Improving argumentation: teaching doubt management to support primary students' evidence selection

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Abstract

Over the last few decades, it has become a staple of reform-based science education that teachers promote student argumentation in the classroom. As researchers continue to evaluate ways in which teachers create productive environments for argumentation, a recent trend in the field has focused on how they manage student doubt. When teachers adopt instructional practices that align with contemporary standards, a more diverse range of instructional aims should be considered. Recent studies have focused on teachers raising, maintaining and reducing doubt throughout their lessons (Chen et al, 2019; Chen & Jordan, 2024; Starrett, 2024). In this study, we set out to trace the relationship between teachers' doubt management during lessons of student-led argumentation and how those 8-9 year-old students select evidence. The findings suggest that primary-aged students who had a teacher with a reform-based orientation were better at selecting claims that had empirical evidence. Students taught by a teacher with a more traditional approach (i.e. direct instruction) were more likely to ignore the empirical evidence and select misconceptions with plausible mechanisms.

Keywords: Argumentation, enquiry, talk moves, primary, reasoning

Introduction

For decades, science education researchers have promoted argumentation as a tool for students to use to make sense of scientific phenomena (Duschl, Schweingruber & Shouse, 2007; Ford, 2012; NRC, 2012). When teachers adopt instructional practices that align with contemporary practices like those adopted in Australia, Europe and the United States, they should be encouraged to promote argumentation as a way to enhance enquiry (see National Curriculum in England (Department of Education, 2013); Australian Curriculum, Assessment and Reporting Authority (ACARA, 2022); Promoting Inquiry in Mathematics and Science Education across Europe project (PRIMAS) (Dorier & Maab, 2012), Next Generation Science Standards (NGSS Lead States, 2013)).

As researchers continue to dissect ways in which teachers create productive environments for students to construct claims based on evidence, a recent trend in the field has focused on how they manage student doubt during argumentation (Chen *et al*, 2019; Lammert, Hand & Woods, 2024; Manz, 2015; Strat & Jegstad, 2024). Manz (2015) noted that a critical aspect of scientific enquiry is that it places doubt at its centre and requires students to use reasoning to reduce their doubt. To cultivate productive moments of uncertainty, educators employ approaches where they introduce phenomena and ask students to explain their existing knowledge. Next, the students consider multiple claims that explain the phenomenon or question at hand, with the teacher asking questions that lead students to consider the strengths and weaknesses of the evidence for those claims. Finally, teachers attempt to reduce uncertainty by making a case for claims with evidence backed by reasoning.

In a practical sense, these researchers ask teachers to begin enquiry by raising doubt, allowing students to explore their doubt through investigation, and resolving that doubt through argumentation about the evidence that they collected (Chen *et al*, 2024). Asking teachers to consider adding doubt-management strategies to their pedagogical practices will require them to consider how students select evidence and ask them why it supports their claim (Chen *et al*, 2019).

Developmental psychologists have shown that young students use personal observation to make causal inferences about nature and even ignore empirical evidence that conflicts with their viewpoint (Hewson & Hewson, 1984; Inagaki & Hatano, 2006). However, studies that have evaluated how students select evidence have not considered whether a teacher's instructional strategies impact how a student considers evidence for their claim. In this study, we set out to evaluate the relationship between teachers' doubt management strategies during lessons of student-led argumentation and measure how those students select evidence on a task with multiple plausible answers. The following sections will discuss why doubt management and student evidence selection are important aspects of teaching science.

Doubt management

This study focused on doubt management because, for students to learn how to engage in evidence-based reasoning, they would have to learn to manage uncertainty. Learning science includes learning how to think like a scientist. This practice consists of raising questions, examining evidence, constructing a claim, considering alternative viewpoints, and applying reasoning to explain why the evidence for one claim is more substantial than the other. In order for teachers to create an environment for students to attempt these practices, they need to create opportunities for students to work through their uncertainties.

Young learners engage in causal inference about the world around them as they actively work to make sense of the environment in which they find themselves. Research suggests that children (and adults) ignore or distort data that might contradict prior beliefs (Brownlee, Ferguson & Ryan, 2017; Kuhn, 1989; Yang & Carless, 2013; Zimmerman, 2000). Other researchers have shown that individuals reason by co-ordinating data with informal claims, but it is common for students to look for data that fit their claim instead of considering the plausibility of competing ideas (Brem & Rips, 2000; Koslowski, 1996; Techawitthayachinda *et al,* 2019; Chen *et al,* 2019).

