High School Science Education in a "Post-truth" Society: Confronting Confirmation Bias with Students and Teachers

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Abstract: Incorporating the goals of a comprehensive epistemic education into K12 curricula is increasingly critical. In this study, we worked with high school biology students and teachers to evaluate how to enact strategies to counter confirmation bias while engaging in scientific modeling. We used a video-cued method in interviews with participants and then applied the AIR model to analyze responses. Findings show that most could identify biased epistemic processes. Additionally, teachers listened to some of their students' evaluations and were surprised by what they heard. This suggests noticing students' epistemic cognition in the classroom is difficult and engaging students in video-cued discussions about reliable scientific practices around a familiar activity may allow for learners' thinking to become more visible.

Keywords: Epistemic Cognition, Metacognition, Scientific Modeling, Biology Education

Introduction

Science denialism has become increasingly prevalent, with the internet allowing for the exponential spread of misinformation on important socioscientific issues, such as vaccine safety and climate change (Sharon & Baram-Tsabari, 2020). Individuals' tendency towards *confirmation bias* is likely one important underlying cause of this worrying trend (Gorman & Gorman, 2021). One manifestation of confirmation bias is the evaluation of evidence to favor one's prior beliefs, as when evidence supporting one's beliefs is considered accurate and reliable, whereas equally relevant and sound evidence against one's beliefs is dismissed as false or erroneous (Nickerson, 1998). As a result, processing new information with an open-mind and demonstrating the ability to change a belief in light of contradictory evidence can be extremely difficult (Gorman & Gorman, 2021). Thus, the repercussions of unconfronted confirmation bias and its effects in propagating anti-science beliefs will continue to have detrimental effects on global public health and safety (Gorman & Gorman, 2021).

Given the gravity of current socioscientific issues, it is imperative that science educators improve students' abilities to critically evaluate evidence and distinguish well-justified and accurate information from false and misleading claims (Chinn et al., 2021). This involves emphasizing epistemic educational goals for students, among which, include increasing their awareness of cognitive biases, as well as helping them to develop and implement strategies that can counteract those biases (Barzilai & Chinn, 2018; Hofer, 2016). Such educational goals have emerged from research on *epistemic cognition*, which can be defined as people's ways of knowing—including cognitions and practices used to establish, critique, and use knowledge within disciplines (Greene et al., 2016). Research has revealed that teachers need support in developing the best ways to cultivate a comprehensive epistemic education given the complexity of the topic; however, we are still limited in our understanding of the best ways to design and enact such supports (Fives et al., 2017; Sandoval et al., 2016).

In this study, we investigate how students and teachers are working with well-developed modeling curricula from the perspective of their epistemic performance, specifically as it relates to confronting confirmation bias in evaluating evidence. Using a video-cued interview method (Tobin, 2019), we identified a case of confirmation bias occurring in previously collected video footage of past high school biology students engaging in a modeling unit and then asked current students and their teachers to evaluate the epistemic performance of the students in the clip. In an effort to contribute to research and design that promotes effective epistemic education in science classrooms, we addressed the following research questions: 1) How did current students and their teachers evaluate the epistemic performance of past students working with the modeling curriculum? 2) How did teachers respond and react to hearing some of their own students' evaluation of the epistemic performance exhibited in the video clip?

Supporting teachers in promoting an epistemic education

The complexity and relevance of epistemic cognition in science teaching is critical to address, yet current instructional practices tend to fall short of developing students' capacities in this way (Chinn et al., 2020; Elby et al., 2016). Indeed, multiple contextual factors are likely to affect teachers' abilities to focus on epistemic performance goals in the classroom, as teachers are likely to hold a multitude of goals for their students (both epistemic and non-epistemic) simultaneously (Fives et al., 2017; Buehl & Fives, 2016). Furthermore, the contextualized nature of epistemic cognition demands that teachers attend to the specific tasks and learning environment of a given activity, as well as to become proficient in teaching across various knowledge domains (e.g., biology and scientific modeling) (Sandoval, 2014). This means that teachers must be able to notice and assess their students' epistemic cognition to better understand how to support it; yet the development of such an awareness and assessment requires significant time (Fives et al., 2017).

