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Analyzing Teacher Epistemic Moves in Science Classrooms

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Abstract: Science education needs to be transformed to meet the needs of the current "post-truth" era. One way to face these challenges is for science educators to promote apt epistemic performance in classrooms. In this paper, we use Barzilai & Chinn's (2018) Apt-AIR framework to analyze teacher instructional moves as they work to encourage apt epistemic performance in their science classrooms. Findings present a portrait of teacher moves directed at epistemic performance. Specifically, we highlight teacher epistemic moves that emerged from our analysis. We discuss trends in teachers' moves and implications of these for improving classroom epistemic discourse, and we discuss the potential to develop epistemic routines that coordinate productive sequences of moves. We conclude with the affordances and implications of our analysis for science education.

Introduction and theoretical background

As science denialism and the spread of misinformation become ever more rampant (Cooke, 2018), there is a widespread rejection of well-justified scientific consensus on matters such as COVID- 19, vaccination safety, and climate change. Current science education has failed to meet the growing challenges of this "post truth" world (Chinn et al., 2021). Thus, there is an urgent need for teachers to develop and implement instructional strategies that enable students to accurately appraise scientific information (Barzilai & Chinn, 2018; Chinn et al., 2020; Duncan et al., 2018). One way to address these concerns is to develop science instruction to promote *apt epistemic performance* that can extend to thinking about scientific issues outside of school (Chinn et al., 2020; Gorman & Gorman, 2021; Hussain-Abidi, et al., 2022).

Apt epistemic performance is successful epistemic performance (e.g., developing a good understanding of climate change) achieved through competence (e.g., skillful appraisal of scientific expert consensus on the topic and consideration of the many lines of supporting evidence) (Barzilai & Chinn, 2018). Apt epistemic performance is further unpacked along two dimensions that define the *Apt-AIR framework* (Barzilai & Chinn, 2018). The first dimension specifies three components of epistemic thinking: (a) Aims, or goals (e.g., aiming to reach an accurate conclusion), (b) Ideals, or standards for evaluating whether an aim has been achieved (e.g., fit with relevant evidence and the consensus of experts as ideals for determining whether an accurate conclusion has been reached), and (c) Reliable processes (RPs) that are used to achieve the aims with a good likelihood of success (e.g., evaluating multiple sources of information, evaluating the expertise of sources, determining the degree of scientific consensus, and so on). Current science education has often not explicitly addressed all these components (see Chinn et al., 2021, for arguments). Therefore, there is a need to support students' development and use of appropriate aims, ideals, and reliable processes to evaluate scientific information.

The second dimension of apt epistemic performance in the Apt-AIR framework consists of five aspects of engagement with aims, ideals, and processes (Barzilai & Chinn, 2018). These include a *cognitive* aspect, involving the use of reliable cognitive processes to achieve valuable epistemic aims that meet appropriate ideals (e.g., testing a toy car to determine how it works and ensuring that the resulting explanation fits the evidence gathered); a *metacognitive* aspect, encompassing metacognitive skills and metacognitive understanding of appropriate aims, ideals, and reliable processes (e.g., reflecting on what the best methods are for testing the car to see how it works); a *social* aspect, including working effectively with others along with an awareness of the role of social processes in producing knowledge (e.g., working in groups, receiving and responding to critiques from others, and using these critiques to improve one's explanation); a *caring* aspect, which involves positive affect and dispositions towards pursuing and achieving apt epistemic performance (e.g., being deeply committed to making sure the explanations fit the evidence); and an *adaptive* aspect, which includes adjusting aims, ideals, and reliable processes to meet the demands of diverse contexts (e.g., considering how the best investigative methods might differ between trying to figure out how a toaster works, and trying to figure out how a toy car works).

The crossing of the 3 components and the 5 aspects of Apt-AIR yields 15 cells in a 3x5 table; apt epistemic performance involves coordinating adept engagement across all of these cells (see Table 2). For science instruction to successfully promote students' apt epistemic performance, instruction needs to encourage adept engagement in all 15 cells. One way to encourage such engagement is through *teacher epistemic moves* in classroom discourse, which we define as discourse-based moves that aim to support apt epistemic performance in students. To do this, teachers might call attention to, or prompt engagement with the components and aspects of Apt-AIR. This raises the question of how often teachers *do* employ moves that engage students with each of the components and aspects, as well as what kinds of moves they make. The purpose of this study is to investigate these questions. To facilitate this, we have performed an initial analysis of teacher moves using the 3x5 Apt-AIR framework.

