The Creation of an Epistemically Authentic Learning Environment: Making Space for Epistemic Practices in High School Science Classrooms

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Abstract: With the rise in post-truth discourse, there is growing urgency to develop an informed understanding of the evolving nature of scientific knowledge through the teaching of epistemic practices (EPs) (i.e., practices scientists use to establish knowledge). Researchers recommend creating *epistemically authentic* environments to help meet this objective. However, creating such an environment requires teachers to make fundamental shifts in the way science is taught. Specifically, it requires highlighting the ambiguity inherent within the application of EPs and creating evaluation measures that communicate the socially negotiated nature of science. We have limited models examining how this goal can be accomplished inside formal classrooms. In this study, we examine how a teacher created an *epistemically authentic* environment using a curriculum designed to promote EPs. Our results show that the teacher was successful in creating this environment by distributing instructional authority, crowdsourcing parameters to evaluate EPs, and normalizing making wrong predictions.

Introduction

Increase in post-truth discourse has resulted in citizens questioning the validity of science and scientific methods (Hobbs, 2017; Peters, 2017). Citizens' skepticism about the nature of scientific knowledge is particularly relevant among topics such as climate change, evolution, and vaccination, where the information evolves based on emerging evidence (Chinn et al., 2021; Hobbs, 2017). Researchers recommend the integration of epistemic practices (EPs) into K-12 science classrooms to help with this reasoning gap among the public (Barzilai & Chinn, 2020; Muis et al., 2016). EPs are domain-specific processes that scientists use–such as peer review, systematic experimental design, and collecting ample evidence–to negotiate, debate, and establish knowledge across fields such as science and mathematics (Barzilai & Chinn, 2020; Sandoval et al., 2016). A deeper understanding of EPs is likely to help students understand the nature of scientific knowledge, as a construct that changes over time and one which is socially negotiated among scientists instead of as an absolute and static construct (Sandoval, 2016; Ford, 2008). However, current high school instructional structures lack an explicit focus on EPs as a primary goal of instruction (Chinn et al., 2021). Additionally, most instructional models inside schools lack the messiness of scientific information found in the real world where multiple claims are made with evidence that appears convincing (Sandoval, 2016; Ford, 2008).

Researchers recommend creating *epistemically authentic* environments inside classrooms to teach EPs (Chinn et al., 2021; Muis et al., 2016). These are classrooms designed to intentionally narrow the gap between environments found inside and outside classrooms - by engaging students with information that vary in claims, authorship, quality, and reliability of methods used. The premise is that engaging students in the ambiguity involved in the processes of *how to know* instead of processes of *what to know* - through these environments - will promote students' understanding of the nature of scientific knowledge. However, creating such environments requires a significant shift in how disciplines such as science are taught in schools. For example, from a content perspective, it requires selecting portions of science curricula that can communicate the epistemological underpinnings of scientific knowledge as fluid and changing rather than binary and static (Muis et al., 2016). With respect to pedagogy, this requires teachers to create an inquiry environment where students negotiate EPs as being good or bad, mirroring the real-world practice of peer review and the socially negotiated nature of knowledge (Chinn et al., 2021). Additionally, this environment also requires assessments that evaluate the EPs students use and additional supports that help students through negative emotional experiences that may be triggered by navigating ambiguity inside classrooms that usually direct them toward the right answer (Muis et al., 2016). In sum, this requires creating a classroom climate where ambiguity inherent in using EPs is emphasized and evaluated as opposed to a climate that focuses on content-driven instruction (Muis et al, 2016). However, important components of *epistemically authentic* environments, such as pedagogical choice, evaluation structures, and instructional supports, continue to be under-examined (Chinn et al., 2021; Muis et al., 2016). This limits our scope to understand the nuances teachers navigate to create such environments and consequently, limits the field in providing teachers with the support they need to teach EPs effectively.