Indeed, the best ways to support teachers in promoting a successful epistemic education have not yet been clearly defined (Muis et al., 2016). For example, more research examining the links between various aspects of teacher practice (e.g., specific instructional designs, pedagogy, student agency in the classroom) and how they can lead to successful epistemic performance when learning science is needed (Sandoval, 2014). As a start, science classrooms need to incorporate activities that allow students to engage in the real practices of scientists (Gorman & Gorman, 2021). In addition, teachers must also be able to identify and assess their students' knowledge about these scientific practices and then use this information to improve instruction (Fives et al., 2017). In the next section, we describe a pathway (situated within the context of scientific modeling in high school biology) that would allow teachers to begin investigating ways of noticing and assessing their students' epistemic cognition.

Epistemic performance within the domain of scientific modeling

To promote the goals of an epistemic education (Barzilai & Chinn, 2018) in high school science classrooms, we adopted the AIR model of epistemic cognition as a framework to evaluate learners' epistemic performance as they engaged in scientific modeling (Chinn et al., 2014). The AIR model establishes three main components of epistemic cognition as being: Aims, Ideals, and Reliable processes. Aims refer to the specific goal of inquiry, whereas Ideals are the standards or criteria that an individual uses to determine whether epistemic aims have been met. Reliable processes denote the strategies (individual or collective) that people use to successfully achieve their aims. Because this study focuses on participants evaluating how past students engaged in modeling during their science class, we emphasize identifying only the ideals and reliable processes related to this particular learning activity. Therefore, for the purposes of this study we analyze learners' *epistemic performance* in terms of the reliability of the epistemic processes used, and the appropriateness of the ideals applied, to the modeling task being evaluated. Indeed, previous research has shown that students need support in understanding both how to think like scientists and why scientific processes are reliable (Elby et al., 2016).

Table 1.
A Selection of Ideals and Reliable Processes to Promote Successful Epistemic Performance During Modeling

Epistemic Performance to Promote in the Complex Systems Modeling Curriculum	
Ideal 1 •Rigorous fit with evidence that is relevant, ample, systematic, and conclusive	
Reliable Processes (RPs)	• Multiple hypotheses. Consider multiple hypotheses (even if it is just a hypothesis and its negation). Make predictions based on these alternative hypotheses and test them together. • Multiple trials. Run multiple simulations to establish average phenomena under the same starting conditions. • Revise explanatory models when there are small or large discrepancies with evidence.
Ideal 2 • Has plausible, well-established underlying biological process (or mechanism)	
RPs	• Incorporate underlying biological processes into models to explain phenomena. • Examine interactions of elements in simulations carefully and systematically to grasp underlying processes.
Ideal 3 • Fit with prior (well-established) knowledge	
RPs	• Use previous science to evaluate and understand phenomena being modeled. • Evaluate whether ideas are consistent with well-established prior knowledge.

The AIR model can be used as a lens to examine the thinking strategies within a domain and to analyze various reasoning problems in the public sphere, such as those associated with confirmation biases (Chinn et al., 2014). As an example, biased epistemic performance could involve aiming to preserve one's prior beliefs. The biased ideals associated with this aim could include aligning beliefs with flawed or limited evidence. The biased processes associated with this ideal could then include cherry-picking data, dismissing contradictory evidence, or only seeking out supportive information. In contrast, unbiased epistemic ideals and processes could include aligning beliefs with evidence that is ample and conclusive and then using the reliable process of fairly weighing evidence on multiple sides of a question and developing arguments with thorough evidence-based reasons. This general example using the AIR model to understand how to mitigate against cognitive biases can be applied towards evaluating students' epistemic performance as it relates to the modeling curricula being studied here. Table 1 consists of a (non-exhaustive) list of ideals and reliable processes that can be applied while engaging in scientific modeling that can lead to successful epistemic performance. This list emerged from two main sources: 1) a review of the literature on the epistemology of scientific modeling (e.g., Schwarz et al., 2009) and 2) a previously validated coding manual that emerged from the analysis of past student groups engaging in the modeling units. Next, we describe how Table 1 guided this analysis, as it includes strategies that can support an individual in learning to reason in rigorous, unbiased ways.

