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Are Community Relevant PBL Supports enough to Promote Epistemic Agency? Exploring Variation in Epistemic Pedagogical Practices in Science Classrooms

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Abstract: Promoting epistemic agency using problem-based learning (PBL) in science curricula allows students to co-construct scientific knowledge and practices. However, researchers have revealed that teachers struggle to distribute epistemic authority inside classrooms. We use exploratory case studies of two biology teachers' adaptation of PBL units to explore the variation in pedagogical practices that influenced students' epistemic positioning. We analyzed classroom observation notes, teachers' interviews, and teachers' daily reflection notes to identify different instructional approaches. The findings suggest that teachers perceive the opportunities to activate epistemic agency within the same PBL curricula differently. Their pedagogical choices to leverage these opportunities depend on teachers' perception of the more important learning objectives and the structural limitations and affordances provided by the context of the classroom.

Introduction

There is growing interest to promote epistemic agency in science education (Haverly, Calabrese Barton, Schwarz, & Braaten, 2020; Miller, Manz, Russ, Stroupe, & Berland, 2018; Stroupe, Caballero, & White, 2018). Epistemic agency is the ability for students to engage as co-constructors of knowledge in science classrooms (Miller et al., 2018). When engaging as epistemic agents, students display ownership of the knowledge-building process and share the cognitive authority of directing science inquiry with teachers within classrooms (Hardy et al., 2018; Miller et al., 2018; Stroupe et al., 2018). Classrooms that engage students as epistemic agents, empower students to shape the knowledge production practices (Stroupe et al., 2018), thereby, transitioning students from "receiver of facts" to "doers of science" (Miller et al., 2018). Pedagogical practices that engage students as epistemic agents allow students to co-construct science storylines with their teachers and disrupt hierarchies of power in science education (Calabrese Barton & Tan, 2009; Hand, 2012; Rosebery, Warren & Tucker-Raymond, 2015). Epistemic positioning of students also propels a shift in instructional practices from those that engage students in mimicking "correct" canonical science information to adopting strategies that empower students to develop their own ideas (Hardy et al., 2018; Miller et al., 2018; Stroupe et al., 2018). This helps fulfill the larger need of engaging students in disciplinary practices as advocated by the Next Generation Science Standards (NGSS) (NRC, 2012).

However, despite the known advantages of student's epistemic positioning in science classrooms, current classroom practices and learning experiences often fail to promote epistemic agency (Miller et al., 2018; Brown, 2017). Most schools, especially within formal environments, struggle to engage students as epistemic agents (Eriksson & Lindberg, 2016). Supporting student's epistemic agency within science classrooms is a challenge for teachers because of the tensions that arise from maintaining authoritative control over the content while attempting to create authentic opportunities for students to engage with and construct knowledge that is meaningful to them (Braaten & Sheth, 2017; Windschitl, 2002). Teaching science using epistemic teaching practices disrupts traditional power structures within a class (Bang, Brown, Calabrese Barton, Rosebery, & Warren, 2017; Haverly et al., 2020). This kind of teaching requires different pedagogical strategies, to leverage students' ideas for an active knowledge production process within classrooms (Brown, 2017; Miller et al., 2018; Schwartz et al., 2018).