Recent scholarship has made great progress in developing frameworks for categorizing teacher moves in different contexts, including within discourse-based science instruction (e.g., Soysal & Yilmaz-Tuzun, 2021; Wei et. al., 2018). We consider our approach as complementary to this work. What distinguishes our approach is that we have organized our analysis around a comprehensive evaluation of apt epistemic performance. Accordingly, our goal is to develop a portrait of a range of teacher epistemic moves when there is a focus on student apt epistemic performance.

More specifically, the objective of this study is to examine the variety of teacher epistemic moves employed by three high school science teachers in order to analyze how they encourage apt epistemic performance. Understanding how these teachers implement a unit focused on epistemic performance in science classrooms allows us to identify excellent practices as well as to spot areas in which improvement is possible. This in turn will ensure that students learn to engage with all of the aspects and components needed to achieve apt epistemic performance. Thus, in this preliminary analysis, we seek investigate: (1) How often do teachers address each aspect and component of apt epistemic performance? (2) What kinds of teacher epistemic moves do teachers use to address each aspect and component of apt epistemic performance? (3) What particular aims, ideals, and processes do teachers address? (4) How do teachers use sequences of epistemic moves to promote apt epistemic performance?

Method

Context

In July 2022, researchers and teachers collaborated to create an inquiry unit focusing on epidemics and the nature of science, largely within the context of a fictional viral outbreak. This unit was created with a deliberate focus on developing apt epistemic performance incorporating all five aspects discussed above. The epidemic unit featured a game-like, agent-based epidemic simulation that combines graphical blocks-based StarLogo programming with a 3-D game-like interface (see Figure 1) (Yoon et al., 2016; 2017). Students engaged with the epidemic unit while working in groups of 2-5 as they tried to control an outbreak by running experiments and gathering data in order to find which mitigation strategies they would recommend for their town in the simulation. Although the unit was constructed to span eight class periods, teachers tended to run the unit over four to six periods to fit scheduling and curriculum constraints.

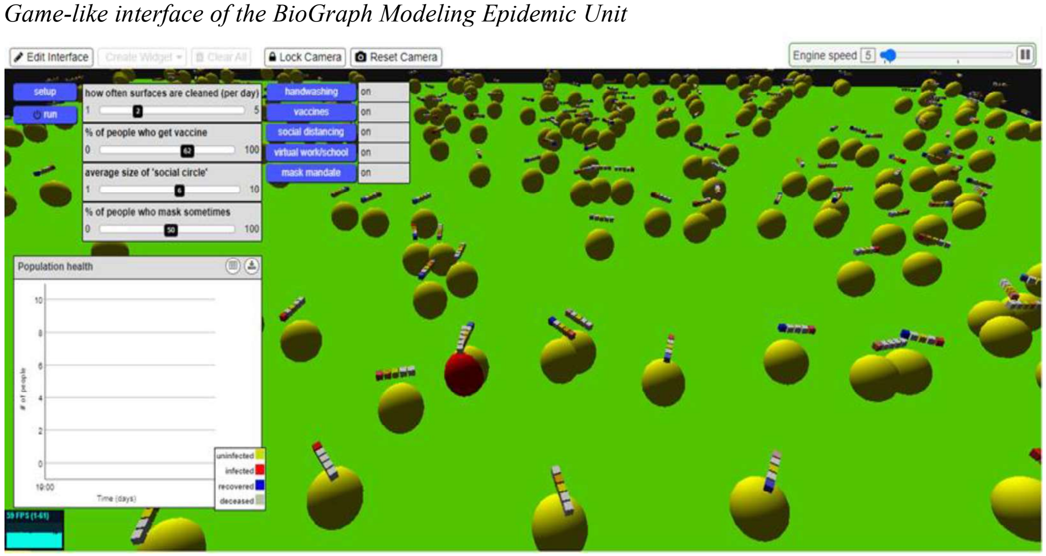
For the present study, a particularly important characteristic of this unit is the focus on teacher epistemic moves. The unit aimed to accomplish this by including activities that directly focus on aims, ideals, and reliable processes across the five aspects of apt epistemic performance. Further, teacher reminders called "epistemic callouts" were embedded within the teacher guide of the unit to remind teachers of opportunities within the lessons to highlight apt epistemic performance. Examples of activities within the unit include co-creating class criteria of the characteristics of good scientific models and practices (metacognitive engagement with ideals), peer review and iterative revision of student models (reliable social processes), and reflection on applications of classroom activities to science practices encountered out of school (adaptive engagement with aims, ideals, and processes). An example of an epistemic callout while students peer reviewed models is a reminder to encourage students to justify why particular criteria are important (metacognitive/caring engagement with ideals) and explain why particular criteria are or are not found in different models that they looked at (metacognitive/adaptive engagement with ideals).