Methods

Context and participants

In this exploratory study we used previously collected video footage from students working with complex systems modeling curricula that combine experimentation with data analysis to generate discussion about epistemic performance with current students and their teachers. We asked students and teachers to evaluate a clip of a pair of students engaging in a modeling unit where they were investigating the effects of enzymes on the breakdown of starch to sugar (see Table 2).

Table 2

Transcript and the Research Team's Analysis of Video Clip Shown to Study Participants

Dialogue between Student A and B (regular font) with contextual descriptions of the scene (italics)	**Epistemic Processes Identified by the Research Team**
The clip begins with Student A reading the worksheet instructions aloud to partner, Student B. The students are trying to understand how varying the starting amount of substrate (starch) will affect the amount of product (sugar) produced in the absence of enzymes. **Student A:** Hypothesize: If you started with 60 starch molecules, how many sugar molecules would you expect to form? Use your graph to help make a prediction. Use the simulation to test your prediction…Group prediction I'm gonna say about like 50…50… **Student B:** 55? **Student A:** 55. Alright now we have to run it. Ready? Are you ready? *Student A then runs the simulation.* **Student B:** Why does is say hashtag? Oh wait, it says number of sugar molecules. **Student A:** *Laughing at her partner's comment. Once the simulation is finished running Student A points to the counter indicating the number of sugar molecules formed and says,* "It only produced 31!" **Student B:** That's fake. **Student A:** Can we do it again? **Student B:** Yeah. *They run the simulation a second time without speaking. The output after this run again reads 31.* **Student B:** That's so fake! **Student A:** *Laughing as speaks.* We said 55….We're doing it one more time. (*The student then runs the simulation a third time using the same starting conditions).* **Student B:** It was the same number every time, it's obviously going to be the same number. **Student A:** No, see (*pointing to the sugar output counter on the simulation)*, look, no. It's 49! This is cray. **Student B:** F-a-a-a-k-e. **Student A:** Can we do it again? **Student B:** No, just do 49. It's fine. *This student chooses to report the number that is closest to their initial prediction.* **Student A:** *Pointing to the sugar output counter in the simulation, student says,* **"**Hold on, I'm doing it one more time." *The simulation runs as in previous trials but the output from this run reads, "34".* **Student B**: The simulation result was 49! **Student A:** Relax, relax. I'm doing it one more. *And student runs the simulation with the same initial conditions for the 5th time. At the end of the run the sugar output counter reads, "43".* **Student A:** This is so inaccurate. **Student B:** It's called randomizer [sic].	• Did not appear to use prior knowledge (e.g., data from previous runs to justify their prediction) to better understand the experiment (less reliable) • Did not articulate multiple hypotheses, only considered one prediction (less reliable) • Believed contradictory evidence to be "fake" and "inaccurate"; could have been more open-minded (less reliable) • Ran multiple trials using the same starting condition (more reliable) • Could have looked to see what was going on in the simulation (e.g., did not observe how the molecules were moving and interacting during the runs) (less reliable) • Did not compute averages of data points collected, tried to cherry pick the result that matched their prediction most closely (less reliable) • Could have addressed whether their initial prediction, or overall understanding, was correct (i.e., did not try to understand why their results were different from prediction) (less reliable) • Student B eventually seemed to recognize that randomness/ stochasticity could be contributing to their results (more reliable)

While the clip in Table 2 was filmed in 2013, the unit used has remained largely unchanged since, and was therefore familiar to the participants. The clip was chosen because it demonstrated a clear case of confirmation bias. We employed a video-cued ethnographic method (Tobin, 2019) with the intention of eliciting participants' metacognition to gain contextualized insight into the learning practices they enact during modeling. This allowed us to measure aspects of their *metacognitive knowledge* (or the knowledge about how to perform an activity that will result in knowing) of the modeling task and the strategies used (Barzilai & Zohar, 2014). Table 2 also details our a priori analysis of the epistemic processes observed in the clip and whether we considered them less or more reliable. Our identification of these processes and assessment of their quality is directly aligned with the selected list of the more general ideals and reliable processes outlined in Table 1. Of the 8 processes identified, 6 were categorized as less reliable, while the remaining two were considered more reliable.

