Scientific Inquiry and Research - in the Science Classroom

What is Inquiry?

Inquiry-based teaching and learning is both recommended and expected in today's K-12 science classrooms (National Research Council [NRC], 1996; NRC, 2000). This method of teaching and learning actively engages students in science processes and skills developing their abilities to do and understand scientific inquiry while learning science (NRC, 1996). Since 1996 the endorsement of the inquiry-based approach has shifted science education from the traditional confirmation lab experience to one in which questions, data collection, and other scientific practices drive the learning of science content. On a national scale the science education community has embraced the inquiry-based approach (NRC, 1996; NRC, 2000; American Association for the Advancement of Science [AAAS], 1998).

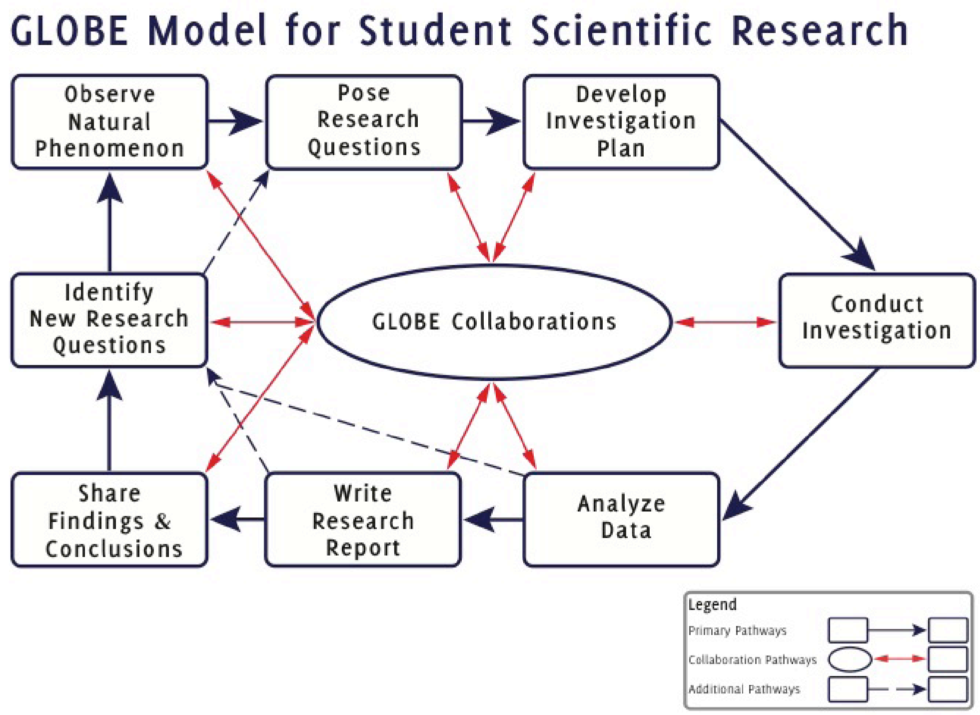
Inquiry

According to the authors of the National Science Education Standards "Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world." (NRC, 1996, p. 23)

In fact, the Next Generation Science Standards (NGSS), include a framework that emphasizes students' direct engagement with scientific investigations in order to gain scientific practices and knowledge (NRC, 2011).

The framework includes 3 dimensions, which are all to be drawn on equally when preparing K-12 science curriculum, standards, lessons, and assessments. The first dimension is the Science and Engineering Practices. These are eight practices that mirror those of professional scientists and engineers and help to better elucidate what is meant by the term "inquiry". They specifically identify the range of cognitive, social, and physical practices that are required for students to perform "inquiry" tasks in the classroom (NGSS Lead States, 2013).

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information



Inquiry & Student Research

In 2011 GLOBE developed the *GLOBE Model for Student Scientific Research* (GMSSR). This diagram depicts the scientific research process as an inquiry cycle with interconnecting parts.

