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Painting an Accurate Picture of the Nature of Science

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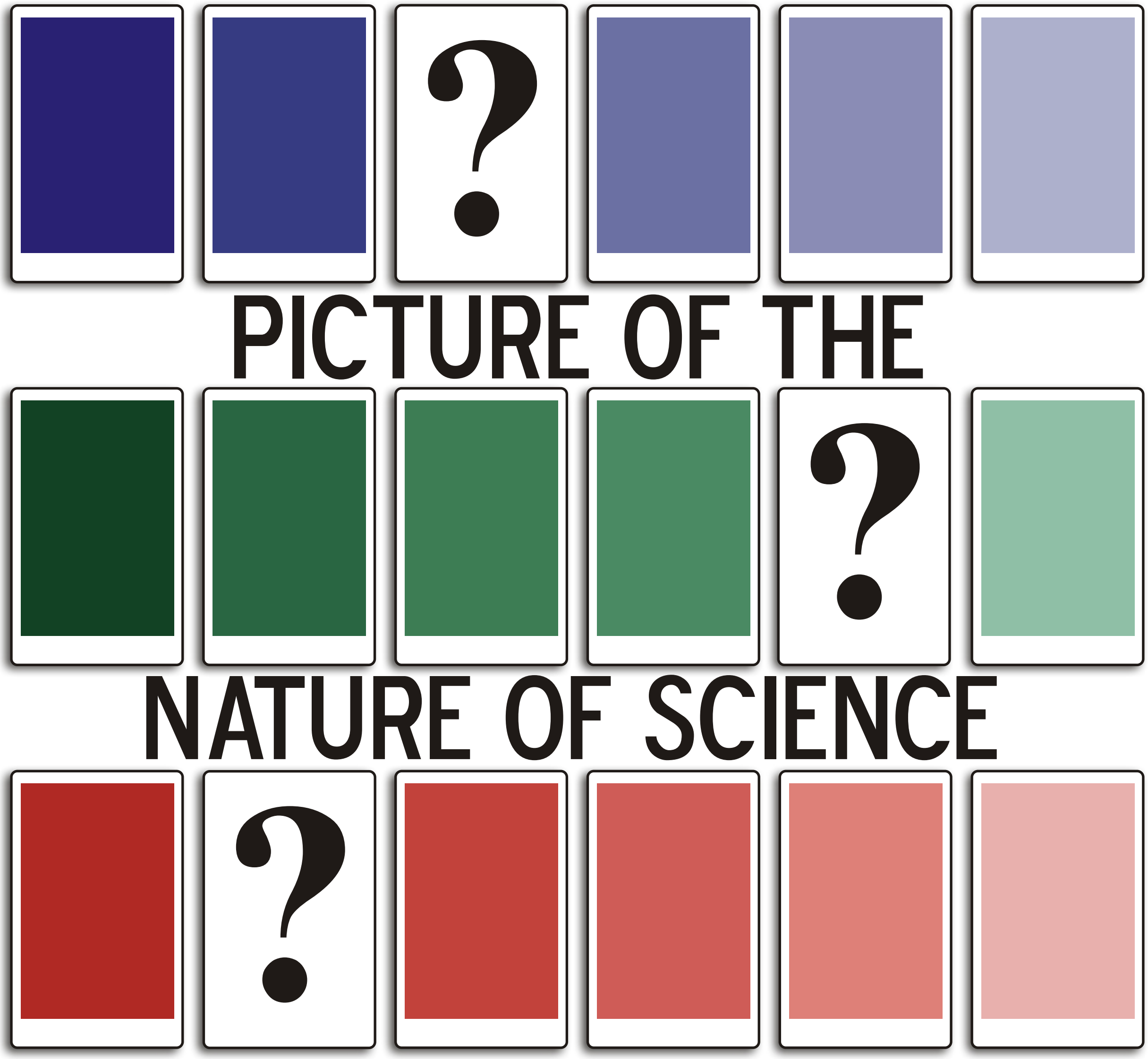

