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STEPPING AWAY FROM COOKBOOK LABS AND MOVING TOWARDS SELF-WRITTEN LABS TO EFFECTIVELY PORTRAY THE NATURE OF SCIENCE

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ABSTRACT: Incorporating accurate and explicit nature of science (NOS) instruction throughout the school year is important for overcoming long engrained student misconceptions regarding what science is and how it works. This can be challenging when addressing abstract content such as microscopy and cells. I developed an inquiry based lab that accurately portrays aspects of the NOS while also teaching cell microscopy. The teacher's role in encouraging students to reflect on the NOS is also described. *This article addresses National Science Education Standards A, C, and G and Iowa Teaching Standards 1, 2, 3, 4, 5, and 6.*

Doing science has often been compared to playing a game (Clough, 2004; McCain & Segal, 1981; McComas, 2004), and the nature of science (NOS) has been likened to the rules of the game. The analogy has some value for initially helping students grasp what is meant by the *nature of science*. However, no rule book for doing science really exists and the NOS refers to far more than how science is done. The nature of science also addresses what science is, what it is not, what scientists are like and fundamental assumptions that underlie all scientific disciplines.

Many science teachers don't devote significant time to explicitly teaching the NOS, or only address it early in the school year. Regardless, the NOS *is* conveyed to students by the textbook and multimedia used, laboratory activities that are done, and by the language teachers use and the way they speak about science. For example, cookbook laboratory activities imply that science is a stepwise process with little need for creativity, and that prescribed results stem from completely objective experiments (Clough and Olson 2004). So the NOS is conveyed by all science teachers, but that view is not necessarily accurate.

Considerations of the Nature of Science in the Biology Classroom

Biology teachers face a greater challenge in accurately and explicitly addressing the NOS because inquiry laboratory activities are more difficult to implement in biology instruction. This is particularly the case when students are conducting microscopy labs. These sorts of labs typically have students observe previously fixed slides, many which contain a specimen label. Students are often required to draw, label, and explain what they are observing, perhaps with the aid of a standard, lab guide, or textbook that provide the sought after answers. Using these kinds of experiences to teach that science requires creativity, problem solving, critical thinking and other NOS ideas is obviously problematic.

These sorts of lab experiences also degrade the work of pioneering scientists who contributed to the development of our knowledge regarding cells. In the early 1600's microscopes were invented and the previously unchartered microscopic world was beginning to be noticed. Classic instruction notes that the first formal description of cells was by the English Physicist Robert Hooke (1635-1702). Hooke's interpretation of his observations of a slice of cork as “cells” or “pores” in the journal *Micrographia* in 1665 illustrated the potential importance of microscopic studies for naturalists. Hooke's initial description of “cells” and the use of such terms stems from his analogizing his observations of cork cells to those of how honeycombs appeared which were described through the Latin language *Cellulae.* In addition, the derivative of this word used to describe the six sided appearance of honey combs is *Cell*, which is also Latin of origin and means small room (Mazzarello, 1999).

Although interesting, addressing only Hooke's work ignores other scientists' contributions, their setbacks, and the role these aspects played in the emerging knowledge of cells. For instance, shortly after Hooke's contribution, Antoni van Leewenhoek (1632-1723) sent a letter to the Royal Society describing observations of motile microscopic particles. In this letter, van Leewenhoek used his observations of these motile particles to justify they were living organisms. Much time and many additional papers were written describing many forms of these microscopic animals before he dubbed them “animalcules” which includes what we know today as a group of unicellular organisms that includes the protozoa.

Although van Leewenhoek's often cited work was mainly with protozoa, most initial microscopic work was directed primarily at plants because their cellular features are much more readily distinguished than that of animals. Interestingly, early observations were focused primarily on the cell wall instead of the cell itself. In addition, initially the wall between cells was thought to be shared. This interpretation resulted in cells *not* being considered individual units with material inside. The idea that a cell was an individual unit came later when a separation between a double wall was noted. Although this was the case, studies conducted until around the late 1700's continued to focus on the cell wall rather than the contents within the cell. Not until 1809 did Link write that cellular tissues “consist of little bladders completely separated from one another; but their membranes [cell walls] usually lie so close to one another that they appear to constitute only a single partition-wall” (Baker, 1952).