According to the GMSSR schematic diagram, the student scientist often follows a primary pathway beginning research with an initial observation of natural phenomenon and then developing a question and investigation plan. The investigation plan leads to the investigation, analysis, reporting of the conclusions, and finally to additional research questions. Research activities may veer from this primary research pathway, as indicated by the additional pathways on the diagram. For instance, analysis of initial data sets may lead to developing new questions instead of developing conclusions. GMSSR was created as a tool for secondary science classrooms to further enhance students' understanding of scientific inquiry. The GLOBE Carbon Cycle materials address many areas of the GMSSR and so it will benefit students to highlight where they are in the research process as they study the carbon cycle. (*For more support on scaffolding student research in the classroom see the Planning Guide for Scientific Research below*)

Inquiry Continuum

While students benefit from direct experience with all parts of the science inquiry cycle, K-12 science teachers recommend initially structuring the experiences to support students' development of their abilities to inquire. The degree to which the teacher structures what students do is referred to as the inquiry continuum. In fact, different levels of inquiry can be classified depending on the relative amount of teacher-directed versus student-directed behaviors during the inquiry activity (Bell et al., 2005; NRC, 2000). The literature refers to the more teacher-directed science activities as guided inquiry and the more student-directed activities as open inquiry. For instance, it is considered guided inquiry when a teacher provides the research question, data, and method of analysis while the student independently formulates and communicates explanations from the evidence. Open inquiry, on the other hand, demands more self-direction on the student's part throughout the inquiry cycle from question formation to communicating results.

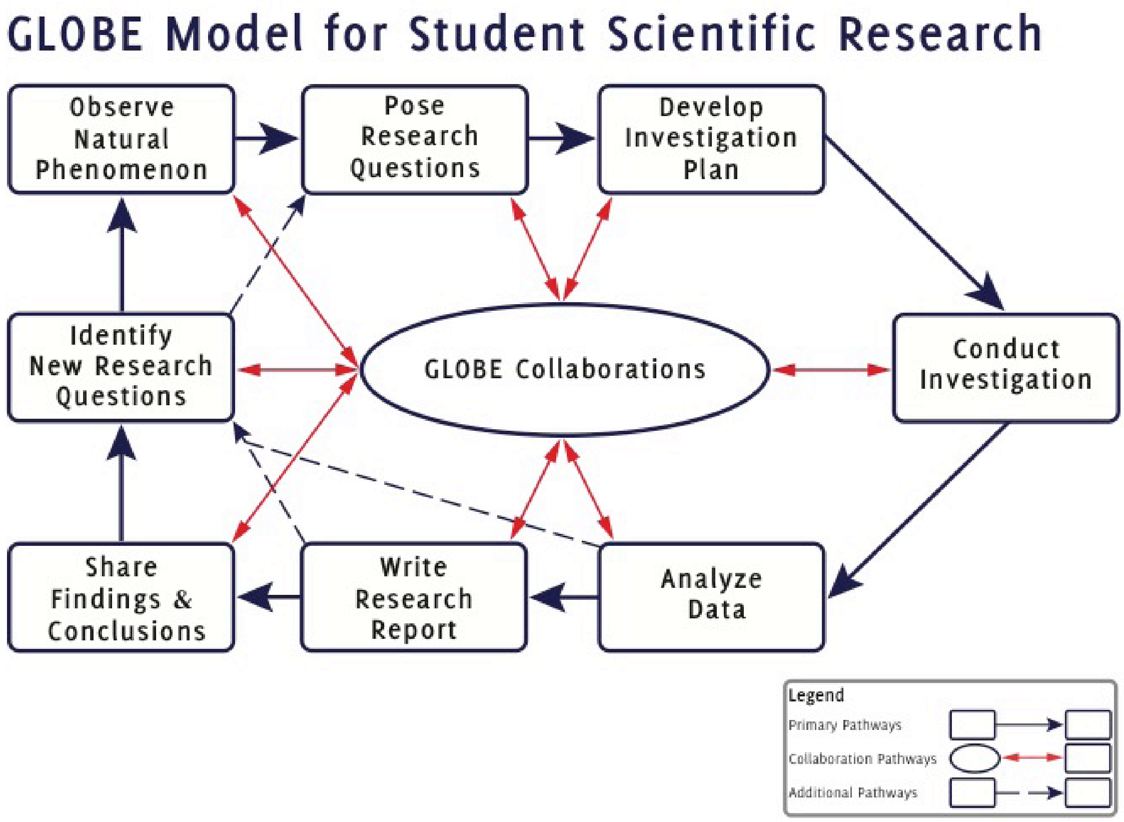
The Carbon Cycle learning activities and protocols are intended to promote inquiry-based learning and teaching. A wide range of inquiry levels—from structured to guided to open—are embedded within the Carbon Cycle activities. When deciding how to implement the Carbon Cycle program, consider the kinds of inquiry opportunities and scientific practices offered in each activity. Then adjust the kinds of inquiry used in your classroom to match your students' prior knowledge and skills. Evidence suggests that students who are not challenged will not develop their cognitive abilities as much as students who are challenged. At the same time, if students are challenged too much, learning is not maximized. Maximum learning occurs when the activities are cognitively challenging and doable for students.

