is important to teaching students science that matters in their everyday experiences.

Additional Standards-Based Instructional Curriculum

Recent movements in education are shifting to a more inductive approach to instruction that is tempered by deductive reasoning activities. The creators of instructional materials are being funded to produce curricular materials that reflect a balanced approach to science instruction and learning. The "learning cycle models" best depict this kind of instruction. Learning cycles are cyclic processes that continually develop, test, and generalize information. The success of this style largely depends upon the teacher and how effectively they implement their skills, as needed within the activity as presented in this style of learning. One critical skill is questioning strategies. Another key skill is recognizing when it is "time to tell" learners the significance of their newly discovered distinctions. (17) The goal of such an approach is to use textbooks, lectures, and inquiry within the confines of an instructional unit so that student learning is maximized.

The 5 E Model

Other instructional models use inquiry as the basis for learning cycles.
One such model is the 5 E learning approach proposed by Biological Sciences Curriculum Study (BSCS). (18) This model helps teachers plan and organize each component of scientific inquiry: engage, explore, explain, elaborate, and evaluate.

The 5 E approach is an integrated, student centered model that devotes time to the processes of scientific understandings as well as to science content. The engage section brings the learner's mind into the frame of something new. The student should find interest or relevance in this stage. For example, reading a story of how a popular athlete eats and trains to stay fit could be an engage activity for a chapter on the matter and energy transfer in the body. The explore portion provides a common experience for all learners and helps the teacher identify the prior knowledge of the learner. This kind of activity would ask the learner to place what they already know in a specified context. One instance might be to list the foods eaten in a day and place them into categories. The explain section of the model is designed to allow the learner to construct an explanation for the concept being explored. In this section experiments or data analysis takes place, where the learner has to propose an account of data reviewed or gathered. Students studying energy transfer in the body may now experiment with indicators and foods to determine their properties and how they are identified.

The goal of elaboration is to extend the knowledge or understanding to a deeper level. This stage also may include activities such as labs or higher level application situations. In the example of the energy transfer study, this would be a good time to have a lab where students had to identify unknown organic nutrients based upon their knowledge of the indicators they learned in the explain activity. The evaluate component provides an opportunity for learners to assess their own understanding and be able to demonstrate the depth and breadth of that understanding to others. Students in this stage could be asked to develop a fitness program for their peers based upon the knowledge gained throughout the activity.

The overall outcome for this type of student learning is to connect prior knowledge in a relevant or interesting manner to new information and experiences that will foster understanding around a particular scientific topic. Critics of this process assert that so much time is spent on seemingly unrelated activities that the content of the science concepts become buried in the process. Supporter of this method claim that students learn how to think and interact with science in real life situations and allow students to make proper connections for learning science instead of memorizing endless facts.

The E-Learning Model

Another recent instructional model is known as e-learning. E-learning is defined as technology-based learning that engages students through the use of media, such as pictures, video, and sound. There are many papers appearing that aim to compare the effectiveness of e-learning to the traditional classroom. This area of research may lead to new insights that would not only impact education in general but science education in particular. Can we teach students to behave and think like scientists through the medium of a laptop? Are simulations and interactive computer models sufficient replacements for hands-on experimentation?

Supporters of this method claim that e-learning represents a constructivist instructional ideology in that the learning is an active process that engages the learner (19). That claim seems to be true in that the learner is able to actively control certain variables within a program. One such type of program studied involves causality. This particular program is a virtual environment that teaches students how to reason causally about specific phenomenon. (20) Researchers claim that the aspect of interactivity, or maintaining student interest, is the key component that allows e-learning to compete with lecture-based learning in the traditional classroom. This is achieved through use of simulations and dynamic pictures. Others aspects or program design includes having discussion groups, student modification of certain variables, as well as immediate feedback.

The question for this discussion around scientific method is whether or not causality programs and interactivity will provide the needed foundations for the abilities and understandings of scientific inquiry? Are there sufficient numbers of high quality programs to compensate for the tremendous amount of content that is part and parcel of any of the major sciences? The scientific method itself would need to be interpreted with the knowledge that students would not be able to manipulate equipment or have experience with the tools of experimentation. This kind of science instruction would be hard pressed for any type of science knowledge that required some concept of proof based on evidence arrived at through experimentation. On the other hand, theoretical knowledge, as displayed in mathematics, does serve a role in the development of scientific thinking. Once again, the idea of having balance in instructional strategies would assist in reaching a broader range of learners and allow for understanding of meaningful science content for the learner.

