

Challenging Traditional Assumptions of Secondary Science through the PET Curriculum

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Abstract. This study seeks to illustrate aspects of a physics classroom experience in an underserved high school through the perspective of the students. This context was chosen with the intent of determining factors that lead to successful secondary physics education outcomes for populations historically underrepresented in STEM. Two class periods of physics were observed and interviewed in an urban high school while using the Physics and Everyday Thinking (PET) curriculum. Findings indicate that students came to value and positively identify with the activities of physics through instruction that fosters a more dignified student experience than traditional approaches. Specifically, this experience was characterized by the valuing of students' naïve and developing understandings and shifting the authority for validating science knowledge from the instructor to laboratory evidence and social consensus.

Keywords: Secondary, Underrepresented populations, Curriculum

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INTRODUCTION

STEM education outcomes in the U.S. are widely recognized as problematic. A variety of measures consistently point to the need for substantive reform in K-12 science education [1]. The racial achievement and participation gap persists despite the prolific rhetorical attention it has received [2]. These chronic problems compel us to re-conceive the fundamental assumptions upon which the dominant models of delivering science education rest.

Existing paradigms for science curriculum and instruction are founded upon assumptions about learning that may take a variety of implicit theoretical positions on the nature of knowledge, as well as the means by which that knowledge may propagate. Acquisition models of learning [3], in which knowledge may be both transmitted and received, have long been the dominant paradigm of curriculum development, delivery, and some areas of education research. Indeed, use of the term “delivery” here is an artifact of the acquisition paradigm.

Lines of education research and, increasingly, PER research have recognized the critical role of social interaction in the development of individual mental processes. Yet, one critical component of any human activity—*emotion*—continues to be largely absent from our models of learning. Sociocultural models draw attention to processes of socialization and enculturation into communities of shared practices, but have largely skirted the perhaps central factor affecting one's participation in any community: *one's sense of personal validation and belonging*.

Our research agenda takes a view of learning that is neither solely individual nor completely communal; one in which learning occurs as we participate in and come to identify with communities defined by the

valuing of certain practices. In the traditional classroom setting, valued practices are created and recreated through unchallenged social and historical doctrines associated with the institutions in which they are set. Such practices are maintained through an ongoing and largely implicit negotiation (or ignorance) of what practices and behaviors are acceptable and which are not. In our attempts to understand why certain populations of students remain largely alienated from physics, we are developing a model of learning that takes into account the need for personal validation, participation, and belonging. In this study, we are interested in how basic human dignity, as contrasted with self-preservation, is a necessary initial condition for experiencing learning. We posit that the more energy students subconsciously allocate to protecting themselves from undesirable social outcomes, such as being made to feel stupid for not knowing the physics, the less likely they are to engage the curriculum in meaningful and productive ways.

As a setting for our study, we selected a high school physics program in an underserved, urban community. This high school suffered from a lack of resources, and the physics teacher, a Noyce Master Teaching Fellow associated with our university, approached the second author in need of curriculum for her physics courses. The second author provided the PET curriculum and supporting materials to this teacher, who found it to be effective in engaging her students in physics. The first author, a former high school physics teacher, visited this classroom as part of his research assistantship and also found the level of student engagement and scientific argumentation to be atypically high, for any high school.

Although a variety of education research has begun to test specific factors that might lead to retention and achievement of groups traditionally underrepresented in physics and other fields, these studies frequently

assume (often on the basis of published rhetoric) the factors that are tested. We take a slightly different approach, whereby we identified a curriculum that appears to have positive impacts on student achievement and participation, and attempt to investigate this environment and extract the aspects that are critical for allowing students to behave as the smart, able, and curious people that they are. In this effort, we take a *critical* perspective and assume that most, if not all, educational contexts carry some degree of inequity and that this is unacceptable. High school physics is too often wrought with fear and failure rather than being a challenging experience that can be both enjoyable and empowering. We address the following research questions: (1) In what ways do the structures and enacted practices of the PET curriculum encourage students from historically underserved groups toward greater participation in classroom activities? and (2) How do students perceive the PET experience?

RESEARCH CONTEXT

The setting for this study is a small, urban high school with a high proportion of students from groups that are historically underserved and, therefore, under-represented in STEM. Approximately 70% of students at this school are eligible for free or reduced lunch, and demographic data for the sample are found in Table 1. The physics teacher involved in this study has implemented the PET curriculum twice in her high school classes, and this study took place during her second full-year of implementation.

The PET curriculum was originally designed as a one semester undergraduate physics course to help pre-service elementary teachers and other non-science majors learn basic physics concepts, develop positive attitudes about physics, and recognize the value of their own ideas in the learning process. PET has been studied extensively and has been shown to have measurable increases in understanding of physics concepts and student interest in science [4,5].

