NATURE OF SCIENCE CURRICULUM GUIDE

Timeframe:
50 minutes

Target Audience:
Grades 6-12

Content Area:
General Science, Science and Society

Description:
Many scientific studies conclude that students do not have a foundational understanding of how science happens. Instead, traditional educational systems have focused on learning the end-results of science, resulting in many misconceptions about the nature of science and the role it plays in our society. Understanding how scientific research is conducted, coupled with an understanding about how to assess the information we receive daily to determine its credibility, promotes civic engagement, scientific literacy, and critical thinking skills. Because of this connection, the Next Generation Science Standards emphasize lessons that address the nature of science.

This lesson includes multiple small activities focused on teaching students specific ideas about the nature of science. These activities can be implemented back-to-back (as is written in this this guide), as independent activities, or integrated into other lessons.

Students have been given the definition of science in the past, but students should realize that science is dynamic, hands-on, and changes as our knowledge of the world increases. These activities include opportunities for students to identify moments in their everyday lives that they encounter problems that could be solved scientifically, how scientific conclusions change when new evidence is presented, and how societal pressures can impact what is being studied or funded.

Objectives:
- Students will know:
  - Science is a process and way of thinking rather than a set of facts
  - Science is a process that includes repetition, evaluation, and critique
- Students will be able to:
  - Assess a statement about science and develop a justification
  - Identify questions and situations in their everyday lives that could be solved scientifically
  - Discuss their decision-making and reasoning about complex statements

Activity Introduction:

1. Scientific Inquiry in Your Everyday Life activity:
    a. Pass out the "Using Science in Your Everyday Life" graphic organizer to each student. The graphic organizer is used to help students walk through each of the steps associated with this activity.
    b. Make an observation that is related so some sort of process. It can be about any process, but the key to a decent observation is to be able to ask "why is it like that?" Or "How does this happen?"
        i. e.g. yesterday I noticed a big curved scrape in the drywall on the wall in front of the chair, about 2 feet long, ¼ inch deep. See the drawing below.
    c. Next, ask a question about your observation. This question will usually include the words "how" or "why". If you have trouble forming a decent question, you might want to consider a different observation.
        i. e.g. "how did that scrape get there?"
    d. Then, make at least 3 more observations that can help you answer that question.
        i. e.g. "there are no other marks on the wall." "the scrape is higher on the wall than anything in the room. "there is some drywall stuck to the back side of the elbow of the chair and it has some paint on it that is the same color as the paint on the wall."
    e. Explain how your observations are related to your original question.
    f. Once you have made several observations that help answer your question, go ahead and try to answer your question. The answer to your question is your hypothesis and it should come in the form of a confidence statement. Your justifications from Step 4 will also support your hypothesis.
        i. e.g. "the scrape on the wall happened when they moved the chair into the office and the light arm rubbed against the wall. The evidence I see for this is the paint and drywall stuck on the back of the elbow of the chair. It only happened once because there is only one scrape."

Activity Procedure:

1. Puzzle Activity
    a. Provide each student with a puzzle set. It is important that this initial set does not have the "x" piece. Each piece of the puzzle represents a clue in a scientific puzzle that scientists are trying to "solve". Instruct each student to put the puzzle together. Note that the puzzle only works if all of the pieces are “ink-side up”, meaning they can see the side it was originally printed on. Once students have completed the initial puzzle, emphasize that scientific exploration is influenced by societal/political pressures, as well as related studies.
    b. Pass out on "x" piece to each student and instruct them to reconstruct their puzzle using this piece. In this example, the "x" piece represents a new scientific discovery related to the hypothetical scientific puzzle each student is trying to solve. Students will have to reconfigure the entire puzzle to make the new piece fit, referencing an important component of the nature of science.

c. Tip: There may be some peaking/cheating. Instruct students to cover their final puzzles with a notebook/piece of paper once they are done.
d. Tip: If students are getting frustrated with the puzzle activity, allow them to work in small groups with the person sitting next to them.