Participants

In order to develop a preliminary method of analysis, we started with three of the five high school science teachers who taught the epidemic unit. We selected these teachers due to their rather different pedagogical styles, allowing the method of analysis to be tested on a wider array of styles. Two of the teachers, whom we call Catherine and Aaliyah, taught ninth grade biology. The third teacher, whom we call Rohini, taught tenth grade chemistry.

Catherine taught at a private boarding school, Aaliyah taught at a charter school in an urban district, and Rohini taught at a public high school in a suburban district. All schools were in the northeastern United States. All teachers spent time during summer professional development familiarizing themselves with the curriculum and the simulation (see Figure 1).

Figure 1
Game-like interface of the BioGraph Modeling Epidemic Unit



Data sources and analysis

Implementations of the unit were recorded through Zoom meetings, which were active through the teachers' computers during their in-person classes. From these recordings, we analyzed the teacher epistemic moves that were employed in the classroom and classified these moves within the 3x5 Apt-AIR framework. That is, as shown in Table 2, we examined whether teacher moves addressed aims, ideals, and/or reliable processes within each of the five aspects (cognitive, metacognitive, social, caring, and adaptive). In Table 1, we show four general types of moves used by teachers when addressing aims, ideals, and/or reliable processes, which were determined through bottom-up and top-down coding methods during data analysis.

Table 1
Types of teacher epistemic moves used to promote epistemic performance

Type	Definition	Examples
Describe	The teacher directly describes or explains an epistemic aim, ideal, or process	"One way that scientists can test something is by running multiple trials."
Label	The teacher attributes value or clarity to an epistemic aim, ideal, or process	"It's better to say 'make accurate measurements' instead of just 'make measurements'."
Justify	The teacher provides a reason or argument for an epistemic aim, ideal, or process, sometimes justifying it with another aim, ideal, or process	"They need to run multiple trials because there can be variation in each trial, and error in each measurement."
Prompt	The teacher prompts students to use, describe, evaluate, or justify an epistemic aim, ideal, or process.	"What are some good processes to follow to make sure that we test things thoroughly?"

Results

In Table 2, we present the Apt-AIR framework, along with the specific teacher epistemic moves that are being described. We also include examples of teacher epistemic moves for 13 of the 15 cells (we found no instances of teacher moves addressing the adaptivity of aims or ideals). Note that most teacher moves can be coded into multiple aspects. For example, "Let's put together a list of criteria for good scientific models" is a statement about an epistemic aim that is both social (collaboration with peers) and metacognitive (planning and evaluating epistemic performance).

Table 2
Examples of teacher epistemic moves analyzed within the Apt-AIR framework

	Aims	**Ideals**	**Reliable processes**
Cognitive	Describing **cognitive aims**	Describing **cognitive ideals**	Prompting justification of **reliable cognitive processes**
	"And so you're going to **make a model** that is going to explain how **the cars** work."	"So, this is an example of a model that a student has for their car to see how it works, right? **That explains their car's internal mechanisms** to determine how this car is working. Okay? And then, in addition to that, they have an explanation."	"The sugar pill didn't do anything. So, let's talk about that sugar pill, does anyone know why **they would give them a sugar pill**? That's not just a random detail, that's something scientists do."
Metacognitive	Describing **metacognitive aims**	Prompting description of **metacognitive ideals**	Describing and labeling **unreliable metacognitive processes**
	"So your goal with your partner or your group, are to now **come up with one characteristic of good scientific methods** with your partner, and referencing part two of the homework if needed, initial your idea with both of your initials, and try not to repeat something that's already written."	"Alright, so, I want us to think about what would be some great criteria for our, for a model. So, thinking about what you have actually reviewed, right? Let us come up with **a list that we all agree upon that would be great criteria**."	"Now sometimes when we write a prediction, we become very biased in collecting the data, because we only look in one direction. We have to prove our hypothesis, **let's just cherry-pick the data that we like, and let's write it down**. And let's say it proves our hypothesis. We tend to do that, it's very common, but that is incorrect science."
Social	Labeling **social aims**	Justifying **social ideals**	Describing and prompting justification of **reliable social processes**
	"Why do we need to critique each other's work?" [student says, "So that everyone can improve?"] "**So that everyone can improve**. What else could be the reason?" [student says, "So we can get other people's perspectives?"] "Why is it important for us to know other people's thoughts and perspectives?"	"We are trying to read what is written, we don't go around and explain our process. I should not be hearing, oh, this is how you should be reading my process, or my step-by-step procedure that is written there. No. We don't get to do that in real science. When someone publishes it we get to read their thought process. That's why **it has to make sense to everyone**."	"You are critiquing, nothing personal is happening here. It's what we do in science, we **critique each other's work**. Why is it needed in science? Why do we need to **critique each other's work**?"
Caring	Labeling and describing **caring aims**	Prompting justification of **caring ideals**	Justifying reliable metacognitive processes with a **reliable caring process**
	"Very good, very good, if we're not **following good scientific methods**, we	"Why do we need to critique each other's work?" [student says, "So that everyone can	"Even if you're like our prediction was totally wrong, I want you to still put it here,