The PET curriculum engages students in a learning cycle that begins with the elicitation of their initial ideas about a physics concept. Students then collect and interpret laboratory evidence and engage in classroom discussions of this evidence to modify their ideas. These small and large group discussions, as well

as the sharing of initial ideas, make up a large proportion of the PET classroom activities. The PET learning cycle is iterative and designed to leverage laboratory evidence to move students toward more scientifically accurate conceptions. There is no textbook used for the course; students are expected to develop the main ideas on the basis of evidence and consensus. Select activities are also embedded in the curriculum to provide opportunities for metacognitive reflection upon students' own learning as well as reflection upon the relationship of the classroom activities to the work of practicing scientists.

METHODS

Data consisted of ~30 hours of video recordings of classroom activity, 16 individual interviews, and two focus group interviews of six high school students each. We used interpretive coding for these data, and three codes, which frame the findings discussed here, emerged: *ideas*—students articulating comfort in expressing ideas publicly; *role of ideas*—students recognizing the role of their ideas in the learning process; and *evidence*—students prioritizing evidence to support claims.

Four videos of classroom discussions were selected for analysis on the basis of productive talk. These videos include students presenting their initial ideas on a physics topic and whole-class summarizing discussions.

FINDINGS

We found that the students in this course: (1) stated that they became comfortable expressing their physics ideas and came to value having their ideas challenged, (2) expressed a metacognitive awareness of the role their ideas played in the learning process, and (3) came to value participating in a learning context of critical inquiry rooted in evidence-based skepticism. Fifteen students were interviewed in total, and the percentage of students that made statements leading to the above findings were 80%, 60%, and 80% for each finding, respectively. Here, we provide a small set of examples of students' statements in interviews and classroom conversations that led to these conclusions (S_n = student; R = researcher, [...] = dialogue skipped).

By the end of the course, students overwhelmingly agreed that they came to feel free to express their ideas in the PET classroom, though they were initially uncomfortable publicly sharing their ideas. When asked to reflect on how they had felt about having to voice their ideas, they responded:

S_1 : *I myself was like "Why?" Like I was just not used to the whole structure.*

S_3 : *Yeah, we were just kind of like, "Uh..."*

Table 1. Demographic Data for PET Implementation Sample

	Section 1 (n=24)	Section 2 (n=25)
Female	8 (33%)	13 (52%)
Male	16 (67%)	12 (48%)
African. Amer.	3 (13%)	---
Asian	1 (4%)	1 (4%)
Hispanic	10 (42%)	17 (68%)
Native Amer.	1 (4%)	---
White	9 (38%)	7 (28%)

S₂: *It sounded pretty bad.*

S₁: *I was thinking, "I want to switch classes."*

However, students grew to meet these expectations for public sharing and, when asked about the Initial Ideas activities later in the year, students responded:

S₂: *I think Initial Ideas are good because it gives—we get to see all the ideas that come to the table.*

S₁: *We all have like different background knowledge that are applicable that adds to our initial ideas.*

S₄: *And then like the reason I like the Initial Ideas is because like you could put pretty much whatever answer you want. It doesn't have to be right.*

These responses illustrate that these students' seemed to value expressing their ideas in a context in which they did not have to be correct right away. They also expressed more sophisticated views of the value of their ideas as an essential part of the learning process. They seemed to understand that the purpose of eliciting their initial ideas was so that they could modify their thinking toward more scientifically accurate ideas, as illustrated below.

S₅: *Science or physics is just different. Like you have your own thought and we always have to tweak our own thoughts, and it's different from any other class. Like history, you know what you are going to be learning about. Physics is you think of something and you have to tweak it.*

Over time students articulated that they could express their ideas and conclusions freely, without fear of being made to feel anxious or negative about themselves.

S₆: *I think it's really a part of physics. I have been wrong a lot in this class and it's not necessarily a bad thing because you learn from your mistakes.*

S₂: *I mean it doesn't matter if it's wrong.*

R: *Why not?*

S₁: *Because, Initial Ideas it's better if you're wrong. Because if you're right from the beginning, it's boring. You don't argue. You don't have a discussion.*

The excerpts above suggest that students enjoyed critiques. By stating that being right in the beginning is boring, S₁ shows how much she values argumentation. It is also evidenced below that a context was established in which critical discourse was valued.

S₄: *Like in the beginning maybe we were—maybe we were afraid that they'd judge us in what we thought. But we grew more and more each trimester to where we got comfortable around each other and just whatever you think that we know it's OK to think wrong, you know.*

S₂: *Yeah, I definitely agree because I didn't know my class and obviously if you don't know something you are not going to like to share your ideas and share how you thought something worked.*

S₁: *And you wouldn't like to like argue with them because you would think they would take it wrong. So*

we just grew with each other and realized it was right to argue with each other because we were all doing it to help each, other not just to make you look bad in the circle and stuff.

The conversation above illustrates that these students initially feared being wrong, were afraid of being judged, and initially did not feel comfortable sharing answers if they didn't "know." One student expressed fear that others would take critique the wrong way. However, these students came to trust each other and themselves as they became critical producers of knowledge. The culture of critical discourse that developed in this classroom was, by design, consistent with practices common in any productive learning context, such as the scientific community.