This very short and incomplete history of early microscopy illustrates how far more interesting and complex doing science is than is conveyed in most biology courses. Science ideas emerge over time and require even more time to become well accepted scientific knowledge. The long hours, influence of prior thinking on observations, critical thinking, problem solving, creativity, wrong turns, and extensive collaboration is rarely made apparent to biology students.

Teaching About Cells and the NOS

As stated before, simply recalling only one or a few contributors' work to an area of study ignores how scientific ideas emerge and develop, thus conveying the misconception that knowledge of the natural world comes fully formed and in short order. Science teachers should work to more accurately convey the NOS in the context of the content they teach. Here I present an inquiry lab activity that initiates our study of cells and explicitly draws students to important ideas regarding the NOS. The objectives of the lesson is to develop students' initial microscopy skills, build experiences resembling that of the pioneers of microscopy, and conduct the observation and categorization of various cells.

Prior to this activity, I have implemented several inquiry experiences to improve students' abilities at making detailed observations, determining what data is relevant, and speculating on the meaning of data. In addition, students have investigated the relationship between structure and function at the macro level, and how evolution accounts for that relationship. While these actions have not previously been applied to accounting for biological phenomena on a microscopic level, they are important for scaffolding to that level in this activity.

In this activity, at least one microscope is provided to each group of two students. Various unknown slides are labeled 1, 2, or 3 according to whether they are plant, animal, or bacterial samples. The original identifying tags on the slides must either be marked out, or covered with tape and paper. At least six slides, preferably more, should be available in each group. I group the slides according to organism type because having the students accurately group the slides is too time consuming and confusing at this point in their study of cells. While scientists would have to make these groupings themselves (something we discuss at the end of the activity), students must still inquire into the similarities and differences between the provided categories.

When introducing this activity, I usually begin by posing a question to students such as "What are some reasons why scientists classify the natural world?" and "What difficulties might they experience during these efforts?" I also refer back to previous lab activities we have conducted. For instance, I may then ask:

- "How did you investigate the _____ in the _____ lab?"
- "What difficulties did you experience?"
- "How did you handle those difficulties?"
- "In what ways were the difficulties and how you dealt with them potentially similar to what a scientist might experience in his or her work?"

The importance in asking these types of questions at the beginning of the activity is that they provide scaffolds to previous experiences that help students make accurate links to the NOS. Also, these types of questions draw out students' thinking about their prior experiences, and provide me with information that influences my decision-making during this guided inquiry.

After this initiatory discussion, I hand out the first question set appearing in Figure 1. Providing only the first three questions at this time permits me to manage the pace of students' work and ensure they are attending to critical points in the lab. The instruction sheet is primarily a set of prompts that guide the student through this inquiry based activity. While somewhat directive, this approach guides students while still demanding them to make many decisions regarding what observations to make and what sense to make of the data. Moreover, the questions push students to collaborate with their peers and me. This gives me the opportunity to ask probing questions that draw out students' thinking, and then ask further questions that help them come to the desired conceptual understanding regarding cells and the NOS.

Further Guiding Students' Thinking

In the initial stages of this lab, an issue that students often raise is how they are to display their collected data. I use this opportunity to create small group or whole class discussions where I ask students for ways they might describe their methodology and represent their data to readers. This presents an opportunity to discuss how several acceptable ways exist to represent data based on the message to be conveyed, and why scientists will use various strategies in representing data. Figure 2 provides examples of the ways that my students have represented their data and conclusions after having completed the investigation.

While the activity is in progress, the third part of the first question set ensures that interaction will occur between each group and me. This point in the activity is where they make their initial determination regarding what are the visible building blocks of the organisms on the slides. While these interactions vary according to what the students have done and what they say, the following conversation exemplifies the kinds of interactions that often take place:

Teacher: I see you determined that the building blocks on the slides are cells. How did you make that determination?

Student: We observed the slides and gathered evidence that these objects are cells.

Teacher: O.K., in addition to evidence, what other factors helped you make this determination?

Student: Well, we had to use prior knowledge and the microscopes to figure this out.

