Critical Classroom Structures for Empowering Students to Participate in Science Discourse

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Abstract. We compared contextual characteristics that impacted the nature and substance of "summarizing discussions" in a physics and a chemistry classroom in an Hispanic-serving urban high school. Specifically, we evaluated structural components of curricula and classrooms necessary to develop a culture of critical inquiry. Using the Physics and Everyday Thinking (PET) curriculum in the physics course, we found that students demonstrated critical thinking, critical evaluation, and used laboratory evidence to support ideas in whole-class summarizing discussions. We then implemented a model similar to PET in the chemistry course. However, chemistry students' statements lacked evidence, opposition and critical evaluation, and required greater teacher facilitation. We hypothesize that the designed laboratories and the research basis of PET influenced the extent to which physics students verbalized substantive scientific thought, authentic appeals to evidence, and a sense of empowerment to participate in the classroom scientific community.

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INTRODUCTION

Critical thinking and scientific literacy are essential goals in high school science learning. To achieve these goals, students need to construct their understanding of concepts through the use of evidence and scientific models [1]. We are defining this type of learning environment as *critical inquiry*. In inquiry contexts that rely on student-generated evidence and structured discourse, students have demonstrated positive conceptual learning gains and views about how science knowledge is constructed [2].

Specifically, discourse involving articulating, challenging, and modifying scientific ideas has been shown to influence how students critically analyze problems and understand how science ideas are developed. [3]. It is through this critical analysis and careful opposition that students are able to evaluate the quality of arguments and modify their own scientific ideas [4, 5].

Examining student discourse can help educators determine characteristics of the inquiry classroom that may facilitate critical thinking and collective reasoning [6]. This study examined components of science instruction that influenced student participation in whole-class scientific discussions. We specifically evaluated how the nature of discussion questions influenced student ability to provide evidence-based explanations for their claims.

RESEARCH CONTEXT

This study took place in a small, primarily Hispanic-serving, urban public high school where 37 percent of students were identified as English language learners and 66 percent of students qualified for free and reduced lunch. We evaluated how post-laboratory discussion questions influenced whole-class discourse in two physics sections and two chemistry sections, taught by the same teacher (Belleau). Each section was comprised of approximately 22 11^{th} and 12^{th} grade students. The instructor facilitated guided inquiry instruction in each course, utilizing Physics and Everyday Thinking[1] and Active Chemistry[2] curricula.

Learning Sequences in Physics and Chemistry

Physics and Everyday Thinking (PET) is an NSF funded research-based curriculum originally designed for post-secondary, non-science majors. The PET inquiry investigations involve students following a specific learning sequence (Table 1): sharing their initial ideas, collecting and interpreting laboratory evidence, and answering summarizing questions to make inferences and gain conceptual understanding on the basis of observations [2]. Students engage in whole-class summarizing discussions to explain and defend their responses to the summarizing questions. In previous studies of PET implementation in the high

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[1] Goldberg, Robinson, Otero. New York: It's About Time: 2008.
[2] Freebury, Eisenkraft. New York: It's About Time: 2006.

school setting, high school students demonstrated conceptual understanding on the PET post-test that was comparable to university students, and the PET curriculum positively influenced student discourse in their ability to pose questions and oppose their peers' ideas using evidence [7].

Similar to the PET curriculum, Active Chemistry (AC) relies on laboratory-based investigations for students to learn chemistry concepts. In the intended Active Chemistry structure, students are first introduced to concepts in a laboratory activity. Concepts are then concretely explained in a reading (*ChemTalk)* and students respond to a series of content questions (*Chem to Go*).

We hoped that by introducing summarizing discussions to the Active Chemistry curriculum we would observe similar discourse patterns as with PET. We utilized questions directly from the Active Chemistry curriculum (*Chem to Go*) to guide these discussions. Refer to Table 1 for the learning sequences in the PET and Active Chemistry classes.

TABLE 1. PET and AC Learning Sequence

Sequence	**PET:** Intended and Enacted	**AC:** Intended	**AC:** Enacted
Prior Knowledge	Initial Ideas	n.a.	Questions from teacher
Laboratory	Collecting and Interpreting Evidence	Lab	Lab as AC Intended
Reading	n.a.	ChemTalk	ChemTalk
Discussion Questions	Summarizing Questions	Chem to Go Questions	Chem to Go Questions
Summarizing Discussion	Whole-class discussion	n.a.	Whole-class discussion

Summarizing Discussions

The goal of summarizing discussions was for students to establish an understanding of content while participating in evidence-based dialogue. The discussions were student-led and promoted active participation and student voice in the classroom [7]. Prior to each whole-class discussion, students individually responded to the discussion questions (frequently as a homework assignment) and then shared responses in small-groups. Each small group of students then crafted a response to one of the summarizing questions on a small white board, which they then used as a tool to facilitate that question during the class discussion.