References

- American Association for the Advancement of Science. (1998). Blueprint for reform: Project 2061. New York: Oxford University Press.
- Bell, L. R., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction: assessing the inquiry level of classroom activities. The Science Teacher. 72 (7), 30-33.
- National Research Council. (1996). National science education standards. Washington, D.C.: National Academy Press.
- National Research Council. (2000). Inquiry and the national science education standards: a guide for teaching and learning. Washington, D.C.: National Academy Press.
- National Research Council. (2011). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, DC: The National Academies Press.
- NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

TEACHER VERSION

Planning Guide for Scientific Research



When supporting students during the planning and execution of their own science research, refer to the GMSSR diagram along with the following questions to guide their process. Students may use a science notebook to record their research from the planning phase to the investigation phase.

The research process will closely follow the inquiry cycle depicted above however at <u>all</u> times students must be willing to stray from the primary pathway returning to and revising **their question or investigation plan based on their initial research.**

<u>Part 1: Planning Phase</u>

1. What scientific topic will students investigate?

    Often you will select the topic so that the student investigations align with particular curriculum aims and expectations established by the district, state, and/or national science standards. In this way you also ensure that the topic is feasible within a classroom environment and the available resources.

EXAMPLE:
Teacher-selected topic: Carbon Storage in Vegetation

2. Given the topic what do students observe and wonder as scientists? What is the main question that students want to investigate?

Students make preliminary observations of natural phenomenon using appropriate resources such as field or laboratory protocols, existing data sets, and scientific reports. They use these initial observations to develop a question for research. Encourage students to develop a question that strongly interests them. Sometimes (but not always) the inquiry question is posed in the form of a hypothesis statement.

The degree to which you give students responsibility to identify a question will depend on the level of inquiry you are targeting for your students. When students have minimal prior experience generating research questions, they will need you to model how a scientist develops a topic into a well-designed study through a guided inquiry approach. Keep in mind that most students are unfamiliar with the topic area and process involved with conducting research. One way to prompt brainstorming research questions is to provide an opportunity to conduct preliminary observations about the topic. For instance, provide students with an existing data set and ask them to notice patterns and relationships between the variables. A brief writing exercise with prompts such as "These data make me wonder…" can help students brainstorm some potential questions. KWL charts concerning the topic area also support the generation of questions. Another effective prompt is a list of simple and available materials. The materials on the list should be selected to stimulate questions related to the topic area (Cothran et al., 2006). As students develop questions—both the main question and associated sub-questions—support their interests and offer input gearing students to a final research question that is specific, focused, and feasible. Have beginning students limit the number of independent variables to one.

Some studies will include hypotheses. In the above example we could restate the question in the form of a hypothesis: More carbon is stored in the human population than in my schoolyard. Hypothesis testing is most useful when conducting controlled experiments. An excellent resource for designing experiments is Cothron et al.'s book entitled Students and Research (2006).

EXAMPLE:

Prompts to generate questions:

In this example, students are provided multiple prompts. First they learn about the Global Carbon Cycle. Second, students learn about allometric equations and how scientists measure carbon and biomass in vegetation. As a result of these learning activities, students begin to generate questions about how they might assess carbon stored in their schoolyard.

EXAMPLE RESEARCH QUESTIONS:

Main question:
Is there more carbon stored in the global human population, or in my schoolyard?

Sub questions:

- What vegetation is present near my school?
- How is carbon storage measured in vegetation?
- How much carbon is stored in the human population?

3. Students identify the variables and develop an investigation plan.

What kind of data will address the research question? Consider the variables included in your research. What are the independent variables? What are your dependent variables? What are the controls?