Teacher: How did you use your prior knowledge in formulating your conclusion? Also, how is this using prior knowledge like what scientist must do in their work?

Student: Well, we know that these slides are made from living things. We also have prior knowledge that states that all living things are made of cells. Therefore, we can conclude that these are cells. Scientists have to use their prior knowledge from past research they have done, or that others have done in order to make further conclusions with their own research.

Teacher: Why can't we be sure that these samples are from living things?

Student: Well, we….I don't know.

Teacher: Suppose we walked in the backroom and we witnessed the teacher who teaches next door painting images like these on slides. How would that affect our **assumption** that the samples are from living things? Also, how would that affect our research?

Student: Well, it would ruin it because we would have better evidence that they are not of living things. I guess we would have to rethink our observations and data.

Teacher: Now, let me ask you this again. Why can't we be sure these are from living things?

Student: Well, we have to **assume** they are based on our prior knowledge because we did not actually collect them from living things.

Teacher: How might this be a potential problem that may affect the credibility of our research?

Student: We are going off an **assumption** with little evidence that these are from living things, which is a big factor in our determination that these are cells.

Teacher: How can we try and gain some more credibility for our determination?

Student: Well, we can't go back and actually show these are from living things.

Teacher: Okay, (waiting)

Student: We could maybe take samples from living things and see if there are similarities between our observations of the (prepared) slides and the observations from samples we collected.

Teacher: How would this provide credibility to your research?

Student: If there are enough similarities, we can reasonably conclude that the slides we did not prepare came from living things.
Teacher: How is this situation similar to things scientist research such as the fossil record and evolution?
Student: Scientist couldn't actually witness evolution happening firsthand in many of the species, so they had to gather evidence after the fact to support its happening.
Teacher: So, based on our conversation, how is your team going to proceed in your research?
Student: We need to gather samples from living things.
Teacher: Such as?
Student: Well, the plant over there is a living thing, we are living things. We could take samples from the plant and compare the slides that were already made to the plant slide.

Through my further questioning, students decide to make slides from various specimens throughout the room. These specimens can range from classic stained onion cell slides and cheek cell slides to samples from house plants, yogurt cultures, and pond water.

This provides a nice segue to have students determine the three groups that make up the prepared slides, and I provide students the second half of the instruction sheet (Figure 1, Question set 2). For instance, if students compare stained onion cells and cheek cells to several of their observations of the prepared slides, I ask questions like those below that draw their attention to the similarities between these fresh slides and the groups of prepared slides such as:

- How does the structure of the magnified onion cells and cheek cells compare to each other?
- How does the structure of the magnified onion cells and cheek cells compare to the samples on the prepared slides?
- How do you think the structure and shape of the cells on these slides contribute to the overall structure, function, and mobility of the organism they came from?

This typically leads to a class discussion where I ask questions that result in their making the decision to organize their qualitative data on the board. During this discussion, I again ask questions such as:

- Based on the data you took in your lab groups, of the similarities and differences between the groups of already prepared slides and the fresh slides you prepared, what would be the most effective way to collectively represent your data as a class?
- How can you use the similarities and differences to categorize the kind of organism that is represented in each category based on structure and function?

Questions such as these help students determine what types of organisms each group of slides belongs to (plant, animal, or bacteria), and which organisms (e.g. protists from pond water) doesn't fit into those three categories. They make these decisions based on the comparative characteristics of fresh and prepared slides (making reference to organization, shape, and structure). Many times, students will even take the initiative to approach the board and lead the class in a conversation pertaining to the data which with facilitation results in students making the desired determination of the categories of the slides.

Once the determination of categories is reached by the students, I have them compare their work to that done by other groups (see question six in Figure 1). Once they have completed this task, I have the students come back together as a class to discuss how this activity accurately illustrates several aspects of the NOS. Helping students develop accurate conceptions of the NOS demands that I ask questions that explicitly draw students' attention to key issues. This also includes attending students to how science classroom activities such as this one, because of their limitations in representing what scientists actually do, may not accurately portray the nature of science. Questions I ask include:

- How has the development of technologies such as the microscope affected scientists' progress in understanding cells? How has our understanding of cells affected technology?
- How did you determine what data was relevant to the classification of these cells. How is that process similar to what scientists do?
- What difficulties did you experience while coming to consensus on how to represent your data as a class? To what extent do you think scientists face these same difficulties?
- In what ways did this activity misrepresent the way science works?
- How does my role as a teacher make our inquiry activities different than authentic science?
- Consider my placing the slides in three categories at the beginning of the lab. How does this misrepresent the experiences scientist face in their research? Why was it necessary for me to do this?

