The Scientific Method and Scientific Inquiry: Tension as in Teaching and Learning

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Abstract: Scientific method has been considered by many to lie at the core of scientific inquiry. In this paper, we look closely at teacher and student discourse in a typical high school science classroom to investigate what the teaching and learning of scientific method looks like and to consider the impacts an emphasis on method has on students' inquiry performance. Through a lens of activity theory, our analysis suggests that test-oriented scientific method did not support authentic scientific inquiry. Instead, this focus served to draw teachers' attention away from student thinking and distract students from their ongoing, productive inquiry. By situating the case in a broader institutional and social context, we discuss how the teaching and learning of the scientific method as inquiry is supported and sustained in our current educational system. We conclude the paper with directions for further studies.

Introduction

Inquiry lies at the heart of science education reform, as seen in its centrality in documents such as the National Science Education Standards (NRC, 1996). Despite its prevalence in school and policy rhetoric, the term remains quite ambiguous. Commonly, inquiry becomes conflated with "the" scientific method, taught as a series of steps that flow from asking a question to drawing conclusions. As a result of the extensive adoption of scientific method inquiry models in school, learning the stepwise account of scientific method is often viewed as the practical means of "doing inquiry." In this paper, through a lens of activity theory (Engestrom, 1987), we analyze the teaching and learning processes in a representative case from one high school environmental science classroom to a) explore what teaching and learning look like in a class focused on the scientific method, and b) consider the impacts of scientific method instruction on students' inquiry performances.

Conceptual framework

We begin by defining how we use *scientific inquiry* and *scientific method*. A consensus definition of *inquiry* eludes the field of science education. For a working definition, we draw on Hammer's (2005) work that defines scientific inquiry as "the pursuit of coherent, mechanistic accounts of natural phenomena" (p. 13). This definition offers a variety of different epistemic activities and can be practically used for identifying scientific thinking (Hammer, 2005; Russ, 2006). Inquiry is not limited to rigorous use of scientific language and scientific reasoning; sense-making of everyday experience through everyday language can be a powerful tool for students to conduct scientific inquiry (Warren, 2001). We consider elements in the epistemic process of doing science (such as causal explanation, mechanistic reasoning, scientific argumentation and sense-making) as scientific inquiry, regardless of whether they appear in formal scientific language or are articulated in everyday language. *Scientific method* typically refers to a body of techniques or methodical steps that are shared by all science domains for investigating phenomenon and acquiring new knowledge. While the term is sometimes used interchangeably with scientific inquiry (Zachos, 2000), we use *scientific method* to specifically denote the accounts of scientific process steps that are central to many inquiry models and infuse policy, curriculum and instruction (Edmond, 2005).

In high school science classrooms, inquiry often takes the form of collaborative and collective activities. We adopt the lens of activity theory to understand what we see occurring in the classroom and to clarify the relationship among key elements of classroom activity, including teacher attention, class structure, and student behavior. With roots in Vygotsky's (1978) cultural-historical psychology, activity theory contends that learning involves interaction between social and individual planes, mediated through the use of tools and signs. Learning processes should, therefore, be understood as contextualized within the sociocultural settings in which they take place, rather than constrained solely within an individual's head. This can be represented by a "basic mediational triangle" (Kutti, 1996), which represents a human agent (subject) motivated towards solving a problem or getting to a certain purpose (object), employing available tools to conduct an object-oriented activity. Since an object carries both the topic and the nature of an activity, through careful analysis of this aspect of the activity, we can make connections among what a class activity is about and, to some extent, the influences on students' participation.

While his original work focused on individuals, Engestrom (1987) later added in more contextual components, formulating it into a framework for studying collective subjects and collective activities. In this research, we used the model to understand collective classroom activities. In a class, teacher and students together form the collective subject. Learning activities are framed by the broader socioculturual, political, and institutional contexts (for examples, teaching plans, curricula, state policy, institutional pressure). As facilitator of the activity, the teacher employs language, gestures and other sign systems as communicational tools to externalize his/her attention, directing and adjusting the object of the activity; students use the same tools to comprehend, react to and contribute to the object. Through such interactive processes the activity should reach certain outcomes that teacher and students collectively considered as proper. This model has been generative in other studies that have explored teaching and learning in a single classroom case (Valli and Chambliss, 2007).

