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Recommended Citation

Pazicni, S., Marrongelle, K. and Christensen, W. "Tackling Teaching: Understanding Commonalities among Chemistry, Mathematics, and Physics Classroom Practices." Proceedings of the 15th Annual Conference on Research in Undergraduate Mathematics Education. Stacy Brown, Sean Larsen, Karen Marrongelle, and Michael Oehrtman (Eds), 2012, Portland, Oregon. pp 517-521.

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Tackling Teaching: Understanding Commonalities among Chemistry, Mathematics, and Physics Classroom Practices

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Abstract

Education research in chemistry, mathematics, and physics tends to focus on issues inherent to the discipline, most notably content. At this time, little literature evidence exists that documents fruitful collaborations between education specialists across the STEM disciplines. This work seeks to unite the disciplines by investigating a common task: teaching. This study explores how discipline-specific practices influence the common act of reformed teaching pedagogy with a focus on the use of inquiry. We seek to identify commonalities among classroom teaching practices in these disciplines and contribute to the development of analytical tools to study STEM teaching.

List of Keywords

interdisciplinary, inquiry, RTOP, teaching

Theoretical Perspective and Purpose

What makes good teaching good teaching? To what extent are the qualities of good teaching in science the same as the qualities of good teaching in mathematics? How much is the nature of good teaching influenced by the discipline? Questions about the general or subject-specific nature of high-quality teaching have confronted educational researchers for decades (e.g., Gage, 1963; Lortie, 1975; Leinhardt, 2004). Some researchers acknowledge that ‘good teaching’ involves both disciplinary orientations as well as general principles (Gresalfi & Cobb, 2006). Recently, Grossman and McDonald (2008) lamented that, “...the field of research on teaching still lacks powerful ways of parsing teaching that provide us with the analytical tools to describe, analyze, and improve teaching” (p. 185).

We have begun to investigate teaching practices in three disciplines: chemistry, mathematics, and physics. We initially observed (in the literature and via conversations with colleagues) that chemists, mathematicians, and physicists use the word “inquiry” to describe specific classroom practices. Our work is now proceeding with two caveats: (1) the idea of “inquiry” in the three disciplines has common roots (e.g., Dewey, 1997; Freire, 1984; Piaget, 1964; Vygotsky, 1962) and (2) despite having common roots, “inquiry” has somewhat different operationalized meanings in each of the disciplines. Our intention is to honor the distinctions of “inquiry” among the disciplines and how these distinctions potentially arise from discipline—specific practices, but focus on the commonalities of inquiry-based teaching across the disciplines. **We are investigating the role of the teacher both in the research literatures and in three inquiry-based, disciplinary classrooms in order to identify commonalities among classroom teaching for the purpose of developing a common language to describe inquiry-based**

teaching practice and contribute to the development of analytical tools to study teaching across the STEM disciplines.

Methodology and Preliminary Results

First, we reviewed the research literatures in chemistry, mathematics, and physics education to better understand disciplinary perspectives on “inquiry” classrooms. **We identify here a few of what we consider to be exemplary STEM inquiry instruction at the University level.** While we recognize that this list is not exhaustive, we feel it is consistent with how “inquiry instruction” is described within our three distinct discipline-based education research literature bases.

Process-Oriented Guided Inquiry Learning (POGIL) is an exemplary curriculum from the field of chemistry. POGIL curricula exploit the notion that scientific discoveries are made using standard inquiry practices and models the “discovery” of chemistry knowledge through the presentation and analysis of data/models that undergird the phenomena being studied. POGIL promotes active engagement of students through a series of small group activities that incorporate guided inquiry as well as necessary processing skills such as information processing, critical and analytical thinking, problem solving, communication, teamwork, management, and assessment (Farrell, Moog, & Spencer, 1999). A POGIL activity assists students in develop understanding by employing the *learning cycle* in guided inquiry activities. The learning cycle is a pedagogical paradigm for enhancing student learning that first originated from a 1960s elementary curriculum project and consists of three stages: *exploration*, *concept introduction/formation* and *concept application* (Karplus & Their, 1967). Published POGIL materials are available for general, organic, physical chemistry, and GOB (general, organic, and bio-chemistry) courses. The effectiveness of POGIL in general chemistry has been previously described (Farrell, Moog, & Spencer, 1999; Lewis and Lewis, 2005).