Planning Matrix for Research Design		
What do I need to know?	What kinds of data will I need? Independent or dependent variable?	How will I collect/obtain this data?
Types of vegetation	Tree species, shrubs, herbaceous vegetation	Observations around my schoolyard, a tree guide
Carbon stored in vegetation	Tree measurements, shrub measurements, herbaceous clippings	Using GLOBE Carbon Cycle protocols
Carbon stored in humans	Human population, carbon stored in one person	Database online, library research

Determine the most effective step-by-step procedure in order to investigate the question.

EXAMPLE:

A concise version is included here. Depending on your learning objectives, the students' procedures will vary in the level of detail. For a more detailed procedure, please see the Data Analysis section of the GLOBE Carbon Cycle website.

1. Use the GLOBE Carbon Cycle field protocols to describe the carbon stored in plot or schoolyard.
2. Use online tools or data available in the '*Carbon Stored in Humans vs. Trees*' excel spreadsheet (Under Protocols — Data Analysis) to determine carbon storage in the human population.
3. Enter and analyze data.
4. Present the results in the form of a research poster.

Part 2: Investigation Phase

1. Conduct the investigation and record data in a systematic manner.

    Does the investigation plan work? Does the investigation plan require revision? Do students have the proper equipment and do they know all the safety precautions? How will students organize and display data in a systematic manner (charts, graphs, field notes)?

    Once students have designed the procedure and before students execute the investigation, review their plan and offer input to ensure feasibility of their proposed inquiry.

    Before students conduct their first observation or measurement, provide, co-construct, or ask students to design a data table to record findings. Initially, students will need practice constructing data tables. During this early stage, construct a class data table to show students: 1. how to use the vertical columns for all variables; 2. record values of each variable in the rows; and 3. include titles and units in table column headings.

    Student scientists display their main findings as graphs, a pictorial form of communicating their data. Students usually construct bar or line graphs. To successfully construct graphs students will need to practice how to identify data for which a bar graph or a line graph is most appropriate. You can provide them with established data sets to practice this skill. Once the type of graph is determined, students will determine the graph axes, scale for axes, and plot the data. Finally, students will summarize trends based on the graph. This last step is often the most difficult for students and may need your guidance.

2. Analyze and interpret data

Students consider the results and then analyze based on their scientific background, the strength of their evidence, and logic to decide what the evidence means and which model or explanation best characterizes the data.

The analysis and interpretation will greatly depend on the type of study conducted. Nonetheless, in any study, students will compare outcome variables, consider variation among the outcome variables, identify trends for individual variables and among variables, and state to what degree the data supports the original hypothesis.

3. Share findings and conclusions

Consider a means of communicating students' major findings. How will they summarize data? Will they develop additional charts, graphs, and diagrams to communicate the findings? Some options include: speaking about their study, writing a report, or creating a presentation research poster.