2. Social Nature of Science activity
    a. Create two signs: one sign should read “Strongly Agree” and the other “Strongly Disagree.” You could also create a "Neutral" sign. Attach the signs to a wall of your classroom to create a continuum, allowing enough room for your students to stand between the two signs with a moderate stance.
    b. Pass out the "Statements about the Social Nature of Scientific Research" to each student.
    c. Individually, have students decide whether they agree or disagree with each statement. Allow students time to develop and briefly write down their reasoning for why they agree/disagree on their handout.
    d. After taking a stance on each statement, have students discuss their positions with their neighbor.
    e. After allowing some time for one-on-one discussion, tell students that they will “vote with their feet” by standing along a continuum from strongly agree to strongly disagree to show their stance for each statement. Point out the signs you have attached to the wall to create a continuum.
        i. Note: Students may have difficulty transitioning from a binary "agree/disagree" to a continuum of options.
    f. Read the first statement and have students stand at the point along the wall that represents their stance. Elicit student ideas, and have students share what they think and why.
        i. Allow students from both ends of the spectrum to share as an opportunity for students to change their opinions based on other student's perspectives.
        ii. Note: Although many of these statements clearly have a right or wrong answer, that is not the goal of the activity. Instead, the goal is to elicit positive discussion about the different beliefs students have about the validity of the statement. The teacher resource "Guide to Statements about the Social Nature of Scientific Research" could be helpful in facilitating this type of discussion with your class.
    g. Repeat this process with the remainder of the statements.
    h. Provide an opportunity for students to revisit their worksheet and amend their original opinions based on the perspectives they have heard.

Guiding Questions:

- How does the puzzle activity relate to actually "doing science"? Some similarities include, but are not limited to:
    - Science involves investigating patterns and trying to solve complicated problems using the pieces of information we know to be true.

    - Trial and error is an essential tool scientists use to solve problems, but sometimes they get lucky and find the right answer.
    - New information may require the old theory to be modified or discarded. After completing the puzzle the first time, it is difficult to let go of the format we think it should fit in when the “x” piece is added
    - Our current information may be incomplete and therefore, our theories may be incorrect.
    - Collaboration and soliciting additional perspectives may be helpful in solving the problem.
- Social Nature of Science activity
    - Pick a specific statement and discuss how it relates to the public debate about GMOs and genetic modification technology.
    - Add one statement to the "Statements About the Social Nature of Science" sheet and answer it.

Optional Additional Extensions:

- Social Nature of Science activity:
    - After completing the classroom portion of the Social Nature of Science activity outlined above, distribute the following article to your class. This article briefly outlines both sides of a GMO-related issue as well as the science involved. After reading the paper, have student re-assess their answers to numbers 2, 6, 9, and 12 on the “*Statements about the Social Nature of Science*” graphic organizer to determine if their interpretation of any statements have changed now that they have a specific context to think about these statements within. Discuss as a class.
        - Potential articles:
            - Stecker, A. (2013, June 12). You Say Potato, I Say Double-Stranded RNA. Scientific American. https://blogs.scientificamerican.com/guest-blog/you-say-potato-i-say-double-stranded-rna/
- Potential Activity: Science through the Centuries
- Green Glass Door: a riddle activity focused on having students think critically, identify patterns, and solve problems.

Materials:

- Scientific Inquiry in Your Everyday Life Activity
    - Using Science in Your Everyday Life graphic organizer for students
- Puzzle Activity
    - Puzzle print outs – 1 puzzle (without "x" piece) in a bag for each student
    - One "x" piece for each student to be distributed later in the class period
- Societal Nature of Science activity
    - Statements About the Social Nature of Scientific Research handout
    - Guide to Statements About the Social Nature of Scientific Research (for teachers)

Teacher Background:

Scientific literacy can be defined as "knowledge and understanding of scientific concepts which helps us make personal decisions, participate in cultural and civic speculation and take part in economic productivity" (Reiska, Soika, Möllits, Rannikmäe, & Soobard, 2015). Others define scientific literacy as "developing an ability to creatively utilize appropriate evidence-based scientific knowledge and skills, particularly with relevance for everyday life…in solving personally challenging yet meaningful scientific problems as well as making responsible socioscientific decisions" (Holbrook and Rannikmäe, 2009).