Summarizing discussions involved three phases: (Phase 1) the facilitating group presented the question to the class; (Phase 2) students shared ideas until a consensus was reached (this was when additional questions were posed and opposition to claims or evidence arose); (Phase 3) the facilitating group shared their original thoughts and how the discussion helped them modify their ideas. Throughout the discussion, the primary role of the teacher was to ensure a safe learning environment and that the discussion was on-task. The teacher frequently asked guiding questions and offered support.

METHODOLOGY

Data Collection

Our goals were to implement the Active Chemistry curriculum with the same learning structure as PET so that we could examine how the nature of the discussion questions influenced argumentation in summarizing discussions. To evaluate these goals, we examined the questions that the PET and Active Chemistry curricula asked students following the laboratory investigations, and compared the nature of these questions to the discourse patterns we observed in the summarizing discussions.

In the physics course, the two activities we analyzed focused on forces and force diagrams. In these activities, students collected velocity-time data to analyze when forces were present on an object and how forces influenced motion. In chemistry, we analyzed an activity that focused on physical and chemical properties, and an activity that focused on behavior of electrons and the symbolic representation of atoms' atomic and mass numbers. We intentionally selected activities from October in order to provide discourse trends that accurately represented student engagement once they learned how to participate in summarizing discussions.

We analyzed student comments from video data recorded during the four previously mentioned summarizing discussions. We coded segments of discourse based upon the codes discussed in greater depth below.

Data Analysis

We examined argumentation patterns in summarizing discussions and the questions that guided these discussions (questions taken directly from the PET and Active Chemistry curricula).

I. Argumentation patterns in summarizing discussions: While students contributed numerous types of comments in the summarizing discussions, we focused on student content-based claims [8]. To examine the degree and nature of how students explained their claims, we classified these statements as being *supported* or *unsupported* (Table 2). Comments were classified as being supported if students provided rationale for their claims with (1) evidence from a class activity (often a lab); (2) a student-generated model; or (3) a definition or theory not developed by the student, but rather from a teacher or text.

TABLE 2. Content-Based Claim Subcodes and Examples

Support Provided			Unsupported
Evidence: From class activity or lab	**Model:** Student-generated	**Teacher/Text:** From the teacher or text	The claim was not supported with evidence
Example: "It was friction because the cart was going slower and slower."	Example: "It doesn't show a force arrow so the speed has to be constant."	Example: "Ions have a charge, isotopes have a different number of neutrons."	Example: "Pure hydrogen would be an element."

II. Summarizing discussion questions from PET and Active Chemistry texts: We coded summarizing questions as *concept-development* or *concept-reiteration* (Table 3). *Concept-development* questions asked students to establish their own ideas about a concept. Examples included students predicting experimental outcomes, making inferences from collected evidence, or creating a visual (including graphs or student-generated models) from observations. *Concept-reiteration* questions asked students to explain or apply a definition or a model that was not student generated.

TABLE 3. Summarizing Question Codes and Examples

Concept-Development	Concept-Reiteration
Asked students to generate an explanation of a concept based upon evidence	Asked students to explain or apply a definition or model that was not student generated
Examples: What criteria did you use to decide which materials were metals and which were nonmetals?	Examples: What is the difference between an isotope and an ion?

FINDINGS

We sought to explore how post-laboratory discussion questions from PET and Active Chemistry influenced whole-class argumentation patterns.

Finding I: Argumentation patterns were different in the PET and Active Chemistry classes:

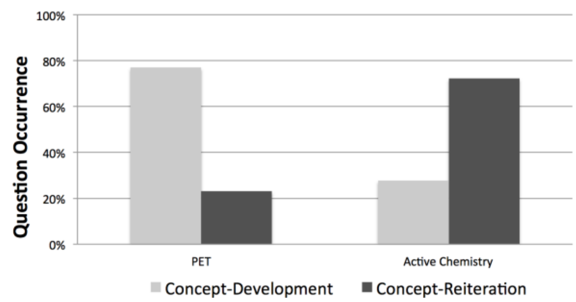
Despite the common learning structure in the PET and Active Chemistry courses, noticeable differences were found in the nature of whether and how students supported their claims in discussions. In physics discussions, only 12% of student claims were unsupported, whereas in chemistry 52% of student claims were made without providing any type of rationale. In physics, students defended 70% of their claims with laboratory evidence, but in chemistry, when students did provide support for a claim, it was most often (30%) in the form of a theory or definition that originated from the teacher or textbook (Table 4).