Over the last couple of years, our work based on design-based research has focused on promoting EPs in science classrooms to address post-truth issues. In our previous analysis, we found that the teaching of EPs is difficult for science teachers to integrate into their existing curriculum (Cottone et al., 2022). So, in our third year of this research, we designed a curriculum unit on epidemics where the primary objective was for students to engage with EPs to understand the nature of scientific knowledge, using an agent-based simulation. In this paper, we investigate the ways in which one teacher created an *epistemically authentic* environment using this curriculum. We ask the following research questions: (1) In what ways did the teacher create an *epistemically authentic* environment? and (2) What strategies did the teacher use to promote an understanding of EPs?

Theoretical framework

There are different conceptual recommendations for creating *epistemically authentic* environments (Chinn et al., 2021; Muis et al., 2016). In this paper, we use the **PACES** framework (Muis et al., 2016) to conceptualize *epistemically authentic* environments. This framework provides a way to analyze multiple salient elements of a learning environment required to create a climate focused on EPs inside classrooms. The framework details five facets of a learning environment that should be intentionally designed to teach EPs. We use these facets to analyze the classroom environment created by the teacher. They are: 1) **P**edagogy: studies show that the use of social constructivist pedagogies, where the nature of inquiry is emergent and there are opportunities for students to engage in the knowledge building process actively - is more likely to engage students with EPs (Stroupe, 2014). Here the focus of the inquiry is on engaging students with epistemological underpinnings of scientific knowledge. Additionally, honing in on opportunities that highlight the ambiguity or paradox inherent within the use of EPs is likely to promote an informed understanding of scientific knowledge (Chinn et al., 2021), 2) **A**uthority: this examines the degree to which the instructional authority is distributed inside a classroom. In an optimally designed *epistemically authentic* environment, the source and justification of knowledge from an expert (e.g., teacher) are decentralized. Teachers will create opportunities for students to actively engage and lead the knowledge building processes by legitimizing the criteria and negotiations students engage in to establish knowledge inside the classroom (Miller et al., 2018). Some emerging literature references this as epistemic agency (Miller et al., 2018; Stroupe, 2014), for clarity we choose to reference this as authority, 3) **C**urriculum: refers to any instructional content, and resources used to achieve the educational objective of promoting students' understanding of EPs. Refutational texts, content that explicitly focuses on scientific methods (e.g., the iterative process of experimentation, systematic planning of experiments, socially negotiating consensus), and prompts that elicit conversations about the tentative nature of knowledge are recommended as more conducive to creating an *epistemically authentic* environment (Muis et al., 2016), 4) **E**valuation: refers to ways in which students understanding of EPs is measured. Complex, less structured, or more challenging tasks that elicit mental processes (e.g., knowledge elaboration, integration of new knowledge into prior knowledge, and critical thinking) are more aligned with the goals of promoting EPs. As opposed to tasks that are simple, overly structured, and require content recall and match processes, and 5) **S**upport is any scaffolding that teachers provide to facilitate the change process in students, such as explicit modeling of critical thinking or resolution strategies opportunities for students to discuss their beliefs or acknowledgment of the negative emotional experiences that students may face during epistemic change (Muis et al., 2016).

A well-designed *epistemically authentic* environment will result in the explicit talk about EPs that lends itself to establishing an informed understanding of scientific knowledge. In such an environment, students are most likely to engage in the EPs scientists use to establish reliable and valid knowledge. This will include, designing controlled experiments, running multiple trials, testing for multiple hypotheses, and socially negotiating the criteria to evaluate EPs. We use this framework to code for interactions that occurred inside the classroom to make inferences about the degree to which the epi*stemically authentic* environment the teacher created was successful in promoting an informed understanding of scientific knowledge.