Graphic Work by Joe Taylor

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ABSTRACT: Understanding the nature of science (NOS) is an essential part of scientific literacy (McComas, 1998; Robinson, 1969; Shamos, 1995; Abd-El-Khalick & Lederman, 2000). When the NOS is taught in context-related inquiry activities and historical examples all school year, students show improvement in NOS understanding (Kruse, 2008; Khishfe & Abd-El-Khalick, 2002) that persists into the next academic year (Clough, 1995). Even so, educators often struggle with how accurately and explicitly incorporate the NOS in an already packed curriculum. This article presents an activity that explains how science content and the NOS can both be effectively taught at the same time. *This article promotes the National Science Education Content Standards A, B, and G and the Iowa Teaching Standards 2, 3, 4, and 5.*

The need for the nature of science (NOS) in the science classroom has been well acknowledged by reform documents (AAAS, 1989; NRC, 1996). Although these documents have been in existence for over ten years, many science teachers do not recognize the benefits of integrating the NOS into the science classroom. Teachers who do address the NOS often do so as an add-on to the curriculum rather than integrating science content and the NOS. Furthermore, the NOS tends to be taught in a decontextualized manner separated from a context of historical examples of science or experiences in the laboratory (Clough, 2006). One difficultly for teachers is finding activities that can be used to teach how particular scientific knowledge was developed.

The July 2006 issue of *The Science Teacher* included an article describing a clever idea using paint "chip" samples to introduce students to the periodic table (Wallingford, 2006). We found this activity intriguing, but modified it as described below to incorporate accurate and explicit NOS instruction, and make clear the teacher behaviors necessary to promote student mental engagement and inquiry. The approach described below illustrates how to integrate the NOS in everyday science content instruction by asking questions that draw students attention to NOS issues that are always present when teaching science (Clough & Olson, 2004).

The Set-Up

Samples of paint colors for this activity may be obtained at no cost at most any store that sells paint. Often these paint chips will have numbers that indicate the color and position of the chip relative to the other chips. The identification numbers on the chips are not necessary but they can be useful during the discussion that follows the activity. In our activity, we include 6 colors with 6 variants of intensity for a total of 36 chips. We place 30 of these 36 paint chips into plastic bags that will be distributed to students, leaving out one shade of each color. After students have organized their bag of paint chips, they note that six gaps exist in their organizational scheme.

Unknowns or missing chips not only increase the difficultly of the activity, but parallel the original periodic table where gaps were purposely included. These gaps were anomalies in the trends of the table which were interpreted by Mendeleev as existing chemical elements humans that had not yet been detected as of 1869. The missing paint chips in bags present to students a similar puzzle faced by Mendeleev. We don't tell students that chips are missing (no one told Mendeleev that not all the elements had yet been detected), but if necessary we will ask questions that spark this idea.

If the bags are all slightly different, each group of students will have a different puzzle to solve. We highly recommend giving each plastic bag a number (1, 2, 3, etc.) and then writing this number on the back of each chip in the bag. When a chip falls on the floor or goes missing, it will be easier to identify where the chip belongs. The cognitive difficulty of this activity can be altered by increasing the number of unknowns in a bag or by reducing the number of paint chips that have numbers that may indicate their relative positions. We use this activity from grades 9 through 12 by simply varying its difficulty without altering its intent or students' decision-making.

Getting started

We start the activity by asking students, "Why do we organize things?" After student responses have been exhausted, we ask, "Why do scientists organize things?" Students will likely say scientists organize information for many of the same reasons students organize things. These questions not only set up the experience for students, but also establish a foundation for teaching students about scientists' approach to understanding the natural world. We tell students they are going to organize the paint chips in a way that makes sense to them. Initially, this is done in groups of two, but we encourage discussion among group. As students begin to organize, we walk around room, listen to student discussions, and when necessary ask questions that spark ideas regarding how their data might be organized. Examples of questions we ask are:

- “What are your reasons for arranging the paint chips this way?”
- “How else could you arrange the paint chips?”
- “What information could you use to organize the paint chips?”
- “What is the significance, if any, of the numbers appearing on the paint chips?”