The basic unit of analysis for activity theory is the collective activity system. While goal-directed actions are relatively independent episodes during the activity, they can be best understood within the holistic context of the system in which they sit. In this research, class activities become our analytic unit. We consider the moves the teacher or the students take in the activity as the actions, consider the specific purpose behind these moves as the specific goals of the actions, and couch our interpretation in the contexts of the overall object of the activity.

Methodology

In this paper, we draw on data from an ongoing research and professional development project that focuses on how high school science teachers attend to student thinking in their teaching practices. This project focuses on understanding what teachers pay attention to in class and how this relates to the multi-level contexts in which teachers practice. As part of this work, we regularly videotape in participating teachers classrooms and conduct accompanying interviews, before and after the class and when follow-up questions emerged during analysis. With peers in subject-matter cohorts (biology, physics and environmental science), teachers meet biweekly to discuss selected snippets, focusing on student thinking and student understanding. They also participate in an eight day summer professional development session geared towards attending to student thinking and reasoning.

We found similarity across data collected from all three subject matter cohorts (biology, physics, and environmental science). For this paper, we focus our analysis on one classroom episode that is representative of our larger corpus of data. We selected a single 90-minute class period from Liz's 9th grade environmental science class because it concentrated many phenomena upon which we wanted to construct our arguments.

Liz was a 9th grade environmental science teacher in a suburban-urban fringe school. (Her school straddles a mid-Atlantic city and its neighboring county.) Our focused analysis comes from an "inquiry" unit on earthworms, at the beginning of the school year. The 90-minute class period focused on students exploring the best habitats for earthworms, specifically developing hypotheses and designing field experiments for testing the hypotheses on their school site.

Classroom data is central to our arguments. By focusing on the teacher-student and student-student conversations taking place in the contexts of different activities, we tried to understand how the objects of these activities get established and carried out. Data for this paper primarily comes from student and teacher talk during specific classroom activities and the one-on-one interview with Liz. We employed discourse analysis, as defined by Gee (1999), as our analytical tool. By minutely analyzing interactive discourses that happen in the classroom, we can gain insight both directly and indirectly into the social processes through which teaching and learning occur (Kelly & Brown, 2000). After primary analysis, we organized a semi-structured interview with Liz to provide additional insights, to challenge our initial interpretations, and to ask questions generated from data analysis. The paper would be shared with her, providing her an opportunity to clarify and correct our perspective on classroom events.

Data analysis and results

Activity reviewing scientific method

This 90-minute class began with a 30-minute review on the scientific method, which, in Liz's words to students, was "the thing that will be on HSA" so "it's not bad to hear it twice." (The HSA, or the High School Assessment, serves as the sole State measurement of school and individual student achievement for high school science, as mandated by the federal No Child Left Behind legislation. A passing score is required for graduation.) It was obvious in student responses that the emphasis on the scientific method was not something new to them, but rather appeared like an expected routine associated with school science, in terms of both learning activities and assessments. Although the state HSA is geared towards biology, environmental science in this school district has the role of preparing and supporting students for biology. Therefore, learning the steps of the scientific method was a reasonable objective for this class.

Focusing on the initial 30-minute review section on the scientific method as a collective activity, we identified triadic dialogues (Lemke, 1990) as the main language structure: the teacher generated questions, students gave short answers to these questions, and the teacher replied by evaluating the answer. Liz's actions in this 30-minute segment of "conversation" can be summarized as follows:

1) *The teacher actively drew students' attention to the key vocabulary.* When students answered with correct terminology, Liz provided positive evaluations by affirmatively repeating what they said or adding words such as "exactly" and "yeah." On the contrary, when students missed the step she looked for, she would try to prompt the right answer by reframing the question based on their prior answers or with further hints such as "We *test* and what do we *call* that?", using language to indicates that the term she is looking for is synonymous with "test". And, in another example, "we call it *an*…", the indefinite article "an" shrank the range of possible choices to one that began with a vowel.