A few potential paths have been suggested to modify teacher instruction for students to act with epistemic agency in science classrooms (Stroupe et al., 2018). One of these paths include teachers adapting science curricula to intentionally allow their students more say over how the community engages in knowledge construction work using problem-based learning (PBL) (Miller et al., 2018; Stroup et al., 2018). PBL provides one avenue for repositioning learners as epistemic agents as it allows for collective responsibility of knowledge building through sharing of students' individual science stories (Stroupe et al., 2018; van Es, Hand, & Mercrado, 2017). It also provides multiple opportunities to shift the epistemic authority from the teacher, wherein power and authority traditionally lie, to the students (Miller et al., 2018; Stroupe, 2014). However, early studies have shown that teachers tend to identify these opportunities differently (Haverly et al., 2020). They often struggle with interpreting and leveraging pedagogical opportunities to engage students as epistemic agents (Barnhart & van Es, 2015; Jacobs, Lamb, & Philipp, 2010). Hence, there is a need to understand how teachers vary in interpreting pedagogical opportunities to position students as epistemic agents within the design of the PBL units (Haverly et al., 2020; Stroupe et al., 2018). Furthermore, there is a need to explore the factors that influence these decisions (Stroupe et al., 2018) in adapting PBL supports to formal science classrooms. To design professional development (PD) supports that scaffold teacher's epistemic instructional practices, we need to understand how teachers vary in their degree of engaging students as epistemic agents within the implementation of PBL units (Miller et al., 2018; Stroupe et al., 2018). In this paper, we explore how two science teachers improvise PBL units on the topic of bioinformatics that had students explore a problem relevant to their community, collect and analyze data from their neighborhood to make inferences about the topic, and propose interventions. We look closely at select movements where the teachers differed in providing opportunities for students to engage as epistemic agents. In this paper, we ask the following research questions: 1) How do teachers' pedagogical practices vary in engaging students as epistemic agents during the implementation of the PBL unit? and 2) What factors influence these decisions?

Conceptual framework

Over the years, researchers have found that students engage with epistemic agency when they contribute to the knowledge-building process while engaging in science practices such as argumentation and experimentation as opposed to replicating the practices modeled by the teacher (Haverly et al., 2020; Zimmerman & Weible, 2018). Also, recent science education studies have found that the learning environment for supporting epistemic agency should be contextualized in a way that values students' ideas as resources in producing useful knowledge in the curriculum (Stroupe, 2014; Stroupe et al., 2018). Miller et al., (2018) detail four opportunities to unpack epistemic agency within the NGSS and argue for these to be specified in the design of the lesson. These are; 1) opportunities to solicit and build on student knowledge as a resource for learning; 2) opportunities for students to build knowledge; 3) opportunities for students to build a knowledge product that is useful to them; and 4) opportunities to change structures that constrain and support action. We use this conceptualization to identify opportunities that existed within the bioinformatics PBL unit. Table 1 shows the definition of each of these pedagogical opportunities and provides examples of how these were incorporated into our PBL unit.

An important characteristic of science curricula that relates to epistemic practices in classrooms is the emphasis on student authority over what counts as knowledge within an activity (Erikson & Lindberg, 2016; Haverly et al., 2020). This kind of teaching requires teachers to notice students' "individual student histories" inside and outside of class (van Es et al., 2017, p. 266). Haverly et al. (2020) explains that teachers make space for students to co-construct knowledge when opportunities for meaningful student discourse and interactions are coupled with visible shifts in epistemic authority from teachers to students. Stroup et al. (2014) recommend an ambitious instructional model, where the cognitive authority of knowledge inside a science classroom is constantly negotiated by both students and teachers. In classrooms characterized by ambitious instruction, teachers give cognitive authority to students by involving students' inputs in framing an argument and evaluating the efficiency of methods employed by the teacher. In contrast, in a classroom setting where cognitive authority is not distributed, the teacher guides students to discover elements of knowledge that the teacher has decided as important. Similarly, Haverly (2020) conceptualizes science teaching across three degrees of distribution of epistemic authorities; (a) co-constructed practices where the teacher and students share epistemic authority, (b) teacher-constructed practices where the teacher maintains epistemic authority, or (c) student-constructed practices where epistemic authority shifts entirely to students.

Teachers make pedagogical decisions to intentionally share (i.e., co-construct) the epistemic authority with students using multiple instructional strategies such as, using "wait time" for students to reflect on their mistake before immediately fixing it with teacher instruction (Haverly et al., 2020) or using collaborative scaffolds that create opportunities for students to critically analyze responses of their peers (González-Howard & McNeill, 2020; Haverly et al., 2020). Another strategy is to use teacher prompts that elicit contradictory responses from students so that they can deliberate about the complexities of the topic among themselves (Haverly et al., 2020; Miller et al., 2014; Stroupe, 2014). Conversely, in classrooms that model teacher-centered pedagogical practices, the visible evidence of shared epistemic authority is minimal. Here, students may be invited to pedagogically share their experiences during the knowledge building process, however, these exchanges do not translate to sharing of epistemic authority as teachers reign control of the class by directly correcting students' mistakes and by using teacher-centered scaffolding such as modeling for students to enact the steps shown by the teacher (Schoerning, Hand, Shelley, & Therrien, 2015; Erikson & Lindberg, 2016). Evidence of student-constructed pedagogical practices, where the epistemic authority completely shifts to students, is limited within existing literature in formal science classrooms (Haverly et al., 2020; Stroupe, 2014). We us this conceptualization to analyze the variation in pedagogical practices adopted by the science teachers in implementing the PBL units.