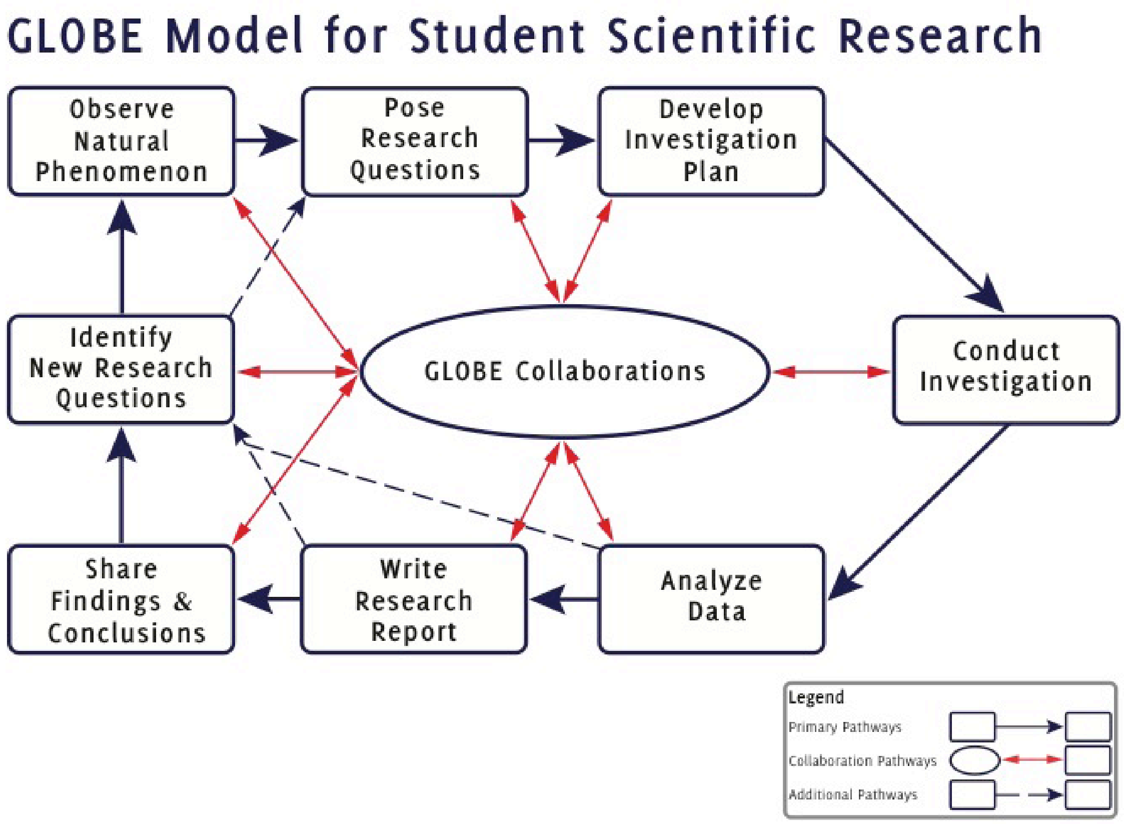
Communicating scientific results is an important science process skill. Options for sharing findings include poster sessions, oral presentations, and brief science reports. According to Cothran et al. (2006), the following questions should be addressed in a student's conclusion: 1. what was the research question?; 2. what were the major findings and explanations for these findings?; 3. did the data support the original hypothesis?; 4. what recommendations can be proposed for further study?

4. Further inquiry

Through the investigation and results analysis did any new questions develop out of the original research question? Are any of these questions substantial enough to lead to new investigations?

Name: Date:

Planning Guide for Scientific Research



The above GLOBE Model for Student Scientific Research (GMSSR) was developed by GLOBE in 2011 to illustrate the process of student scientific research. According to the GMSSR schematic diagram, the student scientist often follows a primary pathway beginning research with an initial observation of natural phenomenon and then developing a question and investigation plan. The investigation plan leads to the investigation, analysis, reporting of the conclusions, and finally to additional research questions. The steps followed may vary somewhat in each scientific study.

When designing and conducting your own science research consider the GMSSR diagram along with the following questions to guide your process. Your research process will closely follow the inquiry cycle depicted above however at <u>all</u> times be willing to stray from the primary pathway returning to and revising your question or investigation plan based on your initial research.

Part 1: Planning Phase

1. What scientific topic will you investigate?

2. Given your topic what do you observe and wonder as a scientist? What is the main question you want to investigate?

Make preliminary observations of natural phenomenon using appropriate resources such as field or laboratory protocols, existing data sets, and scientific reports. Use these initial observations to develop a question for your research. Develop a question that strongly interests you. Sometimes the inquiry question is posed in the form of a hypothesis statement.

3. Identify the variables and develop an investigation plan.

What kind of data will address the research question? Consider the variables included in your research. What are the independent variables? What are your dependent variables? What are the controls?

Planning Matrix for Research Design		
What do I need to know?	What kinds of data will I need? Independent or dependent variable?	How will I collect/obtain this data?

Consider the most effective step-by-step procedure in order to investigate your question.

1. First,….
2.

Part 2: Investigation Phase

1. Conduct the investigation and record data in a systematic manner.

Does the investigation plan work? Does the investigation plan require revision? Do you have the proper equipment and do you know all the safety precautions? Organize and display data in a systematic manner (charts, graphs, field notes).

2. Analyze and interpret data

Consider the results and analyze based on your scientific background, the strength of your evidence, and logic to decide what the evidence means and which model or explanation is best.

3. Share findings and conclusions

Consider a means of communicating your major findings. How will you summarize data? Will you develop charts, graphs, and diagrams to communicate the findings? Some options include: speaking about your study, writing a report, or creating a presentation research poster.

4. Further inquiry

What are new questions that are related to the original question that can lead to new investigations?