Methodology

Context

This study is part of a larger NSF-funded project that aims at designing professional development (PD) supports to promote EPs in high school science classrooms (Cottone et al., 2020). This study explores the implementation of an epidemic curriculum designed to teach EPs. Students use an agent-based simulation to design and run experiments to propose the most ideal mitigation factor to control the pandemic. This issue was chosen because it allowed teachers to draw from their recent experiences of navigating COVID-19 and the publicly contested nature of facts about the pandemic. This is a curriculum that consists of eight lessons designed for 45 minutes each. Students engaged with *"The Epidemic Unit"* while working in groups of 2-5 as they played the role of scientists trying to control an outbreak by running experiments and gathering data to find which mitigation strategies (e.g., masking, vaccination, lockdown, and surface cleaning) they would recommend as the most effective for controlling the spread of the disease. Students start by coming up with class criteria for evaluating scientific evidence and experimental designs. In the following lessons, they collect data and engage in productive disagreements about the validity of methods used across groups to come up with recommendations. In this paper, we examine the last two out of the eight lessons. These two lessons were selected because of the rich discussion we observed unfolding regarding EPs during the implementation. In the first lesson, students were asked to provide feedback on the experimental designs proposed by their peers to investigate the mitigation strategies and revise their respective designs based on the critique received. In the second lesson, students executed their experimental designs and presented their findings. The lessons were implemented in a public school in the Northeast U.S.

Participants

We used a case study methodology which requires researchers to purposefully select information-rich cases, to gain an in-depth understanding of relevant and critical issues under investigation (Yin, 2017). Therefore, we investigated one of the teachers who participated in the PD, Nafisa, and her class implementation of the curriculum. She identified herself as African American and was in her 22nd year of teaching, with previous experience teaching biology, and environmental science, all at the high school level. She taught the unit across two weeks with a section that had 25 students in her environmental class. Students in this class identified as 54% Latino/a, 24% Black, 12% Asian, 7% White, and 4% other.

Data source and analysis

We analyzed three data sources: Videos of the two classroom implementations which included whole-class instruction and small group discussion among students (90 mins), teachers' post-implementation interviews (90 mins), and classroom observation notes. The observation notes included descriptions of the classroom conditions, teachers' instructional practices, and the activities and interactions among students taking place. The semi-structured post-implementation interview was conducted to probe the teacher's specific practices, beliefs, and understanding of implementing the new curricula, as well as the teacher's experience of preparing the class and participating in the project. These two data sources were primarily used to answer the first research question on the nature of the *epistemically authentic* environment the teacher created in the classroom.

Data analysis was qualitative in nature, informed by constant comparative method (Glaser, 2008). There were three interacting phases of data analysis: a) applied open coding to classroom implementation videos, b) used a priori codes informed by **PACES** framework to code for interactions that spoke to **P**edagogy, **A**uthority, **E**valuation, and **S**upport constructs during whole class interaction. The **C**urriculum was conceptualized as the two lessons from the larger *"The Epidemic Unit"*. This included the agent-based simulation students used to design and run their experiments and teacher and student-facing worksheets. The other constructs (**P**edagogy, **A**uthority, **E**valuation, and **S**upport) were coded from teachers' implementation of this lesson (refer to Table 1) and c) thematic analysis and triangulating data. The first phases of data analysis focused on developing a coding scheme. The coding scheme was initially informed by the **PACES**, and later by emergent themes from the data. The coding scheme was debated and iteratively revised until a consensus was reached between the two authors. We each coded a sample of data using the final coding scheme and identified areas of disagreement and refined the coding process over time. Refer to Table 1 for the coding manual used and the excerpt of instructional episodes coded.

Table 1
Coding scheme and examples of instructional episodes that were coded for the lesson where students were asked to provide feedback to the experimental designs proposed by their peers

