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Implementing Student Research in the Classroom: A Teacher's Guide

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Introduction

This guide provides a template for high school teachers interested in incorporating inquiry-based learning practices into their classes. The guide provides specific tips and suggestions to assist teachers, but is general enough to be used in most science classes. It begins with an introduction to inquiry, and proceeds with suggestions on how to enable students to develop their own questions, plan investigations, predict results, conduct an experiment, analyze their results, and explain their findings to classmates. Rubrics useful in evaluating student success are included. A high school teacher participating in the Environmental Inquiry program developed this manual.

Philosophy

Science is a process of developing answers, or improving explanations, for observations or events in the natural world. It begins with a question about a natural phenomenon, continues as the process of scientific inquiry begins, and may conclude with an answer or proposed explanation. The capacity to conduct valid, objective, and accurate research requires skills and experience in scientific reasoning, experiment design, data analysis, and the development of scientific habits of the mind. For students to develop these abilities, they must actively participate in scientific investigations, and they must actually use the cognitive and manipulative skills associated with the formulation of scientific explanations. This can best be accomplished when the scientific investigations are based on questions that are meaningful to the students.

Research Process

There is no simple formula for doing science. The basic form of the scientific inquiry process is generally referred to as the *scientific method* and is illustrated in **figure 1**. In this process, once a scientific question has been posed, a scientist considers all possible hypotheses or explanations, which might answer the question raised. Each explanation must be tested by a separate experiment. After planning an experiment, a scientist then predicts the results of the experiment assuming the hypothesis to be true.

The explanations proposed by a scientist involve a creative process based on one's own personal experiences as well as historical and current scientific knowledge. Thinking of the initial question to ask about the observed phenomenon, and all conceivable explanations (or hypotheses) to explain the phenomenon are among the most creative moments in the process of scientific inquiry. The scientific knowledge acquired from the research is produced, by building on, refining and revising existing laws and theories.

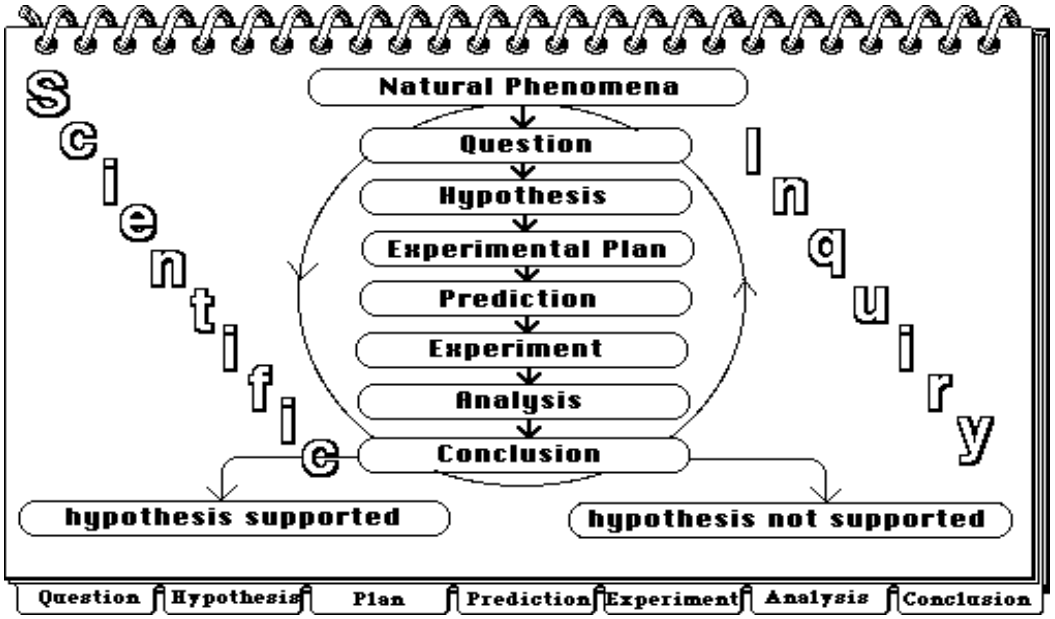

Figure 1. Simplified form of the scientific inquiry process.

Question

Research originates with a question or a problem. Questions can arise from a student's curiosity, scientific topics that have been highlighted by current events, or from actual science- and technology-related problems. Regardless of the source, the question or problem should meet the following criteria whenever possible:

- Open-ended (the answer is not already known)
- Meaningful to the student
- Suggests a testable hypothesis
- Driven by the scientific concepts, principles, and theories related to the course of study

The question to be researched will generate competing explanations based on prior knowledge developed within the class and the concepts of the world each student has brought to school. From a set of different explanations, one is selected and a proposed relationship or model is developed to

test the hypothesis using the process of scientific inquiry. Except for the goal of the inquiry, each element in the research process is subject to change.