Scholars have studied how teachers with different pedagogical approaches manage doubt, and one key difference between a reform-based and traditional approach is the focus on instructional aims (Chen *et al,* 2019; Engle, 2011; Reiser, 2004). Teachers with a more traditional epistemic orientation aim would consider the transfer of knowledge as the primary goal of their instruction (Alexander, 2017). These teachers would likely keep doubt to a minimum by using lectures or other didactic instruction to introduce a concept, followed by examinations and more direct instruction to reduce student doubt. In this scenario, students would receive evidence second-hand from the teacher, or the teacher would explain the pattern of covariation found in the data.

Chen *et al* (2019) examined how teachers with a more reform-based orientation manage doubt and found three significant patterns concerning uncertainty. They showed that teachers use a pedagogical approach, where they raise, maintain and reduce doubt. When teachers use this type of approach, they introduce doubt by asking students to explore a phenomenon (*raise*), then ask students to engage with that doubt through investigation (*maintain*), and finally ask students to present their understanding after argumentation (*reduce*). This student-centred approach problematises students' experience (Engle, 2011; Reiser, 2004), which presents opportunities for them to manage doubt through conversation and evaluate the strengths and weaknesses of the evidence (Chen *et al,* 2019). When teachers problematise scientific phenomena, they position the challenge of resolving the uncertainty as the aim of their instruction. For students to work through the problem, they need to be presented with evidence and then allowed to decide if it helps to support their claim.

Evidence selection

Reform-based instruction asks students to construct claims based on evidence and explain them through reasoning. This approach is similar to how professional scientists must consider all plausible mechanisms that explain the phenomenon that they are investigating, but must remain epistemically vigilant and support the claim that has superior evidence. Authors of contemporary science standards promote this *process* of science as a form of instruction, because research has shown that students in grades as early as Kindergarten are developmentally capable of providing evidence for their claim and explaining why the evidence supports it (Mayer *et al*, 2014; McNeill, 2011; NRC, 2007).

However, Zimmerman (2000) postulated that young children tend to ignore or distort data that contradict their developed beliefs. Hewson and Hewson (1984) noted that when infants take in information about their environment, they make assumptions about it. Before students enter formal education, they construct explanations about the natural phenomena that they encounter, and it is challenging to get students to change those ideas. Research has shown that simple direct instruction is an inefficient way to change those ideas (Chi, 2008, 2009; Hewson & Hewson, 1984; Sinatra & Mason, 2013).

Our project placed emphasis on evaluating teacher discourse and how teachers fostered student thinking about evidence in the classroom. Our interest lies in collecting data to ascertain if these types of learning environments could alter young students' inclination to select a certain type of justification for their claim. These data will aid in addressing the following questions:

Research questions
What type of feedback patterns do teachers use to manage student doubt?
Does the way in which teachers manage doubt during lessons impact the way that primary-aged students select evidence to support their claim?

Participants
In this study, twenty-two second-grade teachers and their 145 students (all aged 8 or 9) served as the participants. All the teachers in the study participated in a ten-day professional development (PD) programme that expanded over two summers. Specifically, the PD was influenced and designed around the research-based Science Writing Heuristic (SWH) (Keys *et al*, 1999; Hand, 2002) and Argument-Based Strategies for STEM Infused Science Teaching (ASSIST) (Kuhn & McDermott, 2017; Kuhn, 2022) approaches to teaching science. All the students in the study attended federally identified low-income schools in a large, urban school district in the Midwest region of the United States. The twenty-two teachers ranged from 1 to 18 years of teaching experience, and all participated in two years of professional development.

The PD programme in which the teachers participated had 53 attendees, and all participants were interviewed using Luft and Roehrig's (2007) Teacher Beliefs Interview (TBI). The TBI is a semi-structured seven-question interview with coding maps that capture the subject's epistemic orientation toward teaching science (Luft & Roehrig, 2007). To meet the expectations of a category, teachers had to provide answers that aligned with at least five of the seven characteristics of that category. The traditional end of the spectrum is defined by its teacher-centred treatment of science as facts. In contrast, the reform-oriented end of the spectrum treats science as dynamic and socially constructed through student-centred approaches to instruction. The participants were interviewed a week after the PD was completed. The authors selected all eleven teachers who scored as more 'traditional' on the TBI and then randomly selected eleven of the nineteen teachers who scored as more 'reform-based'. Hence, an equal number of teachers in the study had divergent epistemological aims.

Methods
Two forms of data were collected to measure the teachers' beliefs about teaching. TBI data were used to establish the teachers' epistemological views of teaching science. Next, to collect data on how teachers manage uncertainty, the authors asked each teacher to record multiple videos of a lesson where students would be confronted with doubt. Each teacher recorded four videos teaching a science lesson where students collected data about phenomena and were asked to make sense of their observations and information available to them. Specifically, teachers were provided with the prompt:

'Record a typical lesson after your students have collected data from an investigation and they attempted to make sense of their observations'.