Codes	Description of Codes	Examples of Instructional Episodes
Pedagogy	Opportunities where the teacher explicitly highlights the ambiguity in *ways of knowing*, presents varying interpretations, and highlights the importance of the justification process through valid evidence, and/or highlights the iterative	The teacher highlighted the ambiguity that the public felt on the dissemination of COVID-19 vaccine information when explaining the iterative nature of scientific knowledge, "So how many people remember that conversation initially? Like if you got COVID-19 and you took the vaccine, you won't get COVID-19 […]. Then there were some people

	process of how knowledge is established in science.	like me like, I'm not taking that, how sure are you of the data?"
Authority	Moments where the teacher reinforces the legitimacy of students' role as active decision-makers by positioning them as scientists capable of driving the decision-making process in class, and by encouraging students to set their own aims for investigation.	The teacher encouraged students to select the critique they want to work on just as scientists do when engaging with feedback received from peers, "I mean you are two brilliant scientists who received feedback from fellow scientists, you don't have to ask me which to pay attention to, decide which feedback is most useful in strengthening your experiment."
Evaluation	Instances when students are exposed to the assessment criteria, and the teachers explicitly link those criteria to facets of knowledge and knowing.	The teacher highlighted that the way to evaluate students' work is to refer to the list of scientific practices students negotiated as good EPs at the beginning of the unit. "Be explicit about the evidence in terms of the data, this is what you set as a class as good way to do science. [...] We need some facts. We need to know that you're just not saying this mitigation factor works because this is what you want. Instead, show some proof that this might work. Okay?"
Support	Teachers help students through negative emotional experiences of being wrong by normalizing those experiences.	The teacher signaled it is okay to get data that negate their initial predictions, positioning this as a practice scientists do in the real world by saying, "All scientists have a plan, okay? And sometimes their plan changes. So, I want you to take that into consideration.? So, you don't have to prove your hypothesis is right, focus on the evidence you see."

Result

In this section, we present the analysis of PACES categories and our coding of how an *epistemically authentic* learning environment was created in Nafisa's classroom. We aim to provide illustrations of the main themes that emerged and how these themes connected to the teacher's attempt to provide an informed understanding of the nature of scientific knowledge.

Pedagogy: Navigating ambiguity with EPs and historical narratives

In implementing the curriculum, Nafisa honed in on opportunities to highlight the ambiguity and uncertainty inherent within the EPs used by scientists to investigate emerging processes and establish scientific knowledge. She used students' lived experiences with COVID-19 to explicitly focus on the ambiguity that resulted among the public, from not understanding the iterative nature of scientific knowledge. For example, she mentioned in her post-implementation interview, "So, I asked the students about the vaccine and how scientists, you know, came up with a vaccine and they first said it won't give you COVID but then people who got the vaccine started getting sick, so were the scientists lying?"

Nafisa navigated these ambiguities by asking students to reflect on the nature of evidence (e.g., did they have a control group? how many times did they run the experiment? Did they test multiple hypotheses?) when confronted with conflicting results or claims when running their respective experiments. For example, the observation notes highlighted that when two groups designed their investigation on a common mitigation strategy (e.g., masking) but found that their experiments resulted in opposing claims of the effectiveness of the strategy. Nafisa asked the two groups to examine their EPs, she noted,

> You need to make sure that your process in which you're carrying out your plan is one that will not be biased toward what you think is right, as you carry out the processes you'll be able to get enough evidence to either prove your hypothesis correct or find something that needs to change [..] Did both of you use the same control design - I see that you (Group A) tested masking with a vaccine and (Group B) tested with social distancing. Now, look closer did you both run the same number of trials [..] "

In the above example, Nafisa draws students' attention to the iterative nature of scientific knowledge by mentioning that the goal of EPs is to improve our understanding of a concept or product as new or opposing evidence emerges. She references EPs as ‘processes’ and points out that these are in place to ensure scientists do not advance knowledge that they are biased to thinking is right, it is in place to avoid confirmation bias.

Nafisa also used examples of incidents in the history of science, where the knowledge changed over time as the field progressed to gather more evidence and began to think about the problem differently. When setting the context for students to critique each other's EPs, she used the example of how vaccination for chickenpox was developed and linked it to the development of vaccination for COVID -19.

> Before you were born, the only way to get over chicken pox was to get it. It took time for scientists to test and retest until they figured from the people who had the disease the antibodies required to fight it and create a vaccine from it. Same with COVID [..] They are still figuring it out. But that's okay! because in science, nothing is necessarily a hundred percent because there are new developments.