Below, we illustrate that these students also grew to be accountable to evidence-based reasoning. Evidence, rather than the teacher or textbook, became the authority. It is plausible that by replacing "authority" with evidence, students were able to allay their fears of being judged and develop an accurate understanding of what scientific argumentation is. When asked how disagreements over explanations are settled in the class, students offered statements such as:

S₁: *Like, what's your evidence? Your evidence then, like, "Well, I saw this"...like just telling them straight up "Prove it. Prove that you know."*

S₆: *It depends on how they use their evidence.*

S₃: *We used to be gullible before this class. We just took the information from the teacher and we were like, "OK, you're right, I guess."*

In the excerpts above, a student actually articulates that she used to be gullible. She had previously accepted what the teacher told her without even knowing that she could, and should, understand it and question it. We infer from this that she realized that she previously felt disempowered and came to reject the notion of accepting someone else's truth with no means for understanding it and no power to dispute it.

Students also developed skepticism toward one another's claims and they often challenged each other to produce evidence for their claims. In most cases, these disagreements were resolved through references to observations made during laboratory investigations, but at times these disputes were difficult to resolve. The following transcript excerpts are from a discussion of the angles of incidence and reflection of a light beam on a smooth, reflective surface. It is set within a disagreement among the students as to whether or not an observer placed at some distance along the normal will observe the incident light.

S₇: *So, what about if you weren't at the perfect angle of the light reflecting, would you still see the light?*

S₈: *For this specific one, I don't think you would.*

S₇: [Repeats question above]

S₈: *Because remember when we did the*

experiment...the side person wasn't at this angle (gestures to one side) so they didn't see anything. [...]

S₂: Well, I said, (reading from his paper) "assuming the source did hit the mirror at the right angle, D would be the only observer to see the light.

S₇: Anybody else got any different answers?

S₉: I said it would be the Observer C.

S₇: Aw, now we got a debate. Whoo!

S₉: It hit him right in the face, but everybody else would see a little bit of light on the side. [...]

R: Does that concur with what Rochelle brought from her experiment?

S₂: No, because we said that the other person wouldn't see the reflection. [...]

S₇: Maybe we should do it (the experiment) real fast.

The conversation above demonstrates the valued practices of evidence-based reasoning, skepticism and challenging. When S₇ realized that what other students said was inconsistent with experimental evidence, he suggested redoing the experiment, though this was not the next step in the activity. This reveals student agency to seek understanding regardless of the prescribed activity. This discussion was typical in that discourse was guided by accountability to evidence, logical reasoning, and other established norms marked by respectful disagreements and resolutions.

Not all disputes were easily resolved by evidence, and the productivity of each summarizing discussion was often affected by the difficulty of the physics concepts and discrepancies between interpretations of laboratory data. There are many challenges associated with engaging in scientific practices under the time constraints of schooling, and though student engagement in PET class activities was unusually high in our data, every student was not fully engaged every day. Also, some students tended to take more prominent roles in the classroom discussions, and typical imbalances in classroom participation were tempered but not eliminated in this context.

CONCLUSIONS AND IMPLICATIONS

The physics class that we described above represents a significant departure from the typical experience in high school physics. The authors themselves have taught high school physics courses and thought that we were serving our students well. In retrospect, our students remained fearful of being judged, uncomfortable expressing themselves, and engaged in the process of powerless acceptance of someone else's truth. The students in this study experienced science. A context was established that allowed them to take risks, to try to understand, to critique others, and to be critiqued. Our evidence suggests that these activities were quite naturally taken up and came to be valued simply because they felt

good, as they were set in a social context that respected who the students were as they came to take up and value practices that were new to them. We assert that these factors resulted in a more dignified experience than the typical physics classroom. These students, from groups historically underrepresented in science, together with the teacher and the curriculum, created a learning context through their voice and participation and came to positively identify with evidence-based reasoning and critical analysis.

Schooling in the U.S. has traditionally coerced students to be "knowers"—to find a way to regurgitate the answers that have already been found by others and that the teachers and texts hold as the authority. We have seen here that the relocation of the authority to sanction knowledge to reside with evidence and social consensus, rather than with teacher and text, can be one key element of an approach that, rather than coercing students to be "knowers," encourages them to be *learners*. This can empower them with the dispositions to be skeptics and, perhaps someday, producers of new knowledge. Our evidence also suggests that another key element of establishing a learning context is encouraging students to take risks, become fully engaged, and become agents on their own behalf; this is only possible if students are sufficiently free to express their ideas and to challenge others without fear of reprisal.

We believe that a prerequisite for the development of positive relations of the self to physics illustrated in this paper is a context in which students can participate relatively free of fear of being made to feel stupid or otherwise bad about themselves. Quite simply, we must be aware of and respect a learner's need for dignity. We believe this is missing from the physics experience of many students. If we can create a context in which students feel validated and that their ideas matter, they can feel a sense of connection and belonging to high school physics.

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