	might give out false information, and then	improve?"] "So that everyone can improve. What else could	because **it's important for us to see where we started**."
	someone will start believing the false information."	be the reason?" [student says "So we can get other people's perspectives?"] "Why is it **important for us to know** other people's thoughts and perspectives?"	
Adaptivity			Describing and justifying **reliable adaptive processes**
			"So when we just did our model, the car, you couldn't take the car apart. Because **scientists can't always take something apart** in order to determine if something is working. **Scientists have to, sometimes, test things out**. Because, can you take a cell apart?" [inaudible response] "Why?" [inaudible response] "It's too small, it's microscopic."

From this initial analysis, several trends stand out that highlight some of the affordances provided by the use of our Apt-AIR 3x5 analysis, which we discuss below.

Identifying coverage of components and aspects

The analysis readily points to components, aspects, and their intersections that are addressed more frequently, less frequently, or not at all. For example, we found a very small number of teacher epistemic moves addressing the aspect of caring, and even fewer moves addressing adaptive engagement. In contrast, there were more moves that involved engagement with the cognitive, metacognitive, and social aspects. Indeed, we found no moves addressing adaptive engagement with aims or ideals. What follows are some examples of prompts that teachers could conceivably use to ask students to engage adaptively with aims or ideals in the epidemic unit:

Example of adapting an aim: "How do you think that our goals relate to what the goals of scientists studying COVID are?"

Example of adapting an ideal: "Are there situations when a smaller sample would be OK?"

The aspect of adaptivity may be especially important in encouraging students to connect what they are doing in class with the scientific issues they encounter out of school. Teachers could encourage students, for example, to contrast the processes they are using to conduct research (e.g., careful control of variables within their simulation environment) to what scientists do (e.g., controlling variables in real-world research settings).

Identifying patterns of moves across components and aspects

The analysis also enables us to observe patterns of the types of teacher epistemic moves used across and within cells. For example, although there were many epistemic moves that addressed aims (typically, teachers described the epistemic aim of the activity), there were very few that explicitly prompted students to evaluate their quality (is this aim a valuable one?) or to justify them (why should we try to accomplish this aim?).

Furthermore, there were few justifications or prompts for justifications of metacognitive aims, ideals, and processes outside of the activities in which classes developed lists of criteria for good models or good methods. When students give justifications, they are providing reasons for why the aims or ideals they are advocating are valuable, and why the processes are reliable. These justifications help the students understand the aims, ideals, and processes, as well as to care about their use. For example, a prompt asking students whether evidence is good or not (evaluation) and to explain why (justification) supports them in developing an understanding of what counts as good evidence and why good evidence is valuable.

In addition to identifying significant trends in how teachers' epistemic moves contributed to students' thinking across the five aspects of engagement with aims, ideals, and processes, our classification provides insights into longer sequences of teachers' interactions with students. We provide examples below.