In the above examples, Nafisa used historical narratives to communicate that scientific knowledge is never absolute. It changes in the face of new evidence. She communicates that EPs make the processes reliable for a certain period and that they are in place to ensure that biased perspectives or one person's agenda are not used to establish knowledge. She tackled ambiguity by using examples that normalized the iterative nature of scientific knowledge and by redirecting students' attention to critically examine the EPs used by scientists to make the claims.

Authority: Providing student choice while retaining invisible authority on EPs

Nafisa created opportunities for students to actively engage and lead the knowledge building processes by legitimizing the criteria and negotiations students engaged in to evaluate EPs inside the classroom. She ceded her authority as the bearer of the ‘correct’ knowledge, by verbally using sentences that positioned students as scientists and thereby communicating their capacity to actively drive the decision-making process within their small groups. For example, when a group of students asked which mitigation factor they should investigate, Nafisa responded, “You can choose any two mitigation factors of your choice, but you need to tell me why! And how will you investigate it? You are scientists so tell me how these factors will help you generate multiple hypotheses?” In this quote, Nafisa emphasizes that they have the agency to investigate the mitigation factor of their choice. She instead redirects their attention to justify the rationale behind the choices they make and to focus on explaining why they made certain decisions around EPs such as running a certain number of trials, and the nature of the control group. By doing so she dissolves her authority as the figure whose criteria need to be met.

Interestingly, while she ceded most of the authority on decisions made about the selection of mitigation factors, the trials to run, and the control group to be selected. She retained authority on the broader criteria of the EPs that should be met to design a good scientific experiment. For example, when setting the context for experimental design, she mentioned that every group should meet the criteria of EPs they negotiated earlier as a class as good practices such as having two hypotheses, running multiple trials, and recording their methods. She noted, “Remember, you have two different hypotheses and that means for each hypothesis you're going to have two different plans [...] but remember, this is your plan and we're going to carry out your plan. And you can always change.” In this quote, Nafisa reiterates that students have the choice to design and change the experiments they saw fit while emphasizing that these choices should be negotiated within the broader EPs that were socially negotiated as the best practices to follow in class. Similarly, in another video of classroom implementation, she communicated that while students are being asked to critique their peer’s designs, she has already graded their designs but made these invisible because she does not want to influence students' opinions about their peer's designs. She said,

> [M]any times scientists receive feedback from their colleagues throughout the process because they have to eliminate bias, okay? So it's not what you think or what you feel, but based on data [...] I didn't put a grade because I don't want to influence your critique of your classmate's design.

The above examples show that the teacher ceded authority in terms of choice in designing individual experiments but retained an invisible authority on whether the broad parameters of EPs that the class had negotiated as good practices were being retained or violated. She justified the maintaining of invisible authority as a way to communicate that while science is subjective (e.g., it is shaped by scientists' choice of the question to pursue, and methods to study) this negotiation occurs within a larger realm of what scientists have established as good EPs or measures to study processes, in her post-interview. She positioned EPs as the authority to defer to instead of her as the teacher or the more knowledgeable one in the classroom.

Curriculum: Focusing on ways of knowing instead of what to know

Nafisa created an *epistemically authentic* environment using a curriculum that explicitly focused on EPs. The learning objective of the unit was on understanding *ways of knowing* scientists use, by engaging with EPs rather than finding the one correct mitigation strategy that could resolve the epidemic students were investigating. The teacher noted in her post-implementation interview that the primary focus of the curriculum remained on the process of evaluating good scientific experiments from bad ones.

> Unlike the lab experiments we run, where students usually just follow a manual imitating scientific practices. I see students actually engaging with scientific practices in this unit because we are not focusing on the content, but on the skill of how scientific knowledge is established […] like changing and tweaking their predictions and using the class criteria of good practices to evaluate their decisions.