Table 3
Coding Examples Illustrating the Less and More Reliable Processes Noted in Student and Teacher Responses

RPs Observed in Clip	Coding Examples
Making Only One Prediction- Did not articulate multiple hypotheses, only made one prediction (less)	"Only one approach was considered." (Teacher Hanna, 4 Aug 2021) "Didn't consider another hypothesis." (Teacher Rachel, 4 Aug 2021)
Cherry Picking Data- Picking one specific result that matched their prediction most closely (less)	"If you're looking for a specific result, you can make the data match that. For example, as soon as they saw the result that there's 49, they went with that." (Focus Group with Cindy's students, 10 May 2021)
Dismissing Opposing Evidence- Believed contradictory evidence to be "fake" and "inaccurate"; could have been more open-minded (less)	"When they got answer that they thought didn't make sense, they freak out a little bit…not freak out, but they just kind of dismiss it in way." (Focus Group with Lindsay's students, 21 May 2021)
Not Reconsidering Mental Model- Could have addressed whether their prediction (or mental model) was correct; did not try to understand why the results were different (less)	"I think they should've thought about why they were getting 31 or whatever instead of the 55. Maybe put some thought into why it was incorrect." (Focus Group with Cindy's Students, 10 May 2021) "Students are unwilling to adjust their initial beliefs even when the same evidence arises multiple times." (Teacher, Cindy, 4 Aug 2021)
Not Observing the Interactions of Agents within the Model- Could have examined the model more closely; did not observe how the agents were interacting (less)	"I also think it would be important for them to possibly look at how the things are moving in there a little more too. Because I know sometimes in the ones we've done, we've had things disappear. We've had things bounce off and things and it might just be interesting to see if it does any of that in this." (Focus Group with Catherine's students, 13 May 2021)
Not Applying Prior Knowledge- Did not appear to use prior knowledge (e.g., data from previous runs to justify their prediction) to better understand the experiment (less)	"I don't know how they came up with the number 55 [as their prediction] at all, so I think they should've talked it over more, use more of the experiment's data." (Focus Group with Elizabeth's students, 11 May 2021) "Student makes argument that 55 starch molecules will occur, based on no evidence-based reasons (that they articulate)." (Teacher Catherine, 4 Aug 2021)
Running Multiple Trials- Ran multiple trials using the same starting conditions (more)	"I think their strategy was decent because they ran the simulation many times to see, does [sic] the numbers change." (Focus Group with Rachel's students, 15 Jun 2021)
Noting Randomness Occurs in Biological Systems- Student B eventually seemed to recognize that randomness/stochasticity could be contributing to their results (more)	"They attempt to explain the different numbers by hinting that there is a touch of randomness." (Teacher Elizabeth, 4 Aug 2021) "Well, I think they didn't understand that it was randomized at first. And then they found out that it was randomized and they were like, 'Oh, it's randomized, it's not fake.'" (Focus Group with Rachel's students, 15 Jun 2021)

In the 2020-2021 academic year, we interviewed 37 ninth grade biology students and eight of their teachers. Participation in student focus groups was voluntary, so only self-selecting students participated; however, teachers indicated that the participating students represented a broad range of students with respect to performance level. Half of the students interviewed attended private, college preparatory schools and the other half attended large suburban public schools in the north or southeastern U.S. The eight teachers were selected for this study as they represented teacher experts with respect to the modeling curricula being studied (i.e., they had implemented the curricula multiple times already and helped to facilitate other teachers' uptake of it). These teachers participated in a virtual professional development (PD) summer workshop with the larger goal of becoming design collaborators in modifying the existing curricula to better promote epistemic performance. The teachers, on average, had 10 years of teaching experience, with a range of 5–18 years at the time the workshop occurred.