String Theory and the Scientific Method

The most current struggle surrounding methods of science has emerged from the development of the string theory. This theory has been under construction for more than thirty-five years. String theory posits that the universe is composed of tiny strands of energy, which vibrate at different frequencies, creating what appears to be different particles. There are different forms of string theory; one popular idea being that there are at least six dimensions outside of the three in space and one in time that we are accustomed to hearing about. There does exist some solid experimental foundations for string theorists have based their generalizations upon, but scientific concerns and problems with the theory still need to be reconciled. Critics of the theory assert that there is not enough empirical data that has arisen from this theory over the past thirty years. Scientists question how much time, effort, and funding have gone into the research for this theory and yet have not produced substantial information. Proponents argue that there is reason to continue looking at these ideas because the search for that data has yielded new lines of mathematics and that there is a possibility of discovering an underlying unification theory that could explain, in a novel way, the foundations of the universe.

The concern of this paper is not to argue for or against the string theory but to assess whether or not the advancement of the theory will impact science education at the classroom level. One question that may arise from string theory is how do we now look to understand the scientific method, if the accepted components of experimentation and validation have again become more abstract than empirical? Traditional lines of argument are based upon the need for science to produce empirical evidence. After all, how can one assert that an idea is correct if there is no type of evidence to support the claim. This argument seems intuitively sound and reason suggests that it is valid also. The line of reason continues in that there is a method that best results in the finding of experimental data that best illustrates the correctness of how that data is analyzed. Thus the scientific method has been developed over the years as a linear 'thought' process consisting of an idea that is to be experimentally tested for attaining a certain outcome. Emperical evidence is the foundation of proof that the idea has merit. Who in the scientific world would argue this point? Certainly as science educators we see that this linear system fits into the structure of traditional educational pedagogy. We have all been taught the method and it seems to work for us intellectually and pragmatically in the classroom.

For our discussion, the role of empirical evidence is not in question as much as the method of viewing or arguing that a theory or idea is valid. In his book *Against Method*, Paul Feyerabend argues that to advance science knowledge and theories, scientists should not only proceed in the traditional linear sense but also employ counterinductive lines of reason. (21) He suggests that there are properties of established theories that can only be found by contrast, not analysis. The goal of such counter activities is "to make the weaker case the stronger, and thereby to sustain the motion of the whole". (22) The point that seems relevant to me as an educator is that there needs to be a pluralistic way of thinking about and teaching science as a method of discovery. A pluralistic educational approach when teaching students about the nature of the scientific method and what it means to 'do' science, historically and in the present reality of the classroom will be the impact of discussion around such areas as string theory. Therefore, science educators are enlightened not only by new knowledge but by remaining open to the possibilities that this new knowledge may bring to their pedagogy in the classroom.

Lesson Designs for Introducing the Scientific Method

The classroom activities for this unit are meant to last no more than two to three class periods each, depending upon whether or not the activities are assigned for the classroom or out of the classroom.

Activity 1*:* *The History of the Scientific Method*

Objectives: Students will be able to describe the contribution of a known philosopher toward the development of the scientific method.

Activity: Students are given a list of philosophers and are able to choose one to research. Teachers can search the internet for the names of contributors, list them and have students sign up for their person. Basic information can be gathered by the students, such as name, country of birth, education, area of scientific research, contribution to the scientific method, etc. The research paper can be as formal or informal as preferred given time restraints. I have students keep their papers to one side, single spaced with references. Students can use the computer lab in school or take the project home as homework. Once the papers are complete, the class can then combine their information to create a timeline that shows the progress of the scientific method as seen by the contributions of the philosophers and scientists over the past centuries. This activity can require little no class time if the timeline is not done or two to three periods, depending on how it presented.

Activity 2: *The Lingo Game*

Objective: Students will be able to describe the process of deductive thinking by playing a game with science words.