In the above excerpt, Nafisa points out this curriculum stood apart from other traditionally used practice-based curricula such as lab experiments because students weren't following a prescribed standard of instructions for emulating EPs. Instead, students were actively making predictions and revising them based on the evidence they collected from the simulation. Additionally, Nafisa pointed out that not having access to which of the mitigation factors was most effective in tackling the pandemic that students were investigating, helped keep the focus of instruction on the EPs. In her post-implementation interview she noted,

> I didn't know the answer myself. The curriculum did not tell me if vaccination or masking or distancing was the most effective. So, I guess there wasn't an answer I could accidentally nudge students towards. When students asked me questions, I would ask them to find their answers in the methods they were using.

The above excerpt indicates that the explicit focus of the curriculum on EPs allowed Nafisa to retain her students' attention on EPs and the nature of scientific knowledge. Not having a predetermined right answer ordained by the curriculum helped Nafisa retain the focus on EPs instead of scaffolding students to design experiments to get the predetermined right answer.

Evaluation: Using socially negotiated criteria for assessing EPs

Nafisa crowdsourced the criteria for evaluating EPs from her students and she used this class criteria recurrently for students to evaluate their own designs and critique their peers' designs. She had students at the beginning of the unit brainstorm and negotiate a list of EPs they considered to be parameters of a well-designed scientific experiment. This included parameters such as reporting the number of trials as an attempt to communicate all evidence collected, designing experiments that tested multiple hypotheses to prevent confirmation bias, etc., These were displayed on the google slides throughout the lessons - especially during the time when students were asked to critique others designs and revise their own. In one of the videos of classroom implementation, when the students asked Nafisa to check their experimental designs to see if they are doing them right, she pointed to the slide that had the class criteria on good scientific experiments and told the students that "The answer does not lie with me. Check if your design meets the criteria you set as a class, [...] look at the critique you got from your peers. Go talk to them and ask if it looks okay to them."

On another occasion, she prefaced the need for students to collect and record the evidence they were referring to make the arguments about the effectiveness of their chosen mitigation strategy. She guided students to take screenshots of their trials from the simulation and record them on their final poster so that other scientists can make sure that they are not making up data to prove their hypothesis correct. The teacher told the whole class, "Remember, you cannot convince people without even running an experiment because [...] We need some facts. We need to know that you're just not saying this is what I want to do, but you have some proof that this might work." Nafisa's implementation of the curriculum used evaluative strategies that were socially negotiated within the class, which dissolved any impression that the right answer lay with the teacher. This allowed an environment where students were more deeply engaged with EPs than attempting to find the answer that the teacher thought was right. She also connected this practice of referencing a socially negotiated list of practices to evaluate EPs to the real-world practice of peer review used by scientists. She mentioned that scientists critique other scientists on the EPs used to establish knowledge. When setting the context for peer critique she gave the following instruction.

> So, what you have at your tables, are your list of good scientific practices. You may use them to help you determine if they are carrying out good scientific practices [...] because scientists

> always give each other advice, right? Scientists do not work alone. So other scientists in class are going to see your plan and give you some advice or suggestions. They will critique to improve your design. They use the criteria we all agreed on are good practices in this class.

In the above examples, Nafisa communicates that the criteria of evaluation are the EPs that students used to design their experiment, and the parameter for evaluating if these EPs are 'good' or 'bad' is by repeatedly referring to criteria the class had negotiated as signs of a good experiment. She communicates to students that the process of peer review is in place to prevent biases and that scientists do not work in isolation. This communicates the socially negotiated nature of scientific knowledge. That scientific knowledge is generated within a larger culture, the norms of which are upheld by the scientists through the process of constantly critiquing emerging research by evaluating the EPs used by other scientists.