Methodology
This study is part of a larger NSF-funded project on teacher PD that aimed at integrating scientific research on the topic of bioinformatics in high school science classrooms. In this paper, we conduct qualitative case studies of two science teachers who used different pedagogical approaches to implement the PBL curricula support distributed in PD.

Participants
We worked with two biology teachers, one female, and one male, who taught in different urban public schools in the Northeastern United States. Both teachers were volunteers. The first teacher, Sam, had 15 years of teaching experience, taught ninth-grade biology in a school where students were identified as 39% White, 29% Asian, 16% Black, 5% Hispanic, and 11% other. The second teacher Linda had two years of teaching experience, taught ninth-grade biology in a school where students were identified as 54% Black, 24% Hispanic, 12% Asian, 7% White, and 4% others. All students in both schools were eligible for free or reduced-price lunch (an indicator of income level in the United States). On the state standardized test, students scored 93% and 33% proficient or advanced in biology respectively from both schools.

Context
The bioinformatics PBL unit was anchored in a scientific inquiry to explore the issue of high asthma rates within urban communities. Students were provided with sensors and phones to measure air quality in different locations of their community and analyzed data patterns using Google Sheets and Microsoft Excel. Based on an analysis of collected data, students were asked to propose an intervention to address the air quality issue in their neighborhood. Table 1 provides an overview of the PBL activities and illustrates its alignment with Miller et al. (2018)'s epistemic opportunities. Teachers were given the agency to adapt these PBL units to align better with their individual teaching goals.

Table 1: Definition of Miller et al. (2018)'s epistemic agency opportunities and alignment with the PBL unit

Epistemic Opportunities	Definition	Examples of PBL Activities
Building on student knowledge as resources	Instructional approaches where students' community and culturally based intellectual resources are used for knowledge building.	- Anchoring the study of bioinformatics in the issue of asthma and air quality - a problem highly relevant in the city especially among students of color (Bryant-Stephens et al., 2012). - Group reflection of asthma cases within family and community.
Building knowledge	Instructional practices that position students to engage in the practices of scientists instead of typical roles as passive recipients of information.	- Students work with large online data sets to identify patterns and make inferences about air quality across years. - Students use mobile air quality sensors to collect and analyze data from areas around schools. Then they design proposals to analyze data around their neighborhood.
Building knowledge product that is useful to the student	Instructional practices that provide opportunities to engage in authentic problems in nature that are part of their experience, rather than trying to learn a fact or idea.	- Students identify areas of relevance in their neighborhood using the air quality sensor and app. Then, they draw conclusions about the air quality and its effects on one's community and propose interventions.
Changing structures that constrain and support action	Instructional practices that position students as change agents in the local and global structures that constrain and support tangible action.	- Students present and defend their intervention proposals.

Data source and analysis

We analyzed three data sources: Classroom observation notes; teachers' post-implementation interviews; and teachers' PD daily reflection notes. The classroom observation notes were used to identify the different instructional strategies employed by teachers in implementing the PBL unit. The post-implementation interviews and teacher reflection notes were used to understand the factors that influenced teachers' decision-making process with regard to engaging in practices that positioned students with epistemic authority. We used an exploratory case study methodology (Yin, 2017) to provide qualitatively rich descriptions of instructional practices and classroom implementations that enacted epistemic agency. The classroom observations were organized to group instances that were reflective of Miller's epistemic opportunities built into the curriculum. The data was then deductively coded to identify instances of teacher-constructed strategies, co-constructed strategies, and student-constructed strategies (Haverly et al., 2020). We did not find any instances of student-constructed pedagogical practices. The transcribed data sources were analyzed and triangulated qualitatively to identify themes that could be attributed to the decision and activation of epistemic agency. All analyses were discussed by the research team to validate the themes. Table 2 describes the coding scheme with examples from the data.