Activity: The Lingo game can be played to serve as an example of deductive reasoning. In deductive reasoning, the thinking is orderly and flows from an accepted set of facts. If these premises are correct and the method is proper, then the conclusions will be correct. In this game, the contestants have to guess what a five letter word is when given a letter to start. If the contestant guesses the wrong word but has the correct placement of a letter within the unknown word, then that letter is written in its guessed place and circled. The point of the game is to deduce the unknown word based on your guess and that of your opponent.

The game can be modified a bit and is fun when used as a review activity. The words can be the key terms from the chapter or content being covered in class. When the game is over and the winning team is done celebrating their trip to the Bahamas, a class discussion of the process behind the game is in order. The teacher should ask the class what method was used to determine the word. The teacher can list the steps as they are offered. The entire class then decides the proper order and relevance of each step. If the students do not know that this is deductive thinking, then the teacher can share that information at the end of the discussion. The activity can be done in one class period, either as a review for a test or just to check for understanding.

Activity 3: Inductive versus Deductive Instruction

Objective: The teacher will be able to differentiate between inductive and deductive instruction.

Activity: There are many manifestations of this comparison of instructional techniques. One basic example of deductive instruction or lab work involves the calculation of walking speed. Speed is basically a displacement over a period of time. This is a common and intuitive science concept, one in which all students have had some life experience.

The deductive approach to this activity may entail a lecture on the concept of speed, velocity, and motion in one dimension. There are also basic calculations that need to be practiced for the skill of this manipulation to be reinforced. Students may then proceed to do a lab or activity that will cause them to apply their newfound knowledge. The activity may be from a lab manual or a teacher created set-up. The structure of the activity follows a step-by-step method that guides the student in how to set up the given materials in order to collect a specific set of data points. In this case, the student will need to find the distance they are walking and the amount of time it takes to cover that distance.   The student creates a data table or is given one to complete. The calculations are done and a graph may be required. The last step is to answer a series of increasingly rigorous questions that are intended to summarize the content of the experience. The goal of this process is to have the student understand the concept of speed.

The inductive approach may entail more process. This activity could be totally unstructured if the teacher knows that students are independent enough in their learning. For example, in its broadest form, the students could be given a statement that asks them to design and conduct an experiment to determine the walking speed of an individual. Students would then work in pairs or groups to determine what materials and methods are required to find the answer to the problem. This is the least structured this activity could be but it serves to demonstrate for a teacher that there are different styles of instruction that can accomplish similar goals. The students will be asked to determine speed but they were also challenged to create their own method to find a solution to the question and then test for its ability to answer such a question. If one method fails, then students would be required to continue in their attempt to create a working solution.

Both types of instruction are appropriate for different educational reasons. Both kinds of instruction will lead to the understanding of the speed concept. In this case, since there was some prior knowledge of the content, the learners may both retain the new concept also. The choice of technique will then be determine by the teacher's goal for the learner, time constraints, or other issues that are apart of lesson planning.

End Notes

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APPENDIX A

Standards

There are two sets if standards that are relevant to and cited in this unit. They are The Pennsylvania Academic Standards for Science and Technology (PA) and the National Science Education Standards (NSES).

PA Standards

Pennsylvania's public schools shall teach, challenge and support every student to realize his or her maximum potential and to acquire the knowledge and skills needed to…

Inquiry and Design:

3.2.12 B

… Evaluate experimental information for appropriateness and adherence to relevant science processes.

3.2.12 C

… Apply the elements of scientific inquiry to solve multi-step problems.

NSES Standards

Teaching Standard A.2:

Teachers of science plan an inquiry-based science program for their students. In doing this, teachers select science content and adapt and design curricula to meet the interests, knowledge, understandings, abilities, and experiences of the students.

Professional Development Standard A.1 and A.4:

Professional development for teachers of science requires learning essential science content through the perspectives and methods of inquiry. Science learning experiences for teachers must:

1. Involve teachers in actively investigating phenomena that can be studied scientifically, interpreting results, and making sense of findings consistent with currently accepted scientific understanding.
4. Build on the teacher's current science understanding, ability, and attitudes.

Content Standard A: Inquiry

As a result of activities in grades 9-12, all students should develop:
… Abilities necessary to do scientific inquiry and
… Understandings about scientific inquiry.

Content Standard G: History and Nature of Science

As a result of activities in grades 9-12, all students should develop understanding of:
… Science as a human endeavor.
… Nature of scientific knowledge.
… Historical perspectives.