2) *The teacher drew students' attention to an ordered account of steps.* This could be inferred from the way she framed the questions or made comments on students' answers. Sequential expressions such as "*first* step", "what comes *next*" and "*next step*", were frequently used. Liz also mentioned the order implicitly. For example, when student suggested "research" as the step following "hypothesis", Liz answered with "we've already done the research. We put that in with the hypothesis," indicating that the student confused the current step with a previous step. The use of explicit or implicit order expressions conveyed to students the idea that an intrinsic order of steps in scientific method exists.

3) *The teacher emphasized that students should treat different steps as separate components of scientific method.* When Joe responded with "We're going to take notes and analyze them," to Liz's question about what to do while doing an experiment, her reaction was, "that's *two* things you just *put together*". She then reframed her question to ask, "What are we going to do *actually* while we're doing the experiment?" After confirming "record the data" to be the right answer, she went back to check with Joe what the "*next step*" was to make sure he understood that analysis is a "*separate step*" right after experiment. This revisiting emphasized to not only Joe and his classmates that the steps in scientific method should be distinguished from each other.

4) *The teacher asked student to associate specific details with each general step.* As she reviewed the list of general steps for a second time, Liz kept asking questions or giving hints to get the students to say the term for each detail item. When certain details were associated with "wrong" steps, Liz also used order-indicated expressions to make corrections.

Based on Liz's efforts, and the ways in which the students coordinated with her, we argue that in this activity of reviewing the scientific method, the object is to remember the stepwise account of scientific method in order to fulfill the state test requirement, rather than to make sense of why and how this account should be applied to the scientific investigation in which they were about to engage. The object of preparing students for the state test, and, specifically for this particular episode, preparing them to learn the steps of the scientific method, was not unique to Liz's class activity. We see this pattern throughout our work with high school science teachers in our larger study. It is the object required by the system, one clearly understood by both the teachers and the students.

In a follow-up interview, Liz verified that her purpose for this activity was "totally for the six steps of the scientific method." She emphatically stated, "students need to know these to answer the test questions." In such test-oriented activity, Liz's class was well engaged in the triadic dialogue; their active responses to all of her questions, suggests high levels of participation. When we look closely at their answers, however, their use of terms lacks explicit scientific thinking. Instead, the pattern and nature of their responses resembled a "guessing the word" game, in which students threw out the terms and the teacher tried to cue for the right vocabulary and arrangements. Lemke's comment of triadic dialogue seemed to be a justified description of what was going on in this thirty minute review activity:

> It is a form that is overused in most classrooms because of a mistaken belief that it encourages maximum student participation. The level of participation it achieves is illusory, high in quantity, low in quality (Lemke, 1990, p. 168)

Teaching the scientific method could be achieved through a variety of activities. And, these different activities could have different conversation structures than the triadic dialogue. As long as the object was on learning scientific method, however, the attention expressed through the tools would be on vocabulary and ordered steps, affording little space for scientific thinking. In some cases, we also saw evidence that teachers' attentions were drawn away from the seedlings of thinking that students displayed in the class. For example, when the "hypothesis has to be an 'if-then' statement" was set as the object, an activity on making hypothesis could be reduced to format correcting, while discussion on the reasoning behind hypotheses or mechanism behind observation was treated as unnecessary or incompatible goals.

Activity shift into student inquiry

At the end of this review activity, Liz announced that they would now be brainstorming hypothesis and experiments for testing on school grounds the best habitats for earthworms. At first both the teacher and the students continued to use the “scientific method” language, but as this instruction went along, the teacher’s language became less formal and the object itself became more ambiguous and open-ended. The following transcript shows this shift:

1. Liz: So you, together in your groups are going to create this experiment and I'm going to help you as you go along. So, the first thing we have is the problem. (write on the board “problem”) What's the next thing that you all are going to write?
2. Student: Hypothesis.
3. Liz: A hypothesis. (write on the board “hypothesis”) What else do you need to have for an experiment?
4. Student: Procedures?
5. Liz: Right, you have to have the procedures. (write on the board “procedures”) What you're actually going to do, ok? And if you have - if you say you want to do some kind of soil test and you're not exactly sure of the procedure, that's ok, I'll help you with that. Ok? Don't not do something because you're not sure of how to do it - does that make sense?