TABLE 4. Type of Support Provided for Claims

	Support Provided			Un-supported
	Evidence	Model	Teacher/ Text	
Physics	70%	15%	3%	12%
Chemistry	7%	11%	30%	52%

Finding II: Summarizing questions from the PET and Active Chemistry curricula are different: In the physics and chemistry curricula, the types of summarizing questions varied in the extent they were *concept-development* or *concept-reiteration* (Figure 1). In physics, 77% of the summarizing questions were *concept-development*, asking students to summarize, explain, or draw inferences from specific evidence collected in class. The 23% of questions that were *concept-reiteration* in physics involved students drawing force-diagrams; this was a skill built upon students' lab understanding that was explicitly introduced through a short reading. A majority (72%) of the chemistry summarizing questions were *concept-reiteration* questions: either relating to a specific skill (for example, classifying scenarios based upon definitions), or a text-provided model (such as symbolic representation for subatomic particles in the atom).

FIGURE 1. Summarizing Question Types



CONCLUSIONS AND IMPLICATIONS

Despite the similar learning structure in the physics and chemistry classes analyzed in this study, whether and how students supported their claims with evidence in whole-class discussions was markedly different. In chemistry discussions, students were less likely to provide explanations for their claims and when explanations were provided, they were more often directly from the *ChemTalk* reading or a theory taught by the instructor, rather than from laboratory evidence. Thus, laboratory evidence did not serve as a tool for students to construct understanding of chemistry concepts. By contrast, students in the physics class relied heavily on their laboratory evidence to support claims. In order to explain our findings, we attempted to understand how the types of questions asked in PET and Active Chemistry fit into the larger learning sequence and influenced these discourse patterns.

I. When questions are used as a tool for students to build an understanding of concepts from observations, students will be more likely to rely on evidence to make sense of scientific phenomena.

The research-based PET curriculum includes carefully written questions that require students to use evidence to make claims and build a conceptual understanding of physics [2, 7, 8]. We conclude that the *concept-development* questions in the PET discussion questions are appropriate for helping students make claims on the basis of their observations; as a result, students learn to rely on collected evidence to come to consensus in whole-class discussions about scientific ideas.

We suggest that the nature of the *Chem to Go* questions in Active Chemistry and the implementation of the *ChemTalk* reading discouraged students from relying on laboratory evidence to make sense of chemistry concepts. The *ChemTalk* reading presents chemistry theories and concepts in a didactic manner, and we observed students relying on the text to sanction knowledge instead of their laboratory evidence. This resulted in students responding to the *Chem to Go* questions using language and ideas that directly originated from the reading. To foster argumentation and a culture of critical inquiry, the *ChemTalk* reading should only be introduced once students have already constructed their own understanding; the reading will then serve as a way for students to compare their ideas to established scientific theories and models.

Additionally, evidence from this study indicates that the *Chem to Go* questions are not a sufficient tool for students to learn to make claims on the basis of evidence because they are primarily *concept-reiteration* questions. These questions need to be rewritten to help students make sense of their laboratory observations and defend claims with evidence.

II. In high-inference situations, an additional pedagogical tool may be needed for students to construct understanding from evidence.

Intentional scaffolds are needed for students to learn to support their claims with evidence [9]. Learning tools (including the laboratory activities and discussion questions) play a key role in helping students make sense of observed phenomena [10]. In the PET activities we studied, the PET summarizing questions were a sufficient tool to help students make inferences and construct claims from their laboratory observations, evidenced by the argumentation patterns in the physics classes.

However, a study conducted by Otero about cognitive processes and pedagogical tools suggests that in high-inference situations, such as molecular-model based reasoning about physical phenomena, laboratory evidence alone many not support students with developing scientific models and conceptual understanding [11]. In addition to laboratory evidence, a mediating pedagogical tool such as a graphic visualization that assists in the development and evaluation of self-constructed scientific models may be needed [11]. Because of the high level of inference involved in connecting macroscopic observations to the molecular and symbolic concepts in many of the Active Chemistry activities, we hypothesize that incorporating a mediating pedagogical tool in the form of a simulator or analogic model will help students construct claims from evidence.

In the future we plan to modify our implementation of Active Chemistry so that laboratory evidence is used to sanction knowledge and students are able to construct claims and engage in scientific dialogue. We plan to examine how the following changes will impact student argumentation: (1) implementing the *ChemTalk* reading following summarizing discussions, once concepts have already been developed by the students; (2) modifying the *Chem to Go* questions to serve as a tool to support student concept development on the basis of laboratory evidence; (3) in high-inference activities, incorporate mediating pedagogical tools to help students develop scientific concepts and models.

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