Support: Normalizing making wrong predictions

Nafisa helped students navigate negative emotional experiences of being wrong or being lost while engaging with ambiguities by normalizing these experiences. She used real-world examples of scientists changing their claims based on new evidence and reiterated that the process of proving predictions wrong is a way of ensuring EPs are not violated by scientists. For example, where students appeared frustrated on getting their predictions about their chosen mitigation strategy, masking, wrong. The teacher told the group,

> All scientists have a plan, okay? And sometimes their plan changes. So, I want you to take that into consideration. [J]ust to give you an idea, initially, when the vaccine was introduced? How many people do you think they tested it on before introducing it, and how many times did they run those tests?

On another occasion, when setting the context for students to provide feedback on each other's findings. She mentioned that the focus should not be on if the group's prediction came true, it should be on how they investigated their mitigation factors and made sense of the data. She reiterated that it is okay if the group's findings demonstrated that their data proved their respective hypothesis wrong.

> So what you're going to do today is we are actually going to give each other feedback. We're gonna be honest because it's always a good practice to notice if you or others as scientists did not get something correct, it's how you do good science.

In the above examples, Nafisa creates an environment for students to feel okay with being *wrong* about their predictions or hypotheses. She normalized the process of making the *wrong* predictions with personal narratives that normalized the idea that scientists change their claims based on evidence they see, which eased students' frustration of finding and reporting data that did not align with their hypothesis.

Discussion

This paper contributes to the recent calls to investigate curricula that teach EPs in formal classrooms, specifically the supports that result in the creation of *epistemically authentic* environments in science classrooms (Chinn et al., 2021; 2020; Muis et al., 2016). Our findings affirm assumptions that attending to multiple salient features of an environment such as curriculum, assessment, and evaluation concurrently and intentionally directing them to emulate EPs scientists do in the real world is an effective way to create an *epistemically authentic* environment. We found that a curriculum that explicitly focused on EPs where students actively engaged in a scientific investigation where outcomes were emergent and not predetermined facilitated the creation of an *epistemically authentic* environment. The epidemic unit Nafisa used did not focus on students' ability to find the right mitigation factor. There was not one right answer the teacher could guide students to, therefore the focus of instruction remained on the EPs scientists use to establish knowledge (e.g., designing systematically controlled experiments, socially negotiating the validity of claims through peer review, and revising predictions based on evidence). Our findings provide empirical evidence to advance the existing hypothesis that engaging students in curricula where teachers explicitly highlight ambiguity and engage students with paradoxical perspectives of the ways in which scientific knowledge is established (Chinn et al., 2020; Muis et al., 2016) - is an effective way to engage students with EPs in science classrooms.

Our findings suggest the importance of attending to distributed instructional authority in the classroom when creating an epistemically authentic learning environment. Our findings align with previous research (Author et al., 2020; Stroupe, 2014) that indicates providing students with authority to negotiate the knowledge building process that occurs in classrooms can successfully afford students to engage with EPs. Nafisa consistently redirected questions about the "correctness" of students' experimental design to the class criteria of good EPs the students had negotiated early on in class. She used the socially negotiated EPs as the evaluation criteria to consult - she did so by ceding authority to students to provide critiques and recommendations to each other's designs but by retaining an invisible authority on the border parameters of EPs. Our findings also reveal that instructional supports are necessary to address students' emotional reactions when engaging with e*pistemically authentic* environments. Previous research recommended teachers to explicitly model resolution strategies or provide real-world examples that normalize the negative emotions students may associate with getting their predictions wrong (Muis et al., 2015). In our study, Nafisa provided emotional support in the form of linking the ambiguity students experienced to lived experiences with COVID-19. She repeatedly emphasized how scientists conduct experiments to find the truth and not necessarily to prove their predictions right, students in the class felt comfortable reporting their methods even when they nullified their predictions. Previous research has shown that students struggle to engage with this complexity of normalizing "wrong predictions" (Cottone et al., 2022). This indicates that emotional support can help students grapple with the tension they may experience when pursuing directional goals (i.e., goals that promote more inquiry) instead of accuracy goals (i.e., goals of finding the right answer) when creating an *epistemically authentic* environment. Future research will examine how this environment resulted in improving students' epistemic performance in class.

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