Table 2: Coding scheme and examples from the observation notes

Epistemic Opportunities	Instructional Variations in Positioning Students with Epistemic Authority
Anchoring bioinformatics in student's experiences with asthma.	**Teacher constructed strategies:** Class starts with a "do now" question (Do you know anyone who has asthma? What do you know about asthma?). Here, students are asked to agree or disagree with the statement and write down an explanation. The teacher shows a video on asthma giving students a few minutes to revise their statement if their viewpoint has changed and then, introduces the PBL scenario. **Co-constructed strategies:** The teacher elicits student dialogue about family instances of asthma and allows students to engage in conversations about ways in which it affects family health and routine. The teacher creates "affect" around the topic before introducing the line of inquiry of the PBL unit.
Students use mobile air quality sensors and Google Sheets to collect and analyze data from areas around schools.	**Teacher constructed strategies:** Students are asked to make a copy of the data and analyze them by calculating mean, median, and mode. The teacher breaks down these steps and demonstrates them one by one while waiting for students to follow the steps. **Co-constructed strategies:** Students start by looking at the data they collected and write down what they think. Sam explained the units for the particles. Then, showed two *t*-test videos and asked students how the t-test was going to be helpful for their project. Then, students try mean, median, mode, and t-test on the Car-Barn sites data in groups. For the students who completed getting a *t*-test value, they were guided to do a *t*-test with their indoor data. The teacher reminds students that they are researchers to encourage them to work with each other to resolve emerging questions.
Students identify areas of relevance in their neighborhood using the air quality sensor and app. Then, they draw conclusions about the air quality and its effects on one's community and propose interventions.	**Teacher constructed strategies:** Teacher explains the assessment criteria (informal rubric - Full sentences, check grammar; Two sentences for each question; 30 points in total). Teacher provides a sample data chart table on the writing board. Then, the teacher provided a template for how to do data comparison and describe data in sentences. She also explains what data students could compare with examples of Carbon Monoxide and Particulate Matter 2.5. **Co-constructed strategies:** Students analyzed data and discussed ways to help solve the problem of rising asthma rates in Philadelphia. Sam provided a Google Document template for writing the project report, at the same time he

	allowed students to make one of their own. Sam walked around each group to check how students are going to analyze data for their final report. Class ended with sharing what students observed so far and what were some things that students might have done differently with their data collection.

Result

The findings are organized into themes that illustrate how the two teachers differed in their implementation of the PBL activities, particularly in their distribution of cognitive authority within the PBL activity, and to explain the rationale behind these differences. In the next section, we explain how the two teachers differed in the instructional practices employed for the same PBL units.

Variation in teacher instructional practices: Teacher-centered versus distributed epistemic authority

Among the two teachers. Sam adapted the PBL in ways that allowed students to co-construct the science inquiry process by engaging in epistemic pedagogical practices. However, Linda struggled with sharing the cognitive authority of directing science inquiry with the students and instead relied heavily on teacher-centered strategies.

In the classroom that used co-constructed practices, Sam created multiple opportunities for students to take ownership of their science inquiry process. For example, Sam provided students with choices in selecting the context of data collection, setting investigation questions, framing final reports, and presenting their community solutions to the whole class. Throughout the implementation, Sam consistently referred to students' epistemic authority while encouraging student ownership. He also directed students to use their peers as resources when they ran into issues with the use of mobile sensors, and data analysis resources. He used collaborative scaffolding immensely during the data collection and analysis portion of the PBL. For instance, in the lesson where students engaged with online data sets to build inferences about the air quality data over different years. Sam had students freely explore the website and discover various elements of the site and share their observations with the whole class. He also gave students the freedom to choose the years they wanted to compare to infer varying data patterns. During the discussion, he asked students to critique the analysis each group presented. Throughout the activity, Sam kept reminding students of their agentic positioning by telling them that they were researchers of the project and hence should drive their own conclusions. Moreover, when students ran into issues with setting up mobile sensors for data collection and navigating the Google Sheets for recording and analyzing indoor collected data, Sam referred students to direct their questions to peers who showed proficiency for navigating these tools. In his interview, when referring to using collaborative scaffolds, he mentioned,