Inquiry-oriented differential equations (IO-DE) is an exemplary curriculum from the field of mathematics. The IO-DE curriculum capitalizes on advances within the disciplines of mathematics and mathematics education. From the discipline of mathematics, the IO-DE projects draws on a dynamical systems point of view and treats differential equations as mechanisms that describe how functions evolve and change over time. Interpreting and characterizing the behavior and structure of solutions are important goals, with central ideas including describing the long-term behavior of solutions, the number and nature of equilibrium solutions, and the effect of varying parameters on the solution space. From the discipline of mathematics education, IO-DE draws upon two complementary lines of K-12 research: the instructional design theory of Realistic Mathematics Education (RME) (Freudenthal, 1991) and the social production of meaning (Cobb & Bauersfeld, 1995). RME is an instructional design theory that puts at its center the design of instructional sequences that challenge the learner to organize key subject matter at one level to produce new understanding at another level. This is referred to as mathematization. The process of mathematization is actualized in the core heuristics of guided reinvention and emergent models. Guided reinvention deals with locating appropriate instructional starting points that are experientially real to students and take into account students’ mathematical ways of knowing. The heuristic of emergent models deals with the need for instructional sequences to be long-term, connected, and for which student engage in problems to create and elaborate symbolic models of their own informal thinking. Regarding the social production of meaning, an explicit intention of the IO-DE project is to create learning environments where student routinely offer

explanations of and justifications for their reasoning. In particular, the constructs of social and sociomathematical norms (Yackel & Cobb, 1996) are central in IO-DE classrooms.

Tutorials in Introductory Physics is an exemplary curriculum from the field of physics. The term “tutorial” was first coined within the Physics Education Research community by Lillian McDermott at the University of Washington. (McDermott, *et al.*, 2002) There have been a number of other groups contributing to the general paradigm of the University of Washington model (e.g. Activity-Based Tutorials (Wittmann, *et al.*, 2004, 2005)). The general idea of a “tutorial” is a highly structured series of questions that force students to reason through what are often contradictory models of physical phenomenon. At their most effective level these tutorials take into account an extensive amount of evidence about students reasoning and/or understanding of a given topic in order to present students with accessible but challenging scenarios that force them to reconcile any conflicting aspect of their thinking. They are commonly described as guiding students to realize that their understanding needs revision and provides an accessible path for completing that revision into coherent understanding.

We then examined videos of these three different types of inquiry-based classrooms to extract commonalities and differences that collectively define how inquiry is operationalized in these classrooms. The Reformed Teaching Observation Protocol (RTOP) was employed to identify specific elements of a classroom that we felt were essential, or visually indicative of an inquiry classroom. The RTOP is designed to measure the degree to which classrooms have been aligned with science and mathematics reforms. In particular, the strong relationship between the items and various content and pedagogy standards outlined in documents such as the NSES (NRC, 1996) and the Benchmarks (AAAS, 1993) demonstrates the face validity of the RTOP (Sawada *et al.*, 2002). The RTOP lists twenty-five criteria under three subsections: lesson design and implementation; content and process knowledge; and classroom culture. We chose this instrument because we felt it framed our discussion of the behavior that should be observed in an inquiry classroom.

We identified a number of elements from the RTOP that were deemed “non-crucial” to an inquiry classroom. Most of these elements focus on the “best practice” of the instructor. While we do not mean to diminish the teacher's role within an inquiry classroom, we felt (based on Piaget’s and Vygotsky’s theoretical underpinnings of inquiry) that very often the success of inquiry instruction depends more on the behavior of students rather than the behavior of the instructor. In extreme cases, we feel an instructor need not be present, a unique identifier for certain “open inquiry” activities. Still, in the exemplar inquiry practices of our disciplines, the instructor plays a considerable part in the learning activity. Instructors are often expected to engage students in Socratic dialogue or ask questions to help train their thinking. In special cases instructors can guide a conversation based on their selection of groups to present. For instance, within IO-DE curriculum, students are asked to construct ideas within smaller groups and the instructor takes on the role of identifying certain groups who can present their work to the whole class in order to facilitate discussion.

We identified a few RTOP criteria that especially resonated with the exemplar inquiry practices of our disciplines. These criteria included student exploration prior to instructor presentations, students making predictions estimations and/or hypotheses and deriving means for testing them, students engaging in activities that involve assessment of procedures, and to what extent were

they reflective about how their thinking had changed. Essentially, these activities reflect common practice within a community of professionals within each of our disciplines.

Questions for Discussion

1. We have identified common theoretical underpinnings of exemplary inquiry instruction across our three disciplines (Karplus, Piaget, Vygotsky, etc.). Because of our somewhat limited scope (investigating only three instructional methodologies), have we bypassed any significant contributors to the understanding of teaching by inquiry in any of our disciplines?
2. Do our preliminary results (use of the RTOP with exemplary inquiry practices to uncover classroom behavior associated with inquiry) resonate in any way (good or bad) with this audience?
3. Is our methodology (use of the RTOP with exemplary inquiry practices to uncover classroom behavior associated with inquiry) appropriate for beginning to construct an assessment instrument for inquiry instruction across the STEM disciplines?

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