(Liz got “a list of material” from the students. She wrote that on the board and added “safety precaution” herself.)

7. Liz: …you're going to start *thinking* about what you are going to do. What you want to do for your procedure. You don't necessarily have to answer these in order - you can skip around, ok? And I'm going to come around and help you and make sure everybody's on the right track and knows what they're doing…Everybody got it, sort of? It's a little ambiguous and there's a reason for that. I want you guys to start *thinking*, ok?...

…

13. 13. Liz: …this is going to be a total rough draft because you're going to have a lot of ideas thrown on these papers. All your ideas, get them down there. This is going to be mainly a brainstorming and then we're going to start getting it organized into these…

The conversation began with a similar structure to what we saw in the review section. Liz directed the students to take apart the task. Besides the problem part they “have already got,” she drew from the students “hypothesis” and “procedure” as two other components of “writing an experiment”.

Soon, though, Liz described the task in a different way. She first translated “procedures” into the everyday expression of “what you are actually going to do.” The message here was that the students should not be restricted to only the things they have full knowledge of, but should go beyond to what they are “not sure of how to do.” This reframing began to take off the limits associated with writing a formal set of procedures and placed emphasis on the generation of ideas. The potential constraints of formality were further removed when Liz put stress on “start thinking” and told the students that they can “skip around” (Here she pointed to a list of four items on the board: hypothesis; procedures; list of material; safety precautions) rather than follow a certain order; that the product of brainstorming was a “rough draft” for them to put down “all their ideas” and that the organization of these ideas were not the task for now.

Liz also told the students that her requirement was “a little bit ambiguous,” but “there is a reason for that.” In the interview with her, she revealed this “reason” and gave us a more detailed explanation on what her expectation here was:

> Liz: …I want them to be more brainstorming, I think I also had the problem, that (inaudible), I did the scientific method, they get caught up on they have all these steps, and really I want them to brainstorming ideas.
>
> …
>
> Liz: I’ve given them all these stuff to think about. They were trying to put it in; they were trying to make it all happen. I gave…I kind of gave them all these and I said OK, now, brainstorm. I think they really thought they had to go through all these strict, you know, scientific method when I really want them…you know, we would get that into the scientific method, But I just want them to come up with how they were going to compare their two sites.

Although Liz taught the scientific method in strict steps at the beginning of the class, she saw it as a potential restriction and wanted the brainstorm not to be “caught up” on it, but rather focus on the new object of "brainstorming ideas." These two objects, both belonging to her teaching plan for this class, were incompatible to her.

Based on the above analysis, we argue an explicit shift in activity occurred between the review section and the brainstorm section of the same class period. For the students, the object of activity changed from mastering a test-oriented scientific method account to "generating ideas." Accompanying this change in object, the teacher's attention also shifted from vocabulary and steps to ensuring the productivity of ideas. To accomplish this activity shift, she explicitly and purposefully employed special instructional language to weaken the linkage between the two objects and eliminate the influence of rigid formality and order associated with previous teaching.

Evidence of genuine inquiry in the brainstorming section

During the brainstorming section, we focused analysis on the conversation that occurred among one group of three students, two male and one female. They first reviewed the list of places mentioned in class discussion. Then, instead of going over the tasks one by one, their conversation flowed organically with their thinking, jumping back and forth among the tasks as well as to consideration of ideas beyond the tasks.

Three discursive patterns emerged from their conversation that could be considered examples of genuine scientific inquiry, including causal explanation, mechanistic reasoning and scientific argumentation. Due to space constraints, here we only illustrated *scientific argumentation* with excerpts drawn from the transcripts.

In a discussion on "how to test earthworm's preference of habitat," the following exchange to place on whether experimental sites could be created:

MS1: We'll put one wet and then we'll put one dry. Make one wet, make one dry. Then see how many worms come up on the wet side and the dry side. Like which one do you like better?