Identifying particular aims, ideals, and processes

A third affordance of the Apt-AIR analysis is that it enables educators to identify the particular aims, ideals, and processes that are the focus of discussion. It is possible then to consider whether these are productive components to focus on, whether alternatives might be better to introduce, or whether some might be problematized. For instance, in one of the examples in Table 2, a teacher asks, "Why do we need to critique each other's work?" This prompt asks students to justify the value of critiquing in science, which could help students appreciate the role of the process of critique. Critique in science is a core reliable process that is well worth pursuing. On the other hand, the teacher's remark "we are trying to read what was written; we don't go around and explain our process" describes a process of scientific communication that relies exclusively on written work. This is not compatible with what is known about scientific communication, in which interpersonal and other oral interactions are often important for scientists to understand each other's work (Collins, 2014). Rather than endorsing the process of relying on written documents alone, teachers might consider problematizing this process in discussions with students, perhaps considering a fuller range of scientific communication.

The Apt-AIR analysis thus enables us to provide, for any teacher at any time, a portrait of the particular aims, ideals, and processes that are the focus of the community's work, as well as how those components shift over time. This analysis then allows teachers and analysts to reflect on which aims, ideals, and processes are currently the focus, and whether it might be good to consider alternatives.

Sequences of teachers' epistemic moves

Our analysis also provides a lens to examine sequences of teachers' epistemic moves, and how well these are orchestrated to promote better student thinking. Teachers could use productive sequences of discourse repeatedly to promote advances in students' thinking—we refer to such sequences as *epistemic routines*.

In the analyses below, we discuss epistemic routines used by two teachers, Catherine and Rohini, as they led their students' in generating criteria lists for good scientific methods. In presenting these moves, we highlight their classification in terms of our Apt-AIR analysis and note what insights are provided by this analysis.

Catherine starts this activity by pointing the students to open a shared slide in Google Slides on their computers, where each student can see and edit the text on the slide at the same time. The slide has eight blank lines where students can type in responses. Around the classroom, students are seated in small groups of two to three each. Catherine asks that each group of students come up with one characteristic of a good scientific method, or in other words, a criterion that a scientific method should have to meet in order to be considered to be good. She asks each group to type their characteristic into the shared slide, and to make sure that the characteristic they enter is not the same as another groups. Catherine also mentions that, after all of the groups have entered a characteristic, she will ask each group one at a time to clarify the meaning of what they typed and to provide justifications of why they chose that characteristic. What follows is an excerpt from this clarification process.

- "So, first group, having measurable evidence without having to worry about people's opinions, can you tell me a little bit about why you put that?" *Catherine first describes a metacognitive ideal by restating the characteristic that the first group of students typed. This is metacognitive since the characteristic is a criterion for evaluating, and possibly planning, other cognitive or metacognitive performances (scientific methods). Catherine then prompts the students to justify this metacognitive ideal.*
- [student says, "How you measure your evidence is also part of how you support your hypothesis or the claim you're making, and while if you use that evidence people's opinion might not really matter, you still have to deal with it because sometimes if people are fighting it still effects things."] "Mmm. Ok. So can you give an example using our drug experiment of what measurable evidence would be, and what not measurable evidence would be?" *After the justification, Catherine responds by labeling the clarity of the student's metacognitive ideal, though only partially. She then prompts the student to further justify their metacognitive ideal with an additional metacognitive ideal (what makes evidence measurable).*
- [student says, "Like their fevers?"] "Ok, so like, a numerical, your fever is 101. And what's non-numerical evidence? Or like vague evidence?" *Catherine again responds by labeling the student's metacognitive ideal (though this time it is a different ideal), and then follows up by repeating the second part of her previous prompt for justification.*
- [student says, "Some person saying they feel better."] "Ok so I'll agree with that, so having measurable evidence, I'm going to add a little bit, like a fever measurement versus just "I feel better." Because that

kind of gets away from people's opinions, right? So maybe if I'm in the hospital I don't feel better, I still feel bad even if objectively, I'm healthier." *This time, Catherine responds by labeling the value of the student's metacognitive ideal, and further describes that ideal herself before moving on to the next group.*

This excerpt shows a relatively simple epistemic routine that may be useful for expanding students' responses and getting a clearer picture of the student's metacognitive understanding. The routine takes the following form: (1) the teacher prompts for a description of metacognitive ideals (2) a student describes an ideal, and the teacher prompts for justification of the same metacognitive ideal (3) the student justifies, and the teacher labels the clarity of the student's justification before prompting for justification of the same metacognitive ideal with an example of other metacognitive ideals (4) the student justifies with an example, and the teacher endorses the value of the student's metacognitive ideals, and further describes those ideals before moving on.

