Characterizing Chemistry Practices: How Teachers Design and Perform Chemistry Experiments

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Abstract: This study aims to characterize the complicated nature of science practices in an open-ended inquiry chemistry lab in which students participate in group work. In this study, the complicated nature of science practices is framed and traced by drawing on the notion of "science as a mangle of practice." From this notion, the dialectical relationship between human and non-human agency constitutes science through the dynamic process of resistance and accommodation. Tackling these dialectical agencies may allow us to effectively capture a snapshot of students' lab activities and science practices. Methodologically, the study demonstrates how the combined use of social network analysis and discourse analysis may provide insight into the complicated nature of this mangled science practice. The study also explores the advantages of using a 360 VR camera, providing an immersive view while reducing blind spots.

Student assessment on inquiry-oriented labs tends to focus on the understanding of science concepts while essentially ignoring the practical aspects, such as asking questions, designing experiments, and conducting investigations. Unfortunately, there is little understanding of how to integrate content knowledge with science practices. Today, the science content knowledge learned and procedural skills acquired are assessed separately; however, these two aspects need to be understood and analyzed in a dialectical manner in order to effectively address students' engagement in science practice. Importantly, while the understanding of content knowledge from lab activities often focuses on individual learning as the unit of analysis, collaborative work requires a look at group interaction in order to understand students' science practices.

Pickering (1995) conceptualized doing science as a dance of material and human agency in a dialectical relationship. Scientists enact their agency by making hypotheses and designing experiments to understand material phenomena. However, most material phenomena take time to understand fully, and scientists face many difficulties. To overcome such resistance from the material world, scientists reconsider and revise both their material parts (procedures and equipment) as well as their existing scientific knowledge. This integration represents what science practices actually look like. Pickering's idea of science practice aligns with social-cultural learning perspectives in that conceptual and social practices (human and material agencies) are integrated in a given community to evolve the disciplinary field (Manz, 2015). Both Pickering's 'mangle' view and social-cultural learning perspectives demolish the dichotomy between conceptual knowledge and practices. Methodologically, it is challenging to tackle the dialectical relationship between human and non-human agency, along with the process of resistance and accommodation. To address this difficulty with our study, we followed three phases for conducting open-ended inquiry chemistry labs. First, we created an initial design in which students conducted the experiment. Second, when things did not go as planned, we observed students' responses. Third, we sought to determine if students revised the experiment. We observed the resistance and accommodation between material (experimental procedure) and human agency (students as scientists, who design and conduct experiments). To align with the agency-relation view, a linkage analysis used to connect material and human agency while describing changes in agency relationship. Consequently, we utilized a method that combines discourse analysis (DA) and social network analysis (SNA) (author(s), 2015).

The study addressed the following two questions: How do pre-service chemistry teachers initiate their experiment design, change and update their experiments when they do not go as planned, and revise them? How do group interactions differ between groups when conducting experiments?

Methods and analyses

This 15-week qualitative study sought to gain an in-depth understanding of how 20 pre-service teachers plan and conduct their open-ended inquiry experiments. After conducting guided, basic experiments, they were given a week to design a freestyle open-ended experiment. The teachers also were asked to include phone-recorded video clips and pictures in their reports in order to increase the records' accuracy and to supplement note-taking. An integrated 360 VR camera was used to observe verbal and non-verbal interactions among pre-service teachers. The camera enabled the researchers to trace multi-layered interactions during experiments. That is, the camera captured both the verbal talk among students and the experimental procedure (e.g., how students dealt with the equipment as well as how they observed and measured phenomena). The 360 VR camera records an

immerse-view, making it easier to observe multiple-layered actions and verbal interactions without confusion (See figure 1, for comparison between a single lens camera and 360 VR camera). The panoramic overview of this camera also allows one to navigate science with multiple points of views, instead of having a single point of view captured by a traditional video camera. With the 360 VR, a student's movement is literally indexed spatially for subsequent verbal and non-verbal interactions (Pea, 2006). For the DA, two of five groups were selected for detailed analysis. We transcribed all verbal interactions, gestures, and facial expressions before developing free codes based on our readings of these transcripts several times. We finalized these codes after extensive discussion between the researchers: an expert in science education, three experienced science teachers, and a graduate student. To trace changes in human and non-human agency, we created detailed categorizations of how students responded to failed experiments, resulting in eight codes. For the SNA, we utilized UCINET and NetDraw as well as a matrix displaying basic interactions among participants.

Findings and discussions

Scientists actively respond to the resistance of material agency because they have a clear epistemic goal, to construct new scientific knowledge. Having students conduct a freestyle, open-ended experiment enables pre-service teachers to establish a similar epistemic goal—allowing them to create and conduct an experiment based on their own curiosity. They also are expected to negotiate and interact with uncertain and resistant phenomena from their experiments, calling on their ability to engage and integrate their conceptual knowledge with their practice. However, a few issues emerged in terms of the pre-service teachers' engagement in free-style, open-ended inquiry. These pre-service teachers selected the topics of their experiments, driven by external factors rather than their own curiosity about natural phenomena. Rarely did we see the emergent, ongoing negotiation between human agency and material agency resulting from unexpected and mysterious situations. One of the reasons for this failure was that pre-service teachers might not make a strong connection between their conceptual idea (content knowledge) and experimental design (what and how to measure and observe). When they met unexpected, unsuccessful situations, most pre-service teachers decided to repeat the exact same experiment without considering the possibility of revision. This decision diverges from how scientists handle their challenges: scientists revisit and revise both their conceptual knowledge and their material procedures. Because their epistemic goal was not to construct new knowledge, pre-service teachers rarely constructed knowledge or negotiated between human and material agency. To make inquiry-oriented experiments meaningful for students, it seems essential to have them establish an epistemic goal as scientists do. In essence, the purpose of conducting inquiry-oriented, freestyle experiments lies in experiencing a scientist-like curiosity about natural phenomena, directly connected to the establishment of an epistemic goal. Despite some disappointing findings, we noted some progress over the course of the semester. At the beginning of the semester, one group leader tended to decide on issues and proceed with tasks and experiments accordingly. The leader made decisions in isolation when things did not go successfully. However, a couple of groups differed in important ways. When the experiments failed, these groups took time to reflect and incorporated other members' ideas and opinions more actively. More members engaged in the experiments, leading to more ideas and trials. A student who pitched in with the experiments relatively late pointed out that she felt stronger responsibility, attachment, and ownership. In this study, the researchers designed more authentic, freestyle inquiry-oriented experiments and analyzed pre-service teachers' science practices. The description of pre-service teachers' practices indicates that borrowing a form of practice (e.g., freestyle, open-ended experiments) might not work as desired. It seems necessary to establish epistemic goals in order to enact the dance of agency; meanwhile, genuine curiosity toward the natural world must be triggered and activated as part of lab activities.

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