

Comparing Classroom Inquiry and Sociological Account of Science as a Means of Explicit-Reflective Learning of NOS/SI

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Abstract

Research has shown the importance of an explicit-reflective approach to improving individuals' understanding of nature of science and scientific inquiry. What has been less explored is a variety of ways for carrying out an explicit-reflective approach. The purpose of this paper is to share a particular strategy. At the heart of the approach was the comparison of an in-class inquiry based activity and a reading of a sociological account of scientific work. Following this exposure, participants are able to generate a number of key aspects of NOS/SI. Additional suggestions, as well as misconceptions, are able to be used as the starting point for further class discussion. The activity has been utilized in preservice methods courses and inservice professional development programs for teachers at all levels, as well as classes for non-teacher education students.

The Problem

Reform in science education has long had as a central goal student understanding of meta level concepts related to the epistemology and process of science – what has come to be termed nature of science (NOS) and scientific inquiry (SI). Of course, the reason it has long been a goal is that meeting it has proved so challenging. Research has shown the importance of an explicit-reflective approach to improving students' understanding of nature of science and scientific inquiry (Khishfe & Abd-El-Khalick, 2002). That is, simply involving students in authentic inquiry experiences with the aim that students will implicitly learn those meta level understandings about science will not work. Experience with inquiry is crucial, but aspects of NOS/SI must be addressed explicitly. The explicit-reflective approach has been shown to be effective with K-12 students (Khishfe & Abd-El-Khalick, 2002), preservice teachers (Scharmann, Smith, James, & Jensen, 2005; Schwartz, Lederman, & Crawford, 2004) and inservice teachers (Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson, Hanson & Cullen, 2007).

The focus of this body of research has been on detailing the impact of an explicit-reflective approach, rather than providing guidance on the details of such approaches. In fact, there are a number of clear impediments to carrying out explicit-reflective teaching of NOS/SI. Engaging students in authentic inquiry has its own inherent challenges (Meyer, Antink-Meyer, Nabb, Connell, and Avery 2013). Engaging in meaningful scientific inquiry practices such as understanding and forming scientific questions, employing appropriate methodology,

interpreting results all entail background knowledge. The subject of an inquiry has to have something in question, but the scientific content of most K-12 science classes (or even college level science classes) have, by definition, been resolved (Meyer and Avery, 2010). Indeed, the process of validating scientific knowledge often includes removing the particularities of its production (Latour & Woolgar, 1986).

In addition, thinking about NOS/SI is not a natural activity for students. The concepts are not black and white, and have the non-binary, qualitative aspects of many sociological concepts. Furthermore, it is difficult to imagine how to prompt students to think about such issues. Put bluntly, asking students “What do you think the nature of science is?” is not a meaningful question, regardless of what their ideas about it actually are.

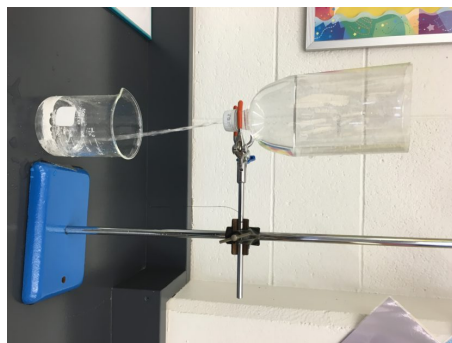
The purpose of this paper is to demonstrate an approach that put participants (preservice and inservice teachers in the cases presented here) in the position of being able to meaningfully generate ideas about NOS/SI. The basic structure is the comparison of two cases – one an in-class inquiry based activity that participants complete and the second a case study drawn from sociology of science. The content of each is completely different, and thus the comparison focuses participants on aspects of NOS/SI, which each is designed to illustrate.

In-Class Inquiry Activity

The in-class inquiry activity is called the Flow Lab (Meyer and Avery, 2009). It is intended to provide participants with an authentic experience of scientific investigation. Specifically, it requires participants to investigate a question without clear methodological guidelines, grapple with ambiguous data, provide empirically-based warrants to claims, and respond to the arguments of others.