Post Lab Reading

Following this lab, I have students read accurate accounts and research of the classic scientists that helped build our understanding of cells, and the difficulties they encountered, from resources such as Mazzarello (1999) or Shuster (2003). I modify these readings so they are appropriate for my students. Throughout readings and accompanying discussions that pertain to individuals like Hooke, Schwann, and others. I ask questions and implement other pre, during, and after reading strategies that help students comprehend key NOS ideas that are embedded in the readings. This lab works well to create a comparison base for addressing the evolution of cells, the endosymbiotic theory, and the rise of multicellularity.

FIGURE 1
Mystery Slides Lab Handout

Question Set 1
Select four different slides from each group (Only take two at a time and return them after you have drawn and explained your observations and data). Prepare data representations much like you have for your previous labs to illustrate your observations, display your data, and answer the questions that follow. Make sure to annotate any outstanding features between and within the three groups.

1. What were some visible similarities and differences **between** the three groups of slides?

2. What were some similarities and differences **within** the different groups of slides you observed?

3. What do you suppose are the visible building blocks that make up these samples of living things? Provide an explanation behind your reasoning including the supporting observations you used to make this decision.

Once you have answered, raise your hand. I will come over to discuss with you your work.

Question Set 2
4. Each group of slides is from a different type of organism. What do you suppose the different types of organisms are for each group? Provide an explanation behind your reasoning including the supporting observations and evidence you used to make this decision.

5. Explain the thought process you used to answer question 4. In what ways did your thought process reflect some of the thought processes that scientists employ?

6. Compare your labs and conclusions with at least two other lab groups. Describe to each other how you made your observations, recorded your data and how you came to your conclusions.
   a. How does your data and conclusions compare with the other groups' work?
   b. How have your comparisons with other groups affected how you view your own data and conclusions?
   c. What might be some reasons for differences and or similarities between your and other groups' work and conclusions?
   d. In what ways does this illustrate how scientists' decision making, the knowledge that results, and ultimately accepted scientific knowledge are affected by the sharing of data and results?

Conclusion

Teaching biology through inquiry is challenging, but necessary to help students develop a deep understanding of the NOS. Guided inquiry, as illustrated here, is one important way of creating experiences that lend themselves to explicit and accurate NOS instruction. However, inquiry experiences alone will not push students to consider the NOS. The teacher's role in explicitly raising NOS issues and having students reflect on those issues is crucial.