Recording the lesson after students collected data allowed the researchers to view how much the teacher supported student-student discussion, how they promoted student negotiation, or if they interjected with the correct answer to the question that students were debating. Each video was 25 minutes long and was submitted throughout the school year (Video 1: September, Video 2: November, Video 3: March, Video 4: May).

Two coders evaluated transcripts of their videos to analyse teachers' doubt management strategies. Initially, each reviewer used an *a priori* approach to code the transcripts and categorised the teacher feedback as a dual or single aim (see Tables 1 and 2), using a framework established by Techawitthayachinda *et al* (2019). The reviewers coded the transcripts as 'Dual Aim: Argument and Content' and 'Single Aim: Content' (See Table 1). A high level of agreement was found between the coders on what was considered a single aim statement or a dual aim statement ($\kappa = .771.\ p < 0.05$).

Next, the total number of dual aim teacher statements was divided by the total number of instructional statements to get a mean number of dual aim statements per video (X=8.3). Teachers with more than 8.3 dual aim statements in all four video submissions were categorised as such, and all other teachers were labelled single aim. Next, the authors compared the TBI results with the qualitative data from the transcripts of the teachers' instruction; all eleven reform-based teachers fell into the category of dual aim and all eleven traditional teachers were considered single aim.

Table 1. Coding scheme for teachers with a dual aim.

Code	Definition	Doubt Management Strategies		
		Raise	*Maintain*	*Reduce*
Dual Aim Doubt Management and Content	Teacher feedback and questioning attempted to help students manage doubt, achieve an understanding of how to construct an argument and learn the content of the standard.	Teacher asked students to share their observations and questions after collecting data in the investigation.	Teacher presented competing ideas to the students and asked them to discuss why they think their answer was correct.	Teacher showed students the correct answer and discussed why the answer was correct.
		Transcript Examples		
		"Why do you think some of the flowers grew and others didn't?"	"Some people think the flower needs water and other people think the flower needs water and sunlight. What do you think?"	"See how the flowers that were placed by the window grew and the flowers we put in the closet didn't? Flowers need sunlight and water."

The coders used another a priori coding scheme similar to Chen *et al* (2019) by defining talk moves into examples when the teacher raised doubt, maintained doubt and reduced doubt (see Tables 1 and 2). A high level of agreement was found ($\kappa = .765$. $p < 0.01$). These data were necessary because they validated the TBI as a predictor of instructional decision-making and gave us data on how teachers managed doubt in an actual classroom setting.

Code	Definition	Doubt Management Strategies		
		Raise	*Maintain*	*Reduce*
Single Aim Content	Teacher feedback and questioning focused primarliy on managing doubt to help students understand science content but little to no focus on helping students construct reasoned arguments.	Teacher asked leading questions and allowed little variability in student choice.	When a correct claim was raised by a student the teacher "built up" that claim and did not ask the students to counter or think about other possible answers.	Teacher provided the answer or directed student to a resource with an answer quickly after argumentation was initiated. Many examples of premature closure where the teacher tried to direct students to the correct claim before uncertainties were fleshed through dialogue.
		Transcript Examples		
		"Did anyone notice that the flashlight is pointing down and the light is up on the ceiling?"	"Did everyone hear what Sarah said? She said that baby bunnies have two big ears like their mommy. Does everyone see this?"	"So we all agree, and repeat after me, a force is a push or pull that changes an object's motion."

Table 2. Coding scheme for teachers with a single aim.

To measure how students evaluate data, the authors created two animated videos using cartoon-creation software (see Images 1 and 2). The authors created the videos to determine how students would interpret the claims of individuals who used direct evidence vs those who used plausible explanations. Videos were used instead of presenting the students with a written transcript because the students in the study were all around 8 years old, with varied reading comprehension abilities. Having the students watch the videos instead of reading a transcript reduced the possibility that the students misinterpreted the questions due to lack of reading comprehension.

In the videos, two characters argue about a scientific phenomenon, with competing explanatory claims. Each set of characters present different types of evidence for their claim and the participants were asked which claim they support. One set of characters pose a question, conduct an experiment and use the results of the investigation for their evidence. The other set of characters refute the original group's claim and the evidence from their investigation. Instead, they provide a plausible mechanism to support a claim that is a common scientific misconception. We asked the teachers in the study to give us a concept that they would teach during the school year and made a video that reviewed that concept.

Image 1. Image from the cartoon that the students watched.