Participants are presented with an inverted plastic beverage bottle that has had the bottom cut off and a hole drilled into the cap (See Figure 1). They are directed to see how much water would flow out in 10 seconds for different starting volumes. They are given the specific challenge to continue to do so until they have a good enough sense of the relationship between starting volume and out flow to predict the outflow volume for a starting volume they had not tested.

Figure 1 (Click on image to enlarge). Basic set-up for the flow lab.



Participants often begin trying a few volumes in a less systematic manner. Reminding them of the challenge – to be able to make a future prediction – helps focus and guide them to a more systematic approach. Likewise, participants might ask for more specific instructions, akin to traditional cookbook labs, such as the number of volumes to try. Again, reminders of the challenge serve to frame and drive the choices participants must make.

Figures 2 and 3 are examples of the results participants get. A feature of the activity is that there is a strong tendency towards a variety of results. Moreover, results tend to be “messy” enough that there are multiple interpretations possible. For example, the data in Figures 2 and 3 could be interpreted as linear, but also could be interpreted in other ways. The data in Figure 2 could be increasing with a decreasing slope or be two linear sections. The data in Figure 3 could be increasing with an increasing slope or be a curved and then linear section. The selection of the challenge starting volume can be used to push participants towards a conclusion. For example, if there is a data point that appears like an outlier, a new starting volume could be given as a challenge that forces an interpretation of the data point in question.

Figure 2 (Click on image to enlarge). Example of student data.

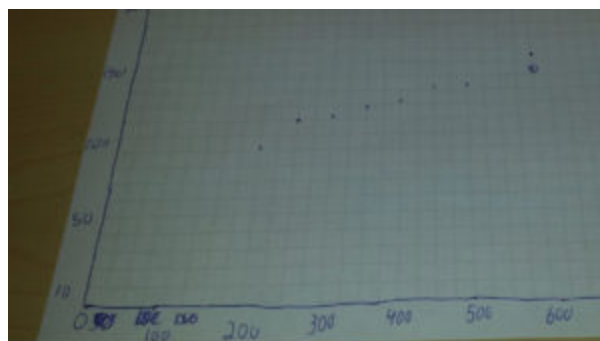
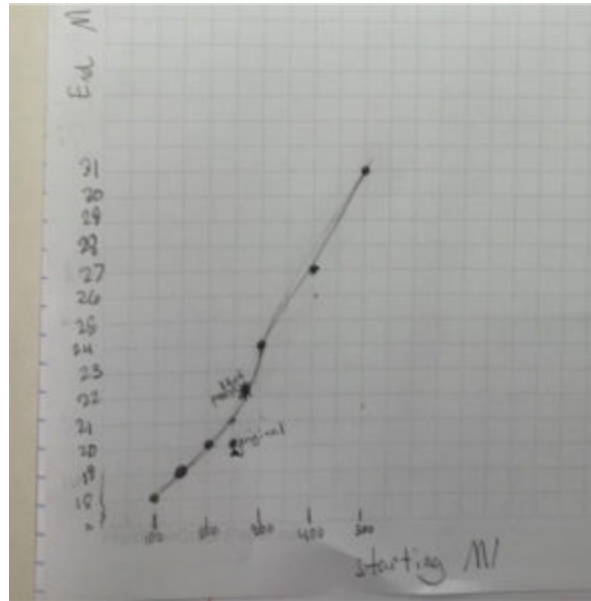


Figure 3 (Click on image to enlarge). Example of student data.



This is demonstrated in Figure 2. The group's original data only extended to 500 ml. That data could be interpreted as linear or it could be interpreted as leveling off. So their challenge was to make a prediction for 600 ml, forcing a particular conclusion. This means that participants are not merely collecting data – they need to reach conclusions from that data. Groups are encouraged to come to a consensus position, but occasionally cannot. The group in Figure 2 had a split, hence the two predictions at 600 ml. The upper value is based on a linear interpretation; the lower value is based on a curved interpretation. The subsequent measured value corresponded to the latter prediction and is circled.