Data sources and analysis

To address research question #1, students and teachers were prompted to examine and reflect on the epistemic performance demonstrated in the video clip. Student data was collected in end-of-school-year focus groups (April-July 2021). We conducted 11 semi-structured focus groups consisting of 2 to 4 students, each lasting approximately 60 minutes. As part of the interview, students were shown the video clip, asked to describe the strategies they observed the students in the clip enacting, and then asked to evaluate whether they thought these were good strategies in terms of better understanding the scientific phenomenon being modeled. Teacher data was collected as part of an activity in a summer PD workshop (August 2021). Evaluation of the video clip by teachers occurred once they had already been explicitly introduced to Ideal 1 (rigorous fit with evidence) and its associated processes (see Table 1) and were ready to begin exploring its applications in the modeling units (this occurred on Day 3 of the ten-day workshop). Once teachers viewed the clip, they responded to similar questions as the students; however, teachers first engaged in individual reflection and then participated in a large group discussion about their reflections. To address research question #2, teachers next listened to select audio clips of some of the students' responses to the clip. Teacher data regarding their responses on hearing their students' evaluations of the clip was collected via asynchronous group discussion posts on Canvas as part of the PD. In their posts, teachers were prompted to identify and react to the more—or less—reliable epistemic processes they heard their current students articulating in their evaluations.

To guide this analysis, we used the 8 epistemic process codes previously identified in relation to the video clip (see Table 3, column 1) and recorded them as being mentioned or not within any single focus group response of students or within any individual teacher response upon viewing the video clip. This list of epistemic processes related to this modeling curriculum were generated by a modified method of interaction analysis (IA) by all the authors (Jordan & Henderson, 1995). Author 1 then initially coded the student and teacher responses and then conducted interrater reliability analysis on 20% of the coded enactments with Authors 4 and 5; this returned a Cohen's kappa = 0.94. Regarding the analysis aimed at addressing research question 2, we identified and summarized the salient themes that emerged in the teachers' Canvas discussion posts as they reacted to hearing some of their own students evaluate the video clip. Here we used a constant comparative method of analysis, where the first author read the first discussion post and recorded overall emergent themes, and that information was then compared to and triangulated with each subsequent discussion post to validate that a particular response emerged from multiple teachers (Glaser, 2008).

Results

Below we first present the percent presence (scored as being noted in any of the 11 student focus groups or in any 8 teacher responses) of the focal reliable processes for students and teachers and elaborate on key ideas from their responses. Second, we include teachers' reflections upon hearing the audio clips of some of their own students responding to the video clip. In asking teachers to evaluate their current students' scientific epistemologies in this way, we gain insight into how teachers understand their level of epistemic performance.

Table 4
Presence of 8 Epistemic Processes in Student and Teacher Responses

Less and More Reliable Processes Coded As Present Within the Video Clip	Student % Presence	Teacher % Presence
Making Only One Prediction	0%	50%
Cherry Picking Data	91%	88%
Dismissing Opposing Evidence	82%	88%
Not Reconsidering Mental Model	82%	50%
Not Observing the Interaction of Agents within the Model	36%	0%
Not Applying Prior Knowledge	73%	63%
Running Multiple Trials	100%	100%
Noting Randomness Occurs in Biological Systems	27%	63%

Students' and teachers' evaluation of epistemic performance in the video clip

Table 4 shows that student groups at some point noted almost all (7 of 8) of the epistemic processes that had been used to code their responses. However, students more rarely identified several reliable processes, such as *Noting Randomness Occurs in Biological Systems* and *Making Only One Prediction.* In addition, the fact that students frequently identified the processes *Cherry Picking*, *Dismissing Opposing Evidence* and *Not Reconsidering Mental Model* demonstrates that many of them readily recognized some of the less reliable processes underlying the confirmation bias evident in the clip (although no one labeled it as such). For example, a student in Catherine's class noted that "one thing that…people do a lot is when they…want to be right and think that they're right, they just disregard other things." Another student in Elizabeth's class pointed out that "after running it three times, they actually ran it more than three times. But instead of averaging their data, they cherry pick the one that was closest to their prediction, which is just not being a good scientist."

However, in one instance a student in Catherine's class seemed to articulate the value in the tendency to want to stick to one's original hypothesis, "I think that it shows the trust they have in their predictions and their hypothesis. It's kind of a good thing how much they trust it." To which a classmate responded, "I feel like they need to realize that…at a certain point, you have to realize that the simulation might be right, and your prediction might be wrong. And instead of…saying it's fake, or whatever, just say maybe our prediction's not quite accurate and…why is it not accurate." In this example with Catherine's students, one student indicated that trusting in your original hypothesis is a "good thing", whereas another cautioned that at some point it is important to consider that you could be wrong. In fact, most students regarded the students in the clip as displaying less reliable strategies in continuing to believe their prediction was correct despite mounting evidence.