MS2: We're not having little buckets…

MS1: No we can do something. We can put some in buckets and test them. It doesn't really matter.

MS2: That wouldn't be in the environment though.

MS1: We'd be outside when we're doing it. That's in the environment.

MS2: Yeah, but it's in a secluded area.

MS1: Ok, ok, ok, ok, ok.

MS2: Cutting off all the other worms around the area. They'll feel the same because you're only using the worms from that one little area.

MS1: Fine. Oh, how about we do this! How about we find a dry place and a damp place.

Male student 1(MS1) first came up with an experiment design using artificially created experimental sites (Make one wet, make one dry/ put some in bucket and test them). Male student 2 (MS2) challenged MS1's design by identifying that "that wouldn't be in the environment" and "it was *secluded*". He also elaborated on why secluded experimental sites might give results different from that of natural ones: "They(the worms) will feel the same because you're only using the worms from that one little area," which implied that worms from a certain area might have something in common because of their interactions in shared environment. It was hard to tell from the conversation whether MS1 totally accepted this reasoning or just compromised, but based on the ex-situ to in-situ change he made to his experimental design at the end, it was safe to say that he at least understood it.

Several distinguishable characteristics of this argumentation allow us to categorize it as scientific inquiry. First, if we judged students' understanding of concepts by their ability of utilizing it, MS1 showed in his original experimental design good conceptual understanding of *independent variable* (dampness), *dependent variables* (earthworm's preference) and *control* group (dry soil as control to wet soil), though these terms had not been literally used (Later in the conversation, we saw examples in which they literally used these terms without showing proper understanding of their meanings. We discuss this more below.). Second, in challenge to MS1's design, MS2 showed the ability to tell the difference between created experimental sites and natural environment, reflecting a deep understanding of the domain specific scientific method in field work: a natural site could be characterized by multiple factors, which makes it hard to replicate in lab; replacing it by artificial site with only one controlled variable would remove the meaning of field investigation. Third, by employing the tool of argumentation, the two students achieved the goal of "figuring out how to test" through revising the design based on a better understanding of the nature of this investigation. Therefore, although the whole conversation was in daily language (except, perhaps, for MS2's use of the word "secluded") and personified expressions ("see which one they like" and "they will feel the same") were frequently used, the good scientific thinking within this argumentation made it a valuable and productive inquiry experience.

Inquiry happened via argumentation several times in this conversation. Another representative argumentation was when they talked about how to bring earthworms up to the surface of the ground. MS2 suggested a method of using a sound device technique to annoy the worms, while MS1 suggested they could just "dig and look." MS2 brought up two factors associated with the digging approach that might influence the results: 1) the earthworms might move away before you get down there; 2) digging had the potential danger of dissecting earthworms. He also referred to two other associated factors that might obstruct the experimental process: 3) under the stage (one area of the school yard they wanted to test) will be hard to dig; 4) it would take more time. Female student (FS) and MS1 came back at point 1) by pointing out that there wasn't obvious evidence supporting its influence; directly arguing against point 3) by pointing out a possible way to conquer the obstacle (somebody small can go down the stage), and indirectly arguing against point 4) by noting the disadvantage of MS1's approach: "we're going to be carrying equipment on our backs (indicate that bringing extra device might be inconvenient)." In this case, the goal of "figuring out how to bring up the worms" had been completed by characterizing the strength and weakness of different approaches through reasoning and comparison, although the agreement was not explicitly reached, the understanding of the two approaches were much more enhanced than just agreeing on an approach without reasoning.

In brief, we claim that this brainstorming section showed students' ability to do genuine inquiry. They employed different inquiry tools, such as causal explanation, argumentation, use of supportive evidence and mechanistic reasoning, for realizing different conversational goals within the context of this idea-oriented activity. Through inquiry, students not only fulfilled the object of generating ideas on where to test and what to test, but also gained much deeper understanding of the ideas they generated, and more important, in an epistemological sense, they experienced the process of constructing scientific knowledge by themselves. In the follow-up interview, Liz also expressed her satisfaction with the outcome of this activity:

> I thought it went very well. I was happy. I was, like I said, I was impressed they had such a, and this is just an example. The class as a whole covered so many aspects of comparing the habitats. And I think they really thought about ways to test the habitats. You know, because I told them, don't worry about the logistics, just tell me what you wanna test, and like if you don't know how to do it…I thought that was fantastic.