> I think the part where kids learned from each other went really well. The couple days where I spent going over stuff with Excel, they really taught each other most stuff and how to get through that quicker than if I did it your typical way, where I do the activity with an example and they model it as a whole class. They as a group were good at collaborating with each other. I prompted them to talk to one another when they were stuck. So, I think that part of it actually was one of maybe more the success stories.

Linda, however, struggled with distributing cognitive authority while adapting the PBL to meet the requirements of her class. Linda’s implementation employed teacher-centered practices where students were either enacting practices modeled to them or were engaging in discussions to get to an answer Linda had decided as the correct one. The classroom observations highlighted Linda's reliance on teacher-centered scaffolds to guide student learning during instances where the PBL lessons created opportunities for students to build knowledge. In implementing the same lesson referenced in Sam's class, Linda modeled the usage of the website that hosted the data sets in a step-by-step manner and had students enact the steps. She also asked students to compare data patterns of specific years. There was a limited choice given to students in selecting the years. As a result, there was limited variation among student responses as all students examined patterns of the same year. Also, when questions were raised about the nature of data or Google Sheets usage in the indoor data collection lesson, students directed their questions to Linda, and they were addressed through verbal exchanges between the teacher and the students. Linda emphasized the use of teacher’s scaffolds used in her lessons, in her post-implementation interview,

> My students don't know a lot of the basics in using Microsoft software, or Excel, or any Google applications. So, there was a lot of fundamental knowledge that I had to scaffold for all of the students. There are a couple here and there who just will shut down once they've struggled so much with trying to use Excel, or copy and paste data, or find the averages. So, it is better to guide all students to one or similar kinds of answers, otherwise, it gets confusing.

In Sam's adaptation of the PBL, he made pedagogical choices to engage students as epistemic agents by giving students more agency over tools, context, framing of results, and by giving students space to discuss and critique ideas. He leveraged collaborative scaffolds to guide the class towards the larger goals of the PBL. However, Linda's adaption of the PBL included less student choice and more teacher-centered scaffolds. While Linda provided space for children to share their experiences, these exchanges did not result in sharing epistemic authority with students as all students continued to refer to Linda to correct their interpretations or their science inquiry instead of referring to their peers or oneself as having the authority to direct one's learning.

Rationale for different instructional choices: Navigating around versus adhering to structural limitations

In co-constructed classrooms, Sam prioritized student engagement with content over canonical knowledge. Sam created opportunities for students to engage as epistemic agents while navigating around normative practices of formal classrooms such as limited instructional time and meeting grade-level learning standard requirements. This is because he felt students' engagement with the content mattered more than their ability to recall terms and definitions. When reflecting on the choice of design assignments, Sam stated in his interview,

> Yes, I felt a sense of urgency that I'm going to be behind with the other content that I need to teach in biology and I also don't know if students can actually remember the definitions but the fact that it was an inquiry activity and they got to choose what they were looking at was more important. Early in the unit when we were going over what asthma was, I was getting some real specific questions from students. They were telling me, "Well, this is what happens when my brother has asthma," or "This is what happens when I have an asthma attack." This project was very personal for my students, and it was unique to them.

Similarly, when reflecting on the effectiveness of the PBL implementation, Sam commented,

> I think they got a sense of some parts of the curriculum like the power of information or data, but I am not sure how well they will be able to define bioinformatics for instance. I also think different students hooked on to different parts, that is why I gave them a choice on the format of the final report as well. I think each student has distinct interpretations of the task.