Beyond recognizing the pitfalls of disregarding or cherry-picking data, some students pointed out that falsification of hypotheses happens often in science and is something you "shouldn't be upset about." One student in Elizabeth's class astutely noted that falsification should be discussed more explicitly in classrooms: "I think in general, more of what needs to be done in…science classrooms…is that it's fine for the data to negate your predictions. Because I think so often students are discouraged by data that disproves what they previously thought, but I think it should be more normalized." Therefore, this student not only evaluated the clip but further suggested an instructional strategy that could improve students' epistemic performance in science class. These findings show that student groups were able to articulate their metacognitive knowledge of working with the modeling units and demonstrated a solid understanding of some of the more reliable epistemic processes related to it.

Teachers' individual responses to the clip also aligned closely with the epistemic processes that the authors had previously identified (see Table 4). Teachers noted almost all the pre-identified epistemic processes (7 of 8) with high frequency (50% or greater), with the exception of *Not Observing the Interaction of Agents within the Model* (0% noted this). Also, the frequent mention of the processes *Dismissing Opposing Evidence* and *Not Reconsidering Mental Model* (88% or 7 of 8 teachers noted these) in their responses demonstrated that, like students, most teachers readily recognized the biased processes evident in the clip. Moreover, while *these* students overall demonstrated the metacognitive awareness of the need to correct for confirmation bias, many teachers (4 of 8) pointed out that while when implementing the modeling units in their classroom, they have also experienced similar situations to what they saw on the clip. For example, Linda recalled, "Doing this the first time with my students, this exact simulation, and I had a group of girls that were like in a panic, calling me over, 'it's broken, it's broken, it's not working.' And I said, 'What's broken?' They [said], 'we keep getting different numbers.' And they were so adamant it was broken, and since it was the very first time that I was doing it, it hadn't really occurred to me that they would have that immediate response." Hanna also mentioned that her students "struggled a lot with the idea of not getting the same results again and again." These responses show that current teachers are indeed noticing instances of confirmation bias during modeling. Many students seem to doubt the probabilistic nature of the simulation and whether it is "right" because they have yet to learn about the authenticity of such scientific processes firsthand. Therefore, these modeling curricula could be an important tool needed in science classrooms to redress the misconception that scientific knowledge is absolute.

Teachers' reflections on hearing students' evaluation of the video clip

After evaluating the clip, teachers then listened and reacted to some of their students' evaluation of the epistemic processes they had observed. Overall, teachers were surprised at how thoughtfully students commented on the reliability of the epistemic processes they noticed, and they noted some contextual variables (e.g., performance goals, societal pressures) that can influence students' epistemic performance. When teachers listened to a clip from Elizabeth's class, which included the observation a student made about "cherry picking" data and another that made a point about normalizing falsification in science class as described above, they mentioned being "really surprised," "astounded," and "completely blown away" at how "insightful" these students were in assessing epistemic performance. In fact, Elizabeth recognized her students' voices and described her amazement in hearing their evaluation of the clip: "One of the speakers who identified several apt practices completely threw me! She was struggling all year, was very quiet, and often seemed to lose focus. I found it very interesting that she was still able to glean some of these practices (I was pretty shocked)! This was very interesting for me to hear."

In addition to being surprised, teachers agreed that their students' insights were "extremely thoughtful" and that "encouraging acceptance of being wrong in your hypothesis was great!" Linda further elaborated that "it always interests me how [students] can have such great understanding of the right practices to use, but in the classroom, they often get focused on that 'task completion' and don't follow through!" This comment suggests that while this video-cued method might elicit some surprisingly insightful reflections, these may be more difficult for students to enact during science class, when performance goals (e.g., task completion, or getting a good grade) may affect the processes students use. The second audio clip teachers listened to was from Catherine's class and included the observation a student made about how it is good to "trust in your prediction," as described above. Teachers identified this response as less reliable, and Julie even suggested it was "possibly a reflection of being a teenager in this country—it seems like there's a lot of messaging about being confident and trusting in yourself and your ideas. So, in a way [this student] seemed to reflect that cultural idea." Catherine agreed adding that "I think that it is likely that societal ideas about confidence and trusting yourself are seeping in."