Tips and Strategies:

- Divide the class into teams of 3-4 students. Team formation generally works best with teacher input. Be sure to emphasize the concept of teaming as opposed to group work. It may be very valuable to spend time doing teaming exercises before the project starts.
- As a first step, provide students with a list of possible research problems. Keep the statement of each problem very general so students will have to brainstorm in order to develop a specific question and possible explanation. This can be done through reasoning, Internet research, and/or discussions within the class. This strategy should be used even if all teams are researching the same problem. Having a variety of research problems within a class makes each teams work more unique and places less stress on the availability if equipment and supplies.
- Research is directed to a specific goal. This goal is determined by the possible explanation, a hypothesis generated by the research team. It is important that the teacher develop the concept of a hypothesis with the class before the research begins. Most students have memorized that a hypothesis is "an educated guess" and really don't have a clear understanding of its significance. Teachers may want to include the following information:
    1) Hypotheses are possible causes. A generalization based on inductive reasoning is not a hypothesis. A hypothesis is not an observation, rather, a tentative *explanation* for the observation.
    2) Hypotheses reflect past experience with similar questions ("educated propositions" about cause).
    3) Multiple hypotheses should be proposed whenever possible. One should think of alternative causes that could explain the observation.
    4) Hypotheses should be testable by experimentation and deductive reasoning.
    5) Hypotheses can be proven incorrect, but can never be proven or confirmed with absolute certainty. Someone in the future with more knowledge may find a case where the hypothesis is not true.
- Upon the formulation of the question and hypothesis, each team can present to the class, or to the teacher, the process they used to arrive at their proposal, the rationale for investigating it and the proposed explanation to be tested. This provides an opportunity to discuss issues about the nature of science as to how external factors influence scientific decisions. This exercise may lead to further revision of the research question and testable explanation. This activity may be directed with a rubric that outlines appropriate inquiry skills for student-generated explanations for the target audience.
- Stress that members of a team document in writing the process used to develop their proposal. The hypothesis they propose will evolve through the brainstorming process. Members of the team can use steno notebooks as laboratory journals. Teachers can track the progress of a team by assessing the individual journals. These journals will also become the primary source for developing a presentation as the final step in the research process.

Planning the Investigation

The design of a scientific investigation is directed by the specific knowledge base of the area being studied and the concepts that guide scientific inquiry. The core of the design requires the identification of a set of variables that can be used to test the proposed explanation; and a specific plan of procedure, including selecting and developing techniques, acquiring and building apparatus, and recording observations. Abilities needed include:

- Using appropriate tools and techniques to gather, interpret and analyze data
- Making precise, accurate and reliable measurements
- Recognizing the use of appropriate technologies
- Identifying significant variables
- Practicing appropriate safety precautions

As the design plan develops, the research question will be modified to meet constraints of time and resources available to the class.

Tips and Strategies:

- Emphasize to students that their research design plan must be guided by scientific concepts and performed to test their proposal. Students will often have trouble determining the appropriate variables to measure and the concept of a controlled experiment.
- Provide time for students to research the appropriate concepts needed to explain their hypothesis. Sources can include the Internet, science textbooks, library research, and experts located within the school community. When appropriate outside sources are unavailable, the teacher may want to assume the role of the expert. When this is done, the teacher should attempt to include the societal influences that are related to the particular expert being portrayed.
- Upon the formulation of the design, each team can present to the class, or to the teacher, their proposed plan. This provides an opportunity to discuss issues about the nature of science as to how external factors influence scientific decisions. This exercise may lead to revisions in the design plan as well as further revisions of the research question and/or testable explanation. This activity should be scored with a rubric that outlines appropriate inquiry skills for the target audience. The teacher should consider using the rubric for self-assessment as well as peer assessment.
- Stress that members of a team record all aspects of the plan in their laboratory journals. The teacher should periodically schedule brief meetings with each team to assess the quality of record keeping. By playing the role of a manager, the teacher can conduct a team meeting that would include feedback on the research plan from all members.

Prediction of Results

Before the research plan is implemented it is important to predict what would happen if the proposed hypothesis were true. The research plan is not meant to prove the hypothesis but to support or not support it. Deductive reasoning is used to move from general concepts to the specific.

Tips and Strategies:

- The teacher should make sure that each student has an expectation of what will happen when they execute their experiment. In addition to recording their prediction in a laboratory journal, each research team should present their predictions to an outside party that may be the teacher, another research team, or the entire class.
- Assessment of this step of the research process should be based on the students' personal background, relevant historical and current scientific knowledge, and the use of deductive reasoning. This can be accomplished using a holistic rubric that includes a combination of peer assessment, self-assessment and teacher assessment.