After making a prediction (and checking it), the different groups are brought together to discuss what claims about the phenomena can be reached. As shown by Figure 2 and 3, there will be a range of claims with a range of levels of agreement and certainty. For example, there will be pretty clear evidence and agreement on the idea that outflow generally increases with starting volume. But some data-sets/participants might support a linear function, some an increasing slope, some a decreasing slope, some with different sections with different behaviors and some even inflections points. An ambiguity that can arise (including being introduced by the instructor) is the possibility that because different bottles and different hole sizes are used, data that looks different may actually be consistent. For example, given the changing diameter of the bottles, two data sets with different patterns may be looking at different parts of the same phenomenon.

There are a couple of features of the activity that should be noted. Participants were given a very specific challenge, but not any guidance for how to achieve it. This required them to develop their own methodology, but also provides the instructor with a response when participants ask for more direction. The phenomena itself is effective in providing a certain degree of variability, to allow for authentic argumentation. In particular, the relationship

between starting volume and out-flow is more ambiguous than water height and out-flow because of the various shapes of bottles. In addition, the use of a variety of bottles and hole sizes introduces more variability.

Case Study from Sociology of Science

Participants then read Harry Collins' account of early gravitational wave research (Collins & Pinch, 1989).¹ This is a classical case in the sociology of science, demonstrating the essential social element to epistemology. The case begins with Joseph Weber attempting to detect gravitational waves, a phenomenon predicted by Einstein's General Theory of Relativity, and widely believed to exist, but also considered extremely difficult to detect. Weber claimed to have succeeded. Moreover, he claimed to detect waves at a higher flux level than predicted by current theory. His claims were taken seriously, however, and a number of researchers responded with investigations of their own. Collins details the subsequent progression in the scientific community, detailing the change in the social and epistemological status of the claims that were made. Specifically, early reports were considered failures to confirmation of Weber's claims. But over time these transformed into active confirmations of the invalidity of Weber's claims. The difference between these states is one of Collins' key points. The final resolution was agreement in the community that Weber's claims were false.²

Collins uses the Weber case to illustrate the concept of *experimenter's regress*. Novel claims in science have no purely logical way of being validated or refuted: Weber tries to build a gravitational wave detector. How can it be determined if he did it correct? Turn it on and see if it detects gravitational waves in the right manner. How do you know what the right manner is? Build a gravitational wave detector. Collins describes how the social interaction among the actors provides the resolution to this infinite loop. Science proceeds through an alternation between *interpretive flexibility*, where there are multiple conclusions can be reached, and *closure*, when the community reaches consensus on one interpretation.

Prompt for Participants

Participants are then given the following prompt:

Please come up with as many generalizations about science as you can through reflection on the class activity and the reading. The subjects of the class activity and reading are clearly different. But are there commonalities that can be identified to form generalizations about the process of science and the nature of scientific knowledge?

Each of the cases alone provides material for participants to draw on. But in addition, the comparison provides a means to focus on NOS/SI, and have the question of providing "generalizations about science" have actual meaning.

Student Generated Aspects of NOS/SI

Table 1 shows data from two participant groups. Participants in a preservice elementary science teaching methods worked in pairs during class time to generate statements. Participants in an inservice professional development course on inquiry-based teaching generated statements individually as a homework assignment. Table 1 shows the frequency of connections between participant statements and standard aspects of NOS/SI.