Many scientific studies conclude that students do not have a solid foundational understanding of how science happens, as opposed to the end-results of science or the scientific method. There are many **misconceptions about the nature of science**, including:

- Science is about facts that need to be memorized rather than a way of thinking or a process.
- All scientists use The Scientific Method in a specific order of steps that requires a controlled experiment to conduct their experiment (Lederman, Antink & Bartos, 2014).
- Science doesn't change, and we already know all there is to know.
- Science is a way to "prove" or produce a desired outcome or invention, rather than a way to explore or build knowledge.
- Experiments can be used to "prove" or "disprove" a theory once and for all (Lederman, Antink & Bartos, 2014).
- Scientific theories can become scientific laws once they have been observed multiple times (Lederman, Antink & Bartos, 2014)
- It is important to be correct in your hypotheses—and doing so makes you a better scientist.
- Science that does not come to a firm conclusion is not useful (Lederman, Antink & Bartos, 2014).
- Scientists are completely objective and don't bring biases, moral values, motives, preconceptions, or creativity into their work (Lederman, Antink & Bartos, 2014)
- Science and technology are the same thing and play the same role in scientific research.

It is important to educate students about these misconceptions to enhance their scientific literacy and critical thinking skills. These misconceptions often promote fallacies and misinformation during public debates about controversial scientific topics, including genetic modification.

Additionally, researchers have identified several **misconceptions about the role of data and evidence in scientific research**, including:

- Students may consider correlation the same thing as causation.

- Students may not understand the need for multiple trials, especially when designing their own experiments, unless they are explicitly asked.
- Students may not understand the difference between a result in which the manipulated variable had no effect on the responding variable and the result in which it had the opposite effect than predicted.
- Students might not understand the need for controlling variables in an experiment.
- Students may not understand that scientists can legitimately hold different explanations for the same set of observations.
- Students will often accept arguments based on inadequate sample sizes, causality, and conclusions based on statistically insignificant differences.
- Students may not clearly understand which types of measurements to take in an investigation and when to take them.
- Students may have difficulty understanding the differences between models and experiments.

Subsequently, the Next Generation Science Standards (NGSS) emphasize activities that teach students the nature of science. They outline the basic understandings in the Nature of Science Matrix (National Research Council, 2013):

- Scientific investigations use a variety of methods
- Scientific knowledge is based on empirical evidence
- Scientific knowledge is open to revision in light of new evidence
- Scientific models, laws, mechanisms, and theories explain natural phenomena
- Science is a way of knowing
- Scientific knowledge assumes an order and consistency in natural systems
- Science is a human endeavor
- Science addresses questions about the natural and material world

Ultimately, scientifically literate individuals should be able to participate in reasoned discourse about science and technology, including explaining phenomena scientifically, evaluating scientific inquiries, and interpreting data and evidence scientifically (Reiska, Soika, Möllits, Rannikmäe, & Soobard, 2015).

The set of activities included in this lesson are meant to combat these misconceptions and provide a platform for students to think critically about how they have understood scientific information in the past and whether the information they receive daily is truly scientific. For example, having knowledge about GMOs may not be enough to develop a scientific perspective or risk perception, and those individuals that only receive the end-product of GMO science will likely have more negative attitudes about perceived risks. Conversely, those individuals that are familiar with the scientific process resulting in that end produce likely have a more positive risk perception and reasonable perspective of GM crops (Cinici, 2016).