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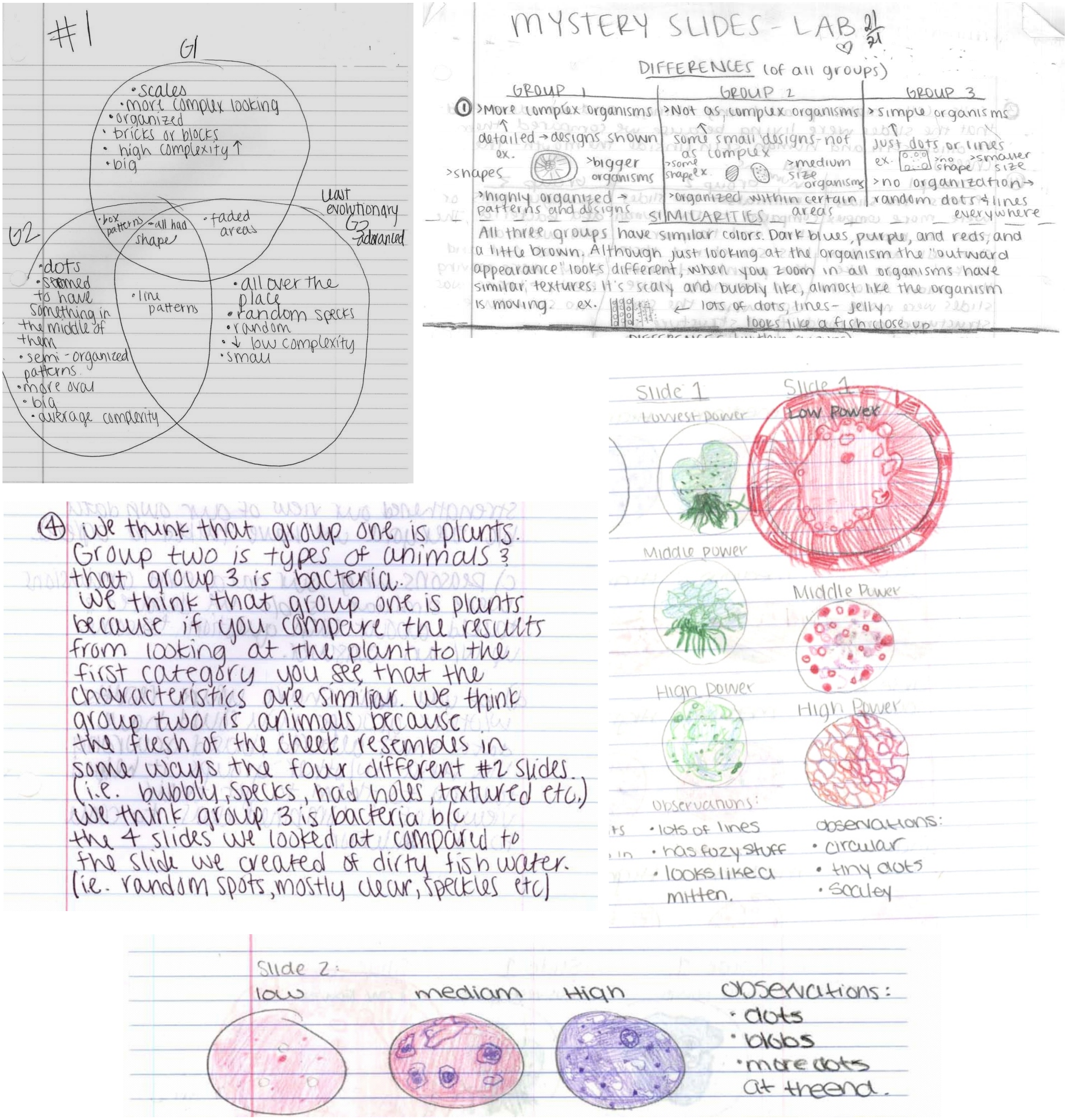
FIGURE 2

Examples of Students' Data Representations and Answers to Lab Questions



MYSTERY SLIDES - LAB 21/21

DIFFERENCES (of all groups)

GROUP 1	GROUP 2	GROUP 3
① >More complex organisms ↑ detailed → designs shown ex.	>Not as complex organisms ↑ some small designs - not as complex	>simple organisms ↑ just dots or lines ex.
>shapes >bigger organisms	>some shape ex. >medium size organisms	>no shape >smaller size
>highly organized → patterns and designs	>organized within certain areas	>no organization → random dots & lines everywhere

SIMILARITIES

All three groups have similar colors. Dark blues, purple, and reds, and a little brown. Although just looking at the organism the "outward appearance" looks different, when you zoom in all organisms have similar textures. It's scaly and bubbly like, almost like the organism is moving. ex. ← lots of dots, lines - jelly looks like a fish close up

④ We think that group one is plants. Group two is types of animals & that group 3 is bacteria. We think that group one is plants because if you compare the results from looking at the plant to the first category you see that the characteristics are similar. We think group two is animals because the flesh of the cheek resembles in some ways the four different #2 slides. (i.e. bubbly, specks, had holes, textured etc.) We think group 3 is bacteria b/c the 4 slides we looked at compared to the slide we created of dirty fish water. (ie. random spots, mostly clear, speckles etc)

Observations:
• lots of lines
• has fuzzy stuff
• looks like a mitten.

observations:
• circular
• tiny dots
• scaley

observations:
• dots
• blobs
• more dots at the end.