Table 1 (Click on image to enlarge)

Frequency of References to Aspects of NOS/SI

Aspects of NOS/SI	Preservice (35 statements generated by 5 pairs)	Inservice (40 statements generated by 6 individuals)
Tentativeness	8	3
Creativity	1	0
Observation vs. Inference	1	1
Subjectivity	1	7
Functions and Relationships of Theory and Law	1	0
Society and Culturally Embedded	0	2
Empirically Based	2	2
Scientific investigations all begin with a question, but do not necessarily test a hypothesis	1	0
There is no single set and sequence of steps followed in all scientific investigations (i.e., there is no single scientific method)	4	0
Inquiry procedures are guided by the question asked	0	1
All scientists performing the same procedures may not get the same results	2	3
Inquiry procedures can influence the results	0	0
Research conclusions must be consistent with the data collected	1	3
Scientific data are not the same as scientific evidence	0	2
Explanations are developed from a combination of collected data and what is already known	6	6
statistical rigor	1	0
demonstration problem	4	1
interconnectedness of science	4	0
dependence on technology	2	0
nature of data (not necessarily numeric)	1	0
record keeping	2	1
reasoning	2	0
experimental design	1	0

Each suggested generalization can then serve as a discussion point. Roughly speaking, they can be seen as coming in four types, with corresponding responses from the instructor. Some generalizations will align very directly with standard aspects of NOS/SI that are the target of instruction (Abd-El-Khalick et. al., 2001; Lederman et. al., 2014). The following are examples:

- *The body of knowledge about science topics changes with time, further research, and technical advancements.* (Tentativeness)
- *There is variance in how data is interpreted* (Subjectivity)
- *Scientists don't always agree or come to the same conclusions* (Scientists may get different results)

Others are opportunities to introduce ideas. For example, the statement “Science is full of controversy, but it can also solve controversies” has a ring of truth to it, but more importantly, it creates an opening to discuss issues such as the centrality to argumentation in science.

Perhaps the most important type of suggested generalizations are those that are deeply flawed. The most consistent examples of this is reference to “the Scientific Method” and statements about the necessity of hypotheses. The key here is that the activity allows such misconceptions to be brought out into the open. When they occur, the instructor can challenge students to consider if they – and Weber – really used “the Scientific Method” and if a hypothesis was necessary to carry out their work.

Lastly, participants make suggestions that are important issues, but that are not part of what is generally considered NOS/SI. Often these relate to inquiry process skills and routines. For example, students consistently make the point that more data is beneficial. This often leads to a discussion potential for statistical power to reduce error.

Logistics and Variations

The pacing and other logistics of this approach will depend on the specific context in which it is used, as well as the participants involved. Depending on participants background (e.g. comfort level with inquiry, ease with measurement, etc.) the Flow Lab itself can take one to two hours. Participants can more formally present their findings, or the instructor can lead the discussion over different groups’ data. An optional follow up activity is to have participants propose (and possibly carry out) a follow-up investigation.

The sociology of science reading is a standard journal paper length reading. While relatively accessible, participants do appreciate and benefit from a modicum of review, and so that should be scheduled accordingly. Participants can also benefit from a warning ahead of time that the reading may be a very different type of reading than they have experienced in the past.

The formation of generalizations statements can take a variety of logistical forms. For example, the preservice participants shown here formed their statements during class time and in pairs, while the inservice teachers formed theirs individually and as an out-of-class activity. This was both because of the difference in numbers and timing. It should be noted, however, that even in the case of a face to face class discussion, explicitly writing down statements has important benefits. It encourages care and precision in language and provides a concrete point of reference for further discussion.

There are also alternatives for debriefing participants’ generalizations. If logistics allow, generalizations can be organized, either by the instructor or by students. However, simply going through the list without any intentional order also has merit. Participants can be directed to respond to and critique each other’s generalizations. One important note, however. There are certainly misconceptions, as well as poorly articulated notions, that will be generated. The instructor’s role should be to challenge those. As noted above, this can often be done by questioning if the generalization was true of the two cases.