The types of questions teachers choose to ask students and the responses to those questions can greatly impact how much mental engagement is required of the students. NOS instruction can be improved with explicit attention drawn to the NOS, not through lecture, but by drawing out NOS concepts that are inherent in the science content being taught. Asking questions that are open-ended and thought-provoking during these lessons encourage reflection and help students make connections between the activity and the NOS.

When a teacher asks a question such as “How else could you arrange the pieces?” the student responding to the question may have to consider an alternative method by reflecting on his or her thinking and process in organization. Furthermore, "Questioning a student and listening closely to the response allows us to assess what students think and why they have that particular idea (Penick, 1996),” thus providing instantaneous and ongoing student assessment.

This information also helps guide decisions regarding what question to ask next. The examples questions presented in this article are designed to get students thinking, but they are not scripts. When asking questions we keep in mind the goals that we have for the lesson and skillfully guide students through the thoughts that are in their minds.

During the Activity

A variety of factors (i.e., age of students, place of activity in curriculum) will determine how quickly students feel that they are finished with the initial organizing of the paint chips, but typically this takes around 10-20 minutes. When students finish early, instead of telling students pieces are missing, we ask questions to keep them thinking, such as, “What other patterns do you notice, aside from organizing it this way?” An added benefit of reengaging students who finish early is a reduction in classroom management issues.

As students continue to organize the chips, some realize that they are missing pieces and place corresponding gaps in their organizational grid of pieces. For some groups making the jump to missing pieces can be incredibly challenging. If a group is really struggling with finding missing pieces, we ask “What information could you use from the paint chips to organize them?” Students will often indicate the hue and color of the chips, the numbers, and the names. “How might the numbers be useful in organizing the chips?” Students often say the numbers go in order from lightest starting at number one to darkest going to number 6. We often point to a column with a missing chip and ask "What do you notice about the numbers in this column?" Once students have accounted for the gaps in their paint chips, we tell students to figure out as much information as possible about the missing chips. Students often determine the colors, hues, and numbers of the chips as well as how many are missing.

Connecting NOS and Science Content Instruction

Numerous connections between the content and the NOS could be addressed through this activity. Identifying the NOS ideas to emphasize in a lesson should be considered during lesson plan. The NOS concepts we determined are worth addressing during this activity are:

- The interpretation of data and the development of ideas require a high degree of creativity.
- Scientific knowledge is developed by a consensus of experts in the field of study.
- Science makes assumptions about the natural world. Scientists assume the natural world has order and that humans can understand this order.
- Scientific knowledge, although reliable and durable, is always open to revision.
- Scientific ideas often have predictive capabilities.

The following sections describe how we raise and address these NOS ideas.

Modeling consensus building

Once a significant number of students are finished, we briefly have them note other ways students have organized the paint chips and then move into a large group discussion about the activity. We raise the NOS issue of consensus building in the following way:

- "You have a number of ideas on how to organize these paint chips. What are the pros and cons of having individual organization schemes?"
- "What is the value of having one universally agreed upon organizational scheme?"
- "If we wanted to have one way to organize the paint chips, how might we decide this in a manner which reflects how scientists make decisions?"

At this point during the year, we have previously addressed how accepted science ideas emerge over time; not through voting (the recent voting regarding Pluto was in regards to what scientists would call it, not what the natural world is like). A teacher could choose to pick an organization schema at random, but this would limit student decision making and distort how science works. Most classes decide on a schema with lighter hues on top and the darker hues on the bottom with a ROYGBIV arrangement of the colors; however we have seen numerous creative arrangements. The key here is to have students work through their different ideas.