Finally, after engaging in this activity, teachers were intrigued by what they heard and eager to hear more from their students regarding their focus group responses. Lindsay elaborated, "Listening to the student samples was insightful. As a teacher…we hear from the student groups we are working with at a particular moment, but often their dialogue is biased towards what they think we, the teacher, want to hear. It was nice to hear their candid conversations." Teachers also agreed that having *all* of their students evaluate the epistemic performance of other students working with the same models (as their focus group students did) as a classroom activity would be beneficial in promoting more reliable scientific modeling processes in the classroom. Lindsay added that this activity "would be a great way to spark the conversations about [more and less reliable processes] and how students can identify when they are putting less productive strategies in play and how to correct them." Taken together, these teacher reflections on some of their students' responses to the video clip demonstrated that they uncovered some very surprising and otherwise hidden aspects of epistemic performance that they were not seemingly unaware of prior to this activity. This revelation underscores the prevalence of a major barrier towards teachers' ability to promote the goals of an epistemic education in their practice: being positioned to notice and accurately assess their students' epistemic cognition.

Discussion

In this study, we used video-cued discussions with students and teachers to uncover their metacognitive knowledge regarding scientific modeling. All participants noticed and discussed at least some of the 8 previously identified epistemic processes at work in the video clip. Many of the biased processes observed in the clip included some hallmarks of confirmation bias (e.g., cherry-picking); thus, students and teachers were aware of confirmation bias and were able to accurately identify some aspects of it in practice. However, engaging students with effective curricular tools, such as the modeling curricula investigated here, is likely only one of many important factors leading to the development of more sophisticated epistemic cognition (Muis et al., 2016). While these modeling units probably contributed to the successful epistemic performance exhibited by students in focus groups, more explicit instruction regarding ideals and the justification of reliable scientific processes could also improve student outcomes, as teachers pointed out that they had seen these kinds of biased processes playing out in their classroom.

The second part of the study, when teachers listened to students identify the epistemic processes from the video clip, revealed that teachers were not necessarily attuned to their students' epistemic cognition. Teachers were "astounded" and "surprised" by the metacognitive knowledge their students articulated regarding modeling. This is problematic because perceiving this and then using it to inform future instruction is a critical aspect involved in promoting an epistemic education (Fives et al., 2017). Furthermore, teachers also accurately pointed out that students' epistemic cognition is shaped not only by cognitive biases, but also by factors such as social and cultural influences, performance goals, and attitude towards learning (Elby et al., 2016); therefore, the video-cued method used to invoke metacognition around a familiar activity was powerful in revealing this kind of thinking. In fact, multiple teachers agreed that showing their students a clip such as this would be a fruitful classroom activity. Because we know teachers need better supports for incorporating epistemic educational goals in instruction (Muis et al., 2016) and more activities that elicit metacognitive thinking are needed to address this (e.g., Chinn et al., 2020), we suggest using this type of method directly in the classroom. Our findings here indicate making this kind of metacognitive knowledge explicit in science class could contribute positively to the epistemic climate of the classroom (Muis et al., 2016). Future studies might then address how an intervention like this might affect epistemic performance across knowledge domains and/or compared to other better-known interventions, such as those that involve reading and responding to persuasive texts (e.g., Porsch & Bromme, 2011).

In conclusion, even though it is well established that teachers need to notice their students' epistemic performance, this is difficult to achieve, and it is likely there are biased processes going unnoticed and perhaps inadvertently being reinforced in science classrooms. Incorporating more metacognitive thinking into science classrooms to redress this is not a new suggestion (e.g., Barzilai & Chinn, 2018; Hofer, 2004) but this study provides support for the value of using a video-cued evaluation of familiar classroom practices as a method to help elevate learners' thinking into the metacognitive realm. Additionally, it seems necessary to make these types of ideals and reliable processes more explicit to students, as this could provide a mechanism for transfer of the more domain-general aspects of successful epistemic performance towards everyday decision-making regarding current socioscientific issues.

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