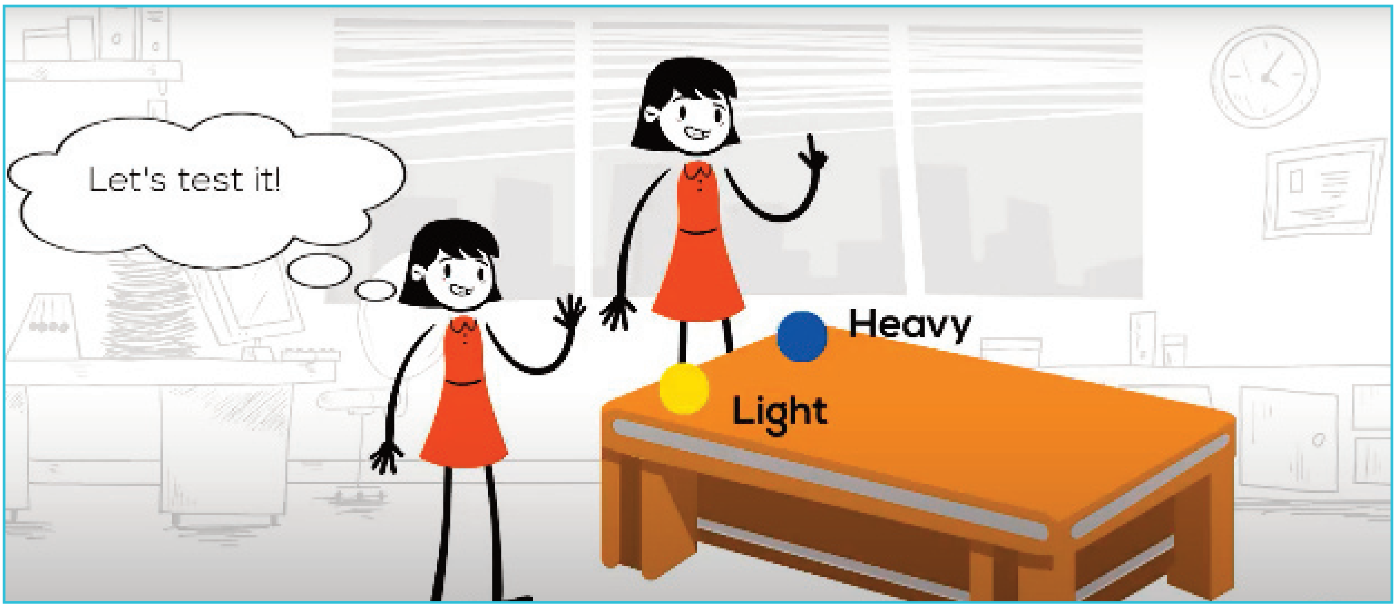
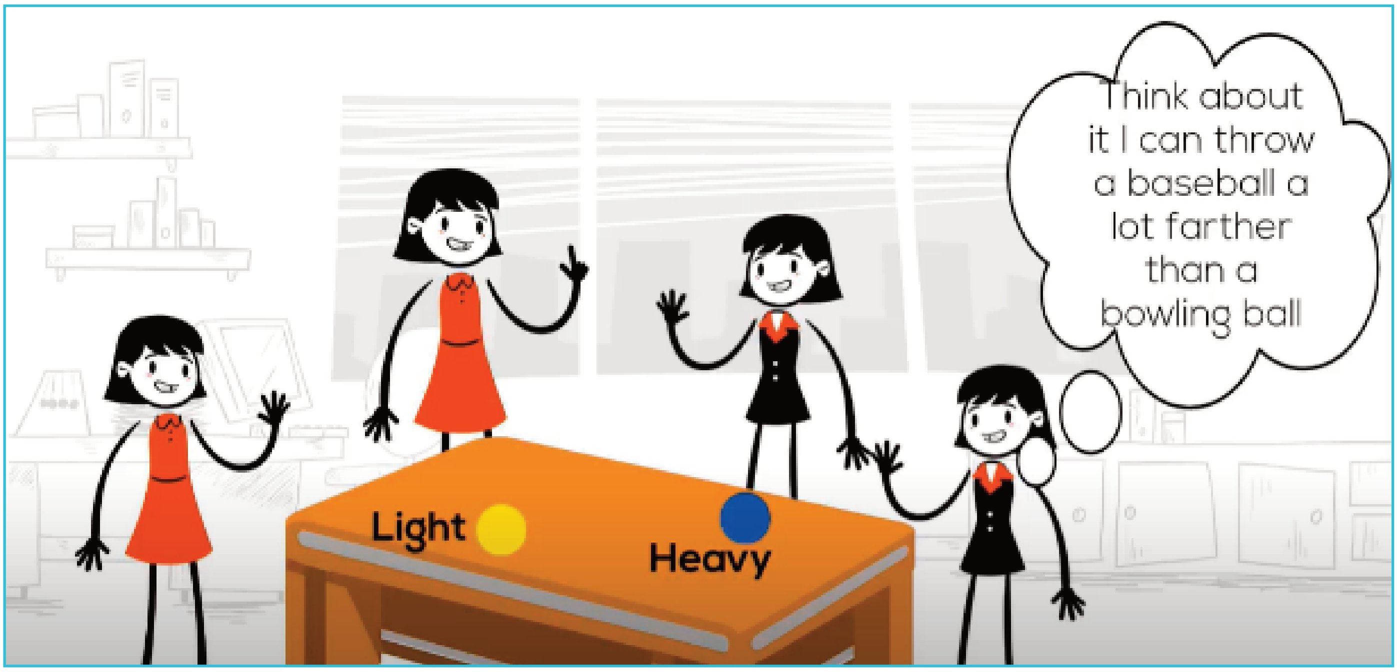


Image 2. Another image from the cartoon, where a plausible mechanism was introduced.



All 145 students in the study watched Video 1 at the beginning of the school year (fall/autumn) and video 2 at the end of the year (spring). The videos presented empirical evidence first and plausible mechanisms second. This order was intentional, because the plausible mechanism supported the misconception and opposed the direct evidence that the first group of characters provided. We wanted the participants to hear the misconception and plausible mechanism last before we asked them the questions.

After the students watched the videos, they were asked two questions and a follow-up question based on their initial response to clarify: 'Which group are right?'
'Why do you think they are right?'

- *So, are they right because they did a test?*
- *So, are they right because they said they can throw a baseball farther than a bowling ball?*

If the participant answered that the characters who used empirical evidence were correct, the follow-up question was *'So, are they right because they did a test?'* If the participant answered that the second group (who used plausible mechanism) was correct, the interviewer asked the second follow-up question, *'So, are they right because they said they can throw a baseball farther than a bowling ball?'* The follow-up questions were used to clarify why they selected the group that they did. The data collectors recorded the interview and transcribed the answers, then noted which type of evidence (empirical evidence or plausible mechanism) the students selected in the fall/autumn and spring. See Table 3 for a breakdown of the videos.

Table 3. Summary of the two videos shown to the participants in the study.

	Fall Video	Spring Video
Question	What will happen if a heavy and light ball are pushed with the same strength?	What will happen if a heavy and light ball are dropped from the same height?
Claim #1	The heavy ball will roll farther.	The two balls will hit the ground at the same time.
Claim #1 Evidence	Empirical Evidence - In the video the first set of characters push the balls and the heavy ball rolls farther.	Empirical Evidence - In the video the first set of characters drop the ball and they hit the ground at the same time.
Claim #2	The light ball should roll farther.	The heavy ball should hit the ground first.
Claim #2 Evidence	Plausible Mechanism - In the video the second group of characters claimed the first group is wrong because they can throw a baseball farther than a bowling ball.	Plausible Mechanism - In the video the second group of characters claim the first group is wrong and their evidence is they saw someone accidentally drop a bowling ball once and it fell really fast.
Common Misconception (Allen, 2019)	Light objects should always move farther than heavy objects when pushed.	Heavy objects fall at a faster rate than light objects.

Results

The students who had a teacher with a reform-based orientation and focused on a dual aim (doubt management and content) changed their evidence selection for empirical evidence from 24% in the fall/autumn to 75% in the spring, and a significant change in their choice of a plausible mechanism (fall/autumn 76% to spring 35%). In addition, the students who had a teacher who focused on a single aim (content) had a shift in empirical evidence (fall/autumn 33% to spring 37%) and plausible mechanism (fall/autumn 67% to spring 63%). The change in evidence selection for the reform-based/dual aim teachers was statistically significant after a *t*-test was conducted (see Table 4).

Table 4. Student evidence selection patterns at the beginning and end of the school year.

Teacher's Aim *Student Answers*	**Fall Selection**	**Spring Selection**	**Change**
Reform-Based / Dual Aim- *Empirical Evidence*	17 (24%)	53 (75%)	Δ + 36 ***
Reform-Based / Dual Aim - *Plausible Mechanism*	54 (76%)	18 (25%)	Δ - 36 ***
Traditional / Single Aim - *Empirical Evidence*	21 (33%)	23 (37%)	Δ + 2
Traditional / Single Aim - *