The analysis of co-constructed pedagogical choices shows how Sam navigated through the structural barriers of formal classrooms by choosing to prioritize student engagement over content recall. However, these reflections reveal that Sam made choices about the tradeoffs that resulted from the use of epistemic practices in the classroom such as non-uniform understanding of the content, non-alignment of learning goals with standardized testing requirements, and extending the time allotted to the unit. These tradeoffs were not explicitly addressed in the PBL design. However, in the teacher-constructed classroom, Linda struggled with providing student agency with assessment and activities as she prioritized science content knowledge over engaging with students' individual or lived experiences. She felt her class would benefit more from a stronger focus on content knowledge as it prepared students better for their standardized testing requirements. She said,

> My head was very invested in reaching the goals for each benchmark, which are tests we have to take throughout the year to make sure students are learning the knowledge that's relevant for the Keystones. There's kind of the other side of it with educational research and project-based learning. Principals like those buzz words. They like to see that their students are active and doing things in the community, but at the same time, principals like for their Keystone scores to be high. While I can engage in dialogue with students, I need to ensure they all have the correct understanding of the terms.

While Sam was successful in navigating around normative structures of formal classrooms to engage students as epistemic agents with the PBL, Linda adhered to the structural demands of formal classrooms limiting students' epistemic agency. The PBL was not successful in helping Linda navigate around the tensions inherent to formal classroom instruction. This decision to navigate around or adhere to normative expectations may have been influenced by teachers' prior experience with science teaching or the urgency of standardized testing in the particular grade. Linda, when compared to Sam, was a novice science teacher with 2 years of experience as opposed to Sam who had 15 years of experience teaching science. Linda also implemented this unit in the 9th-grade science, where students were scheduled to take the state science exam in the same year. This was not the case for Sam as he taught in a magnet school that allowed his students leeway in participating in the science exam. These contextual factors may have given differential opportunities for making curricular choices.

Discussion

This paper contributes to the emerging literature on the use of contextual relevant PBL and its efficiency in supporting teachers' use of epistemic practices in science classrooms (González-Howard & McNeill, 2020; Ko & Krist, 2019; Stroupe et al., 2018). Our findings advance the existing understanding of how teachers adapt PBL supports differently to meet their classroom needs and in doing so enhance or compromise students' agentic positioning within science classrooms. Our analysis aligns with findings of other "sense-making" studies which showed that teachers predict and leverage epistemic opportunities within a curriculum differently (Haverly et al., 2020; Rosebury et al., 2015). Sam perceived the PBL topic of asthma to be of personal relevance to his students and hence identified opportunities within the curriculum to share the cognitive authority with his students and leveraged them. On the other hand, Linda perceived the PBL curriculum as a medium to prepare students for their state science exams through enactments of science inquiry practices. These varied perceptions of the PBL influenced the pedagogical choices of epistemic positioning of students, during the implementation.

Both teachers did not engage in student-constructed pedagogy where students participate in equitable sense-making practices. Sam did not cede epistemic authority entirely to his students, rather, he steered his student's conversations and interactions towards the broader learning goals of the PBL. However, he did position his students as people whose opinions and interpretations were worthy of being challenged by their peers, instead of positioning only his guidance and input as the voice of value which is a movement towards shifting cognitive authority and advancing students epistemic agency (González-Howard & McNeill, 2020; Haverly et al., 2020; Miller et al., 2014; Stroupe, 2014). Linda was successful in making room for her students to share their experiences but was not able to share the epistemic authority with her students as she often corrected students directly and asked students to enact the behavior, she was modeling. This reinforces the existing power dynamics of teachers being the owner of cognitive authority and limiting opportunities for students to engage as epistemic agents (Haverly et al., 2020; Miller et al., 2014).

Our paper highlights the tensions between the inherent free nature of open-ended PBL and the normative practices that drive teacher instruction in formal classrooms, which aligns with tensions hypothesized by Miller et al. (2014) and raised by Stroupe (2014). To support epistemic pedagogical practices in formal science classrooms, PD developers should explicitly address structural limitations and provide supports that illustrate or model how epistemic authority can be co-constructed within these limitations to encourage teachers to shift away from teacher-centered scaffolds while adopting PBL curricula to their classrooms.

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