Science is commonly defined as having 6 specific criteria:

- **<u>Consistent</u>**: The results of repeated observations and/or experiments concerning a naturally occurring event (phenomenon) are reasonably the same when performed and repeated by competent investigators. The event is also free from self- contradiction: it is consistent in its applications. The weight of the evidence is also compatible with well-established observations and limits.
- **<u>Observable</u>**: The event under study, or evidence of the occurrence of the event, can be observed and explained. The observations are limited to the basic human senses or to extensions of the senses by such things as microscopes, seismographs, etc. If the phenomenon cannot be reproduced through controlled conditions, natural evidence of the event's occurrence must be available for investigation.
- **<u>Natural</u>**: A natural cause (mechanism) must be used to explain why or how the naturally occurring event happens. Scientists may not use supernatural explanations as to why or how naturally occurring events happen because reference to the supernatural is outside of the realm of science. Scientists cannot conduct controlled experiments in which they have designed the intervention of a supreme being into the test.
- **<u>Predictable</u>**: The natural cause (mechanism) of the naturally occurring event can be used to make specific predictions. Each prediction can be tested to determine if the prediction is true of false (McKelvey and Aldrich, 1983).
- **<u>Testable</u>**: The natural cause (mechanism) of the naturally occurring event must be testable through the processes of science, controlled experimentation being only one of these. Reference to supernatural events or causes are not relevant tests.
- **<u>Tentative</u>**: Scientific theories are subject to revision and correction, even to the point of the theory being proven wrong. Scientific theories have been modified and will continue to be modified to consistently explain observations of naturally occurring events (Lederman, Antink & Bartos, 2014).

It is important to differentiate between "**textbook science**" and "**emerging science**". Textbook science incudes scientific discoveries that are unchanging and proven to be true repeatedly (e.g. the organelles in a cell, how DNA is replicated, the process of photosynthesis). Conversely, emerging science refers to new scientific discoveries and technologies that are rapidly evolving as a result of societal/political pressures and/or other scientific findings. Examples of emerging science include biotechnology advances related to genetic modifications and the development and testing of new medicines.

When working with **emerging science**, it is important to recognize the context in which that scientific discovery was made and only apply it in similar situations (known as the context of verification). For example, if a study determined that ingesting a specific type of food has X impact on a rat, it would not be appropriate to apply that finding to other organisms because that outcome has not been verified in that context.

One of the key components of the nature of science theory is that students understand how science can change when new things are discovered. Some studies suggest that students with a greater understanding of the nature of science are likely to enhance their scientific literacy and ability to engage in effective evidence-based argumentation (Acar, Turkmen, & Roychoudhury, 2010). Additionally, there are studies that show this instruction helps students understand the non-binary nature of complex SSI, including diverse perspectives.

Understanding Science, a collaborative project between the UC Museum of Paletonlogy, UC Berkeley, the National Science Foundation, and a diverse group of scientists and teachers identify several **limitations of science**, including:

- *Science doesn't make moral decisions*. Science can help us describe how the world functions but cannot make any judgments about whether it is right or wrong.
- *Science doesn't make aesthetic judgements*. Science cannot tell us whether what we are experiencing is beautiful or not. Individuals make those decisions for themselves using their own internal criteria.
- *Science doesn't tell you how to use scientific knowledge*. Almost any important scientific advancement/knowledge can be applied in either positive and negative ways. It is our responsibility to apply science in ethical situations.
- *Science doesn't draw conclusions about supernatural explanations.* Science can only be used to answer questions about the natural world.

Resources:

- How Science Works interactive "flowchart" from the Science Learning Hub
- Understanding Science
  - Misconceptions About Science.
  - The Real Process of Science
- "The Nature of Science" activity. Jason Choi. 2004.
- National Research Council. (2013). Appendix H – Understanding the Scientific Enterprise: The nature of Science in the Next Generation Science Standards, *Next Generation Science Standards: For States, By States.* Washington, DC: The National Academies Press.
- Social Nature of Scientific Research. The Northwest Association of Biomedical Research.

Next Generation Science Standards:

- Disciplinary Core Ideas: Many may work depending on what content the lesson is applied to
- Practices: Engaging in Argument from Evidence; Obtaining, Evaluating, and Communicating Information
- Crosscutting Concepts: Patterns