Rohini begins the activity by opening a slide that is projected to the front of the room. The slide has multiple empty lines, and she describes to the students that they are going to make a class list of good scientific methods. She then immediately prompts the class for what they think one good method would be. Below is the fourth time she prompts this during the activity.

- "Okay, moving on to four, yes?" *Her statement here of "moving on to four" serves as a prompt for a description of metacognitive ideals, as it is a continuation of her initial prompt for such descriptions.*
- [student says, "A control group?"] "A control group. Why do we need a control group?" *Rohini gives an implied label of some amount of clarity of the metacognitive ideal when she restates the student's response. She then prompts for a justification of that metacognitive ideal.*
- [student says, "You need something to compare it to?"] "Okay, we need to include comparisons. Very good." *Restating the student's response, Rohini then labels the correctness of the metacognitive ideal.*

This excerpt shows a routine similar to, but simpler than Catherine's. The structure of this routine is: (1) the teacher prompts for a description of metacognitive ideals (2) the student describes, then the teacher labels the clarity of the student's description of a metacognitive ideal and prompts for justification of the same metacognitive ideal (3) the student justifies, and then the teacher labels the correctness of the justification before moving on.

Something seen in both teachers' routines is evaluation of the value of the student's response at the end, which could lower students' agency and personal investment in the class list. This is especially the case with Rohini's routine, where the assertion of correctness likely directs the students away from further discourse, and towards searching for an answer deemed to be correct. One benefit of our analysis could be the identification of how and when teachers evaluate student responses, and how these routines may affect student outcomes compared to routines that lead the class to evaluate ideals themselves. Otherwise, these two routines are mostly centered around a single component—students' description of metacognitive ideals. However, as Catherine's routine shows, additional components (aims, ideals, reliable processes) can be brought in, and maybe also additional aspects (cognitive, social, etc.) as suggested by some entries in Table 2 (see the example for social aims). Being able to analyze how such sequences of moves shift between the cells of Apt-AIR allows for comparison between the usage of different sequences and student outcomes, enabling the identification and creation of robust routines that can best promote a full coverage of apt epistemic performance.

Discussion

The results of this preliminary analysis present a new way of analyzing teacher moves that aims to promote students' thinking. The Apt-AIR 3x5 analysis yielded a portrait of the range of teacher epistemic moves that were used by the three teachers as they taught a lesson designed to foster apt epistemic performance. Below we discuss our four main findings to date and the affordances of each.

1. Teacher epistemic moves provided little to no coverage of some aspects and components. There were no examples of epistemic moves addressing the adaptivity of aims or ideals. Furthermore, there were relatively few examples of moves addressing the caring aspect. This finding has implications for teachers and researchers for strengthening curriculum to address these aspects and components.
2. There are opportunities to strengthen teacher epistemic moves across the components and aspects. Teachers overemphasized description of aims, ideals, and reliable processes in each of the five aspects, yet rarely pushed for justifications of the described components. Encouraging students to describe, label, and justify aims, ideals, and processes would also increase students' epistemic agency when conducting science inquiry, because students can develop their own sense of which aims, ideals, and processes are valuable and build their own understanding of why they are valuable.
3. This analysis provides a portrait of the aims, ideals, and processes science educators thought were most important to discuss during this unit. This allows teachers and researchers to step back and consider

whether the emphasized aims, ideals, and processes are the most productive ones to focus on. They can also consider whether these aims, ideals, and processes appropriately reflect the practices of science.

4. Lastly, our analysis highlights patterns of epistemic moves that could be developed into epistemic routines. Epistemic routines are a series of teacher epistemic moves that teachers are able to embed in their instruction to target apt epistemic performance. For example, teachers can make soliciting feedback from peers an epistemic routine in the classroom, using it every time students engage in science inquiry.

Ultimately, our findings can help researchers and educators identify how teachers can engage in productive discourse with students to improve their scientific thinking during classroom inquiry and beyond. For example, if students are taught to value gathering ample evidence as a well-justified ideal of science reasoning, we expect them to gather ample evidence as they make sense of socioscientific issues in the public sphere. The analysis identifies particular components and aspects that teachers can address with students, and where further growth might be needed for educators to better prepare students to engage in apt epistemic performance. The analysis also identifies areas in which the moves themselves could be enriched beyond describing, labeling, justifying, and prompting in order to advance students' thinking to better prepare them for reasoning in the post-truth world.

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