Executing the Research Plan (Experimentation)

During this stage of the inquiry process, the necessary equipment is assembled and research design plan is performed. The goal is to collect, record, and organize the experimental data needed to test their explanation to see if the predicted results are obtained. The testing is based on performing a controlled experiment that includes replication. Specific design methods and data collection schedules may have to be tested and modified.

Tips and Strategies:

- Emphasize to students that they will need to assemble and set up the apparatus they will be using to record observations. This should include a detailed diagram of the system in each team member's laboratory journal. They should expect that the completed apparatus would be modified based on equipment and supplies available in the classroom.
- Calculator-based laboratory equipment and computer-based laboratory increases the precision and accuracy of measurements. In many research projects, students' ability to compare predicted results to actual results would be enhanced by the increase in data accuracy. If necessary, teachers can include exercises that emphasize the differences between precision, accuracy and significant figures.
- The teacher should always check to ensure that each research group has identified the control in their experimental plan.
- Students may need to modify their method of data collection. They will need to make trial runs of their equipment to determine collection methods, rates of change in variables, and the number of measurements to make. The answers to these questions may cause changes in the experimental apparatus being used.
- Emphasize that all data collected as well as the methods of data collection are recorded in each student's laboratory journal.
- Replication is very important in scientific research. Every procedure should be performed several times and other researchers should repeat the entire experiment. In classes where different teams are researching different questions a teacher may switch final written reports among groups to see if they can follow procedures and repeat each other's work.

Analyzing the Results of the Research

Upon completion of the research plan, the research team begins a preliminary analysis. Various means of representing data are used and the organized data is interpreted. The actual results are compared to predicted results to determine if the proposed explanation is supported. Statistical

analysis techniques are applied when appropriate to test if chance alone explains the results. Evidence may suggest that more data is collected or the data collection methods are modified.

Tips and Strategies:

- In introductory science courses, teachers should stress using appropriate methods to represent and organize data. These include diagrams, tables, charts, graphs, and mathematical formulas.
- Spreadsheets are an excellent method for organizing data and creating the appropriate graphs. The statistical functions associated with these programs allow students to perform data analysis at different levels of expertise.
- Each research team should prepare a report of their preliminary analysis and present it to the teacher or another research team. This allows for feedback to determine if the data-collecting procedures need to be modified or if more data needs to be collected. The presentation can be focused using the following questions:
  - What explanation did you expect to develop from the data?
  - Were there any surprises in the data?
  - How confident do you feel about the accuracy of your data?
  - Is there a better way to test the hypothesis?
  - Is there another possible explanation?
  - Do you need more data?
  - What are the sources of experimental error?

Conclusion of the Research

The actual results are compared and contrasted with the predicted results. Based on the analysis of the data and feedback received from peer and/or teacher evaluation, a conclusion is finalized as to whether or not the explanation on which the prediction was based is supported.

Tips and Strategies:

- Most students will assume that their results are definitive and the process is over regardless of whether their explanation is supported or not. It is important to emphasize that a hypothesis cannot be confirmed with absolute certainty.
- Stress to students that their scientific knowledge has been advanced even if their hypothesis is not supported by their results. Scientific inquiry is both a content and a process.
- Teachers may use specific focus questions to help students make connections between the experimental conclusion and process of inquiry. Such questions include:
  - How certain are you of your results?
  - In what ways are your results supported by current scientific knowledge?
  - How have your personal ideas changed by doing the research?
  - What changes would you make in the experimental plan if you were to do this project again?
  - What are the positive and negative aspects of working as part of a team?

Communicate and Defend the Research

One of the important characteristics of scientific research is the willingness to share knowledge publicly, including communication of scientific procedures and explanations, process and results. This is accomplished through presentations and publications.

Tips and Strategies:

- The research project is not complete until the entire process is presented in both a written and oral format to a specific audience. The audience may be a teacher, another research team within the class, the entire class, members of a different class at a different grade level or members of a class studying a different discipline. True understanding occurs when students have to present at different levels of complexity and knowledge.
- Stress using a variety of media to create their presentations. Examples include:
  - Written laboratory reports
  - Posters
  - Computer presentation software
  - Lectures
  - School newspapers
- Start with small and comfortable audiences and expand as students gain more confidence.
- Take a field trip to a business or industry that extensively uses the teaming concept that includes team presentations and assessments.
- Assess the presentation with a rubric.

Assessment of the Abilities and Understandings of Scientific Inquiry

The goal of assessing the research process is to determine students' understanding of scientific inquiry and the development of their ability to inquire. Understanding and doing inquiry are contingent on knowing concepts of the physical, life, and earth sciences and also requires reasoning capabilities and skills in manipulating laboratory equipment. Inferences about students' ability to inquire and their understanding of the process can be based on the analysis of performance in the science classroom and work products.