Lastly, there are two possible follow-up activities. First, particularly if there is the sense the participants have not responded to a particular aspect, custom prompts can be used to spark more conversation, followed by an invitation to create more generalizations. Table 2 shows a set of possible questions. (Note that this was not used with either of the groups shown here, due to time restraints and satisfaction with their work.) Second, participants can compare their lists with standards lists. This can include considering what aspects correlate with their generalizations, what aspects were demonstrated in the case studies but not reflected in their generalizations, and what aspects were not demonstrated in the case studies. This comparison can help with the issue of there being different ways to articulate the same concept.

Table 2 (Click on image to enlarge)

Prompts for Further Thinking about Science

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1. What role did prior knowledge play in your work in the Flow Lab? What role did prior knowledge play in the gravitational waves case?
 2. How did you know what to do? How did you know you were doing it "right" (or know that you were not doing it "right")?
 3. How much did you accept what other groups did? Why or why not?
 4. What role did data play in the Flow Lab? In the gravitational waves case?
 5. How was the final conclusion in the gravitational waves reading reached? How was the final conclusion in the Flow lab reached?
 6. What might change your conclusions from the Flow Lab? What might change conclusions in the gravitational waves case?
 7. What type of knowledge did we find in the Flow Lab? (e.g. fact, measurement, law, theory, observation, inference, procedures, technology, etc.) What types of knowledge were used in the Flow Lab? What types of knowledge was found in the gravitational waves case? What types of knowledge was utilized in the gravitational waves case?
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Coverage

As with any such activity, this activity certainly does not cover all the standard aspects of NOS/SI, and covers some much more consistently and strongly than others. There is a limit on what these two cases can represent, and understanding that limit is important for instructors. Tentativeness is perhaps the strongest covered standard. Participants recognize that conclusions are not absolute. They also clearly see both the subjectivity in scientific work, but also the central role of empirical data. The notion of social and cultural embeddedness tends to be completely absent. The difference and roles of theories versus laws will arise, often through statements reflecting the misconceptions that theories become laws. This provides an opportunity to explicitly correct the misconception, but the cases themselves do not actually provide helpful references to discuss the issue.

The following model may help explain what is relevant and therefore useful in this pair of cases and what is not. The enterprise of science does not only consist of what occurs during an investigation, and three levels can provide some order by clarifying where an aspect of NOS/SI is manifest. First, there is the level that contains everything within a particular investigation. Second, there is the level that expands outward to include the work and actors

that are directly connected to the original work. It includes what is utilized in the original work and how others respond to its claims. The level realm expands outward more to include the discipline as a whole. Different aspects of NOS/SI are manifest in different realms. The notion of the empirical basis of scientific claims clearly occurs in the first realm (as well as others). But the notion of theory spans an entire field. One bit of work, even including responses to that work, cannot, by definition, illustrate the concept of theory. The two cases in this activity – and any other pair like them – deal with the first two levels. To provide useful references for aspects occurring in the third level will require a very different sort of experience.

Conclusion

This activity has shown effective in prompting explicit discussion on many aspects of NOS/SI. The comparison of an authentic, in-class inquiry experience and a sociological case study – with very little content in common – allows illumination of the meta level ideas that they have in common. This in turn gives participants a reasonable opportunity to spontaneously offer ideas about those meta level concepts. Many of the ideas are strong. Perhaps more importantly, even those statements that are weak, unclear or contain outright misconceptions do the work of putting those views out in the open where they can be addressed. The activity is not a panacea. It works for concepts closely tied to individual works of science, how they draw on past work, and the scientific community's reaction to specific works and claims. Large issues that look at the community as a whole – such as the relationship between theories and laws – must be approached through a different strategy.

Author Notes

1. There are actually three almost identical versions: the original journal article (Collins, 1981), a chapter in Collins' book on replication in science (Collins, 1992), and a chapter in the Collins and Pinch book on science *The Golem* (Collins & Pinch, 1998).
2. It should be noted that though this story ends there, the effort to detect gravitational waves has continued on in the decades since, eventually become NSF's largest single project and resulting in the detection of gravitational waves in February 2016.

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