Liz did not express direct concerns about the students' being able to construct knowledge through scientific inquiry, either in class or in the interview. However, we ague, it was the activity shift she purposefully conducted that made it possible for such genuine inquiry to take place. She realized that the object of memorizing formulistic scientific method was in conflict with the object of brainstorming ideas. Without removing the restrictions set by the former, she would not be able to engage students in productive inquiry thinking needed for the later activity. In the scientific method review activity, when the teacher's attention was fully on the vocabulary and steps with strict order, the students' attentions were all oriented towards the test-associated correctness, which provided little need for genuine scientific thinking. When Liz reoriented her attention to student ideas, students' attentions were also reoriented to their own ideas. As the object changed from "memorizing the steps" to "brainstorming ideas," and the restrictions of terms and orders were removed, the structure of activity changed from teacher centered triadic dialogue to student centered group discussion. When put in the contexts of real problem solving, students spontaneously gave full play to genuine inquiry.

"Scientific method" talks in brainstorming section

An intriguing question emerged through the sharp contrast between the two class activities: what did the previous learning of scientific method contribute to students' scientific inquiry? In general, besides for testing, why is it necessary for students to learn in such a way about the scientific method?

We consider this question by examining one of the two excerpts in the brainstorming section where students explicitly talked about the scientific method (the other one was presented at the beginning of this paper, which is not included here as the data could be interpreted in two quite different ways.).

1. MS1: Does the moisture increase if pollution decreases? Well, I don't think we're really able to test it.
2. MS2: And the texture of the soil is softer.
3. MS1: That's like more than one hypothesis. We can only have one.
4. MS2: Yeah, but there can be more than one variable.
5. MS1: There can be more than one variable but not more than one hypothesis.
6. MS2: This is the independent and this is the dependent.
7. MS1: Then why are you putting it in your hypothesis?
8. MS2: Dependent depends on the independent.
9. MS1: But why are you putting it in your hypothesis? Why are you putting in your hypothesis?
10. MS2: You have to put all the variables in the hypothesis; otherwise it's not a valid hypothesis. I know this because I was in GT science and my teacher was very, very, very, very, precise.
11. MS1: Ok.

In this excerpt, students held the idea that they can only have one hypothesis, which might come from Liz's earlier instruction of "writing *a* hypothesis". The hypothesis they discussed in their group could be generalized as follows: the moisture will increase if pollution decreases, and the texture of soil is softer. This hypothesis, although making perfect sense, does not conform to a conventional one independent variable, one dependent variable type of hypothesis; instead, it involved a more complex reasoning structure. It could either be considered as a) two connected hypotheses packed together (if pollution decreases, moisture will increase; if moisture increases, the texture of the soil is soft), or b) a hypothesis having two dependent variables (if the pollution decreases, the moisture will increase and the texture of soil will be softer). It could be reasonable to infer that MS1 held the former interpretation and felt its confliction with the "only one hypothesis" requirement, while MS2 interpreted the situation as "having more than one variable" rather than "having two hypotheses."

We previously mentioned that argumentation could be a productive tool for scientific inquiry. However, that was true when the participants scientifically reasoned through their differing ideas and opinions. This scientific argumentation required a deep understanding of the central subject and premise as well as the logic of other participants' arguments. The example of argumentation about the structure of the hypothesis, involved little scientific reasoning processes. Although MS2 at one point provided the correct relationship between dependent and independent variables, he gave it as a statement and did not explicitly connect it with the problem they were arguing about in any way that could support his point or provide specific guidance to the group. Other than that, in support of their respective arguments, the two participants referred to the requirement from the teacher and to another authoritative resource (the Gifted & Talented science teacher who was "very very very very precise."). Little scientific understanding appeared to be gained through this conversation, either towards the concept of hypothesis and variable, or towards the goal of figuring out "how to test soil pollution".