The *National Science Education Standards* envision assessment changes that encompass the following changes in emphasis:

Less emphasis on	**More emphasis on**
Assessing what is easily measured	Assessing what is most highly valued
Assessing discrete knowledge	Assessing rich, well-structured knowledge
Assessing scientific knowledge	Assessing scientific understanding and reasoning
Assessing to learn what students do not know	Assessing to learn what students do understand
Assessing only achievement	Assessing achievement and opportunity to learn
End of term assessments by teachers	Students engaged in ongoing assessment of their work and that of others
Development of external assessments by measurement experts alone	Teachers involved in the development of external assessments

Assessment based on these criteria requires the use of a scoring rubric. Teachers develop rubrics for their class based on specific performance standards. The steps in designing a scoring rubric involve defining the performance standard for the scientifically literate adult and then deciding which elements of that standard are appropriate for students in the specific class. Using rating scales such as satisfactory, exemplary, or inadequate then differentiates student performances. The teacher, using student performance and work, moderates judgments about the quality of students' responses and develops a description for each performance rating.

Tips and Strategies:

- The descriptions for performance rating scales have to be developed for each class or grade level. The teacher must determine what performance standards are appropriate for their students and at what levels. It is probably best to start with very generic descriptions and then become more specific as the rubric is applied to student work.
- The scoring rubrics should be shared with the students before research projects begin. It is important for students to know how their work will be assessed so that they have goals to work toward. Teachers may also want to provide for student input into the development or modification of the rubric. Ownership of the assessment tool may motivate students to strive for a higher level of achievement.
- Use the scoring rubrics for peer and self-assessment as well as teacher assessment. The ability to assess is part of scientific inquiry.
- Make the assessment process public as opposed to a secret that is only shared when the process has been completed.
- Determine the important assessment criteria for each step of the research process. See **Teacher Supplement A** for suggestions.
- **Teacher Supplement B** represents an example of a scoring rubric to assess the development of a worthwhile research question. The category labeled "**Wgt**" is intended to provide teachers a method of emphasizing some performance criteria more that others.

Teacher Supplement A

Possible Assessment Criteria For Student Research

- Identify a Researchable Question
  - Clear statement of research goal
  - Logical rationale for investigating question
  - Based on understandings of the scientific concepts, principles, and theories related to the course of study
  - Evidence of literature review including Internet searches
  - Evidence of a process to reconcile competing explanations
  - Includes understandings of the nature of science
  - Written documentation
  - Presentation skills
- Plan the Investigation
  - Identification of significant variables including the control
  - Directed by the specific knowledge base of the area being studied
  - Performed to test the proposal
  - Includes the use of appropriate tools and techniques to gather, interpret, and analyze data
  - Stresses the importance of safety
  - Defines the constraints of time and resources available to the class
  - Written documentation
  - Presentation
- Prediction of Results
  - Clear expectation of experimental results
  - Prediction based on student's personal background, historical and current scientific knowledge, and the use of deductive reasoning
  - Written documentation
  - Presentation
- Executing the Research Plan
  - Detailed diagram of the assembled apparatus needed to perform the research plan
  - Data collection methods provided for precise and accurate measurements
  - Experimental procedures and measurements can be replicated
  - Experimental procedures and data collection methods are based on a clearly identified control
  - Written documentation of all results
- Analyzing the Results of the Research
  - Data is clearly organized and represented using diagrams, tables, charts, graphs, and mathematical formulas
  - Statistical analysis was used
  - Identification of trends and data that do not fit the trends
  - Actual results were compared to predicted results

- Suggestions for future research
- Sources of error
- Presentation

- Conclusion
  - Clear statement of support or no support for the hypothesis
  - Connections between the conclusion and the inquiry process
- Communication of Procedures and Explanations
  - Effectively communicated the research process at a level appropriate to the specific audience
  - Used a variety of media including graphical, statistical, and presentation software
  - Oral communication skills
  - Written communication skills

Teacher Supplement B

Sample Scoring Rubric

Identify a Researchable Question

Presenters: _____

Assessed by: _____

Date: _____

Assessment Scale**

4 - Exemplary
3 - Satisfactory
2 - Inadequate
1 - No basis for assessment

Assessment Criteria	Evaluation	Wgt.	Pts
Clear statement of research goal	1 2 3 4	1 3 5	
Logical rationale for investigating question	1 2 3 4	1 3 5	
Based on understandings of the scientific concepts, principles, and theories related to the course of study	1 2 3 4	1 3 5	
Evidence of literature review including Internet searches	1 2 3 4	1 3 5	
Includes understandings of the nature of science	1 2 3 4	1 3 5	
Written documentation	1 2 3 4	1 3 5	
Presentation skills	1 2 3 4	1 3 5	
		TOTAL	

** The teacher for the particular class or grade level would determine the descriptions for each of the performance rating levels.