Connecting to the content

Once this consensus is reached, we begin a discussion to link the activity to the periodic table by asking:

- What patterns repeat themselves across the rows? Columns?
- What trends do you notice about the periodic table?
- How do those trends relate to the trends you noted during the paint chip activity?
- What would happen if a 37th paint chip were found?
- How can we predict the properties of something if we have never seen it?
- How might the gaps in your paint chips be related to the periodic table?

Students readily speculate that when the table was developed, there may have been gaps that were later filled in as we gained more information. This provides an excellent opportunity to teach about how scientific knowledge may be revised.

Tentative NOS

Students often struggle with understanding that currently well supported scientific knowledge may someday be modified. Scientific ideas are dynamic and are subject to revision or rejection with ongoing research. Scientific ideas may change due to new information, or new insights that result in a reconceptualization of previous ideas. When presenting this idea to students we ask them to remember the first incarnation of their paint chip periodic table. What did it look like? Why did they place the pieces in that specific order? We then ask them to think about how the final whole class organizational scheme emerged. What caused your paint chip organization scheme to change the first (second, third, etc.) time? Why did you modify your original idea? We can further ask students, "Why might the possibility of scientific knowledge changing over time be beneficial?" These questions not only address how ideas may change to account for additional information or as a result of new thinking about current information, but also the dynamic, creative and social aspects of science.

Organizing and Predicting the Natural World

At the beginning of the activity, we asked students to consider why humans organize things. We raise this idea again to address an important NOS idea–that science is based on the assumption that the natural world has an order to it and that we can understand that order. We do this in the following way.

> *"Prior to the activity you told me that one reason humans organize things is that it creates order and makes things easier to find/understand. Why would that be of interest to scientists who were developing the periodic table? Why would scientists attempt to organize the natural world? What do you think is the purpose of the periodic table?"*

Often times our schemes of organization predict what has yet to be observed. One of the main reasons that we do not initially give students all of their chips is because Mendeleev did not have all the pieces of the puzzle when he constructed the periodic table. Our students mimic Mendeleev's actions by inferring gaps in their grid of chips based on the properties of the surrounding chips. Mendeleev placed gaps in his table based on the properties of existing elements, and on his implicit assumption that the natural world has order to it. He was so confident in this underlying assumption and his work, that he left gaps in his organizational scheme predicting elements existed that would fill those gaps and the properties they would possess. When those elements were isolated, they shared similar properties to those predicted by Mendeleev. We explicitly draw their attention that the paint chip activity was carried out the same way Mendeleev constructed the periodic table.

Extending NOS Instruction

Many times throughout history several people have worked on an idea at the same time, yet only one is given credit in science textbooks. This is the case with work on the periodic table, and can be used to address how science ideas are accepted by the science community and ultimately presented to the public. We often have students read a short story about both Julius Lothar Meyer and Dmitri Mendeleev, similar to the one found on the Chemical Heritage Foundation's website (http://www.chemheritage.org/). After reading the article we engage students in a discussion about the scientific process of sharing ideas. This helps them gain a better understanding of how scientists work, the collaborative nature of scientific work, what may happen when scientists develop the same or similar ideas, and how credit for ideas is fairly and sometimes unfairly given.

Final thoughts

Effectively teaching the NOS does not happen by chance. Teachers should explicitly and skillfully draw students' attention to key NOS concepts throughout the school. Because explicit NOS instruction may initially seem foreign to students, particular effort must be made to ask effective questions, exhibit encouraging non-verbal behaviors, use wait-time, listen carefully to students, and sensitively respond to their ideas.

Understanding how science is done and connecting that to the development of science ideas provides a human context that increases students' interest in science. Moreover, deeply understanding science content is tied to understanding particular NOS issues. For example, underlying the periodic table of elements is the grand assumption of science–that the natural world has order. Linking NOS instruction to the teaching of science content enhances students' understanding of science content and science as a human endeavor.

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