This excerpt indicates that the students expressed confusion about the exact meaning of variables and hypothesis, which were both important components of the scientific method account. They talked about the criteria on variables and hypothesis in a quite different way from how they talked about their own ideas. Instead of resolving problem through reasoning, they tried to draw from memory certain factual knowledge they gained before.

If we looked back at how scientific method was taught (not only in this class, but in many other classes as well), it was not surprising that students would talk about it in this way, for these terms and their meanings were first introduced as perhaps seemingly disconnected facts passed down to them to learn rather than sensible constructs deeply rooted in, and connected to, underlying reasoning.

In the same activity, when working on the specific questions, students showed proper conceptual understanding of variables and hypothesis. The argumentation example presented above showed their understanding of variables. Another example that showed their understanding of hypothesis as well as variables was the hypothesis the students generated by the end of the brain storming section: "As the moisture and health of the soil increases and the soil is softer then the number of earthworms will increase because earthworms like damp, moist, dark, soft and healthy soil." Besides clearly predicting the relationship that number of earthworms (dependent variable) would depend on the combined effect of different soil features (independent variables), this hypothesis also showed students' understanding in two other aspects: 1) they understood that an environmental site (habitat) could be and had to be simultaneously defined by multiple variables; 2) they were considering causal relationship ("because earthworms like damp, moist soil") rather than simple correlation. Both of these aspects are what scientists negotiate when making hypothesis. The first point is especially true for researchers who work in the field, as field investigation sets great limits to the introduction of artificial control, and the multiple factors that characterize one site usually have complicated interactions. In general, hypotheses that synthesize the combined influence of multiple variables are much more common in environmental science and ecology than "single independent variable" ones. Therefore, this hypothesis not only showed a general understanding of what hypothesis and variables were, but also showed a much deeper understanding of how hypothesis and variables functioned in specific contexts.

Conceptually, we argue, the students understood hypothesis and variables. Their confusions were with the terms that labeled these concepts, which were taught as parts of the scientific method throughout their years of schooling. Not knowing these terms did not prevent the students from performing genuine scientific inquiry. On the contrary, when figuring out the literal meanings of these terms and their associated scientific method rules, became the goal, it drew the students' attention away from the productive work they were doing and led to non-productive conversations that were incompatible with the general object of "put down all your ideas" that characterized the brainstorming activity.

Conclusion and Discussion

In the above case, which was representative of many other cases not shown here, we saw that scientific method was taught as rigid, decomposable, stepwise account for memorization, which shifted teachers' attention away from the substance of student thinking and made no place for scientific thinking, but supported the teaching of arbitrary.

Several conclusions can be drawn towards the relationship between scientific method and scientific inquiry:

- Scientific method (test-oriented) and scientific inquiry are two separate objects for teaching; Shift in activity often has to take place to lead students away from scientific method into productive inquiry focusing on “thinking”;
- Focusing on students’ confusion over scientific method terms is a commonly acceptable teaching practice, which can draw teachers’ attention away from the genuine inquiry students do.
- Students can do genuine scientific inquiry using daily language; but when talking in “scientific method” language, they can be confused over terms and rules and distracted from ongoing, productive inquiry.

Taught as a rigid, formulistic piece of content knowledge, scientific method contributed little to promoting scientific inquiry, and in some cases suppressed it. What, then, was the foundation of the extensive acceptance of scientific methods as an indispensable object of inquiry class? When the systematic contexts provide little support for teaching scientific inquiry other than as vocabulary and a set of rules, we cannot identify teachers as responsible for their lack of attention to the substance of student thinking.

We therefore believe that science educators need to consider how to change (and challenge) the current implementation process of scientific inquiry in order to emancipate the students from mandatory futile learning of scientific method, so they could truly engage in productive thinking and practice through inquiry. The assessment of inquiry, at the same time, should not be a formulistic measurement focusing on their memorization of terms, steps and rules; it has to provide a way that enables teachers, students and researchers to take a closer look at students’ thinking, as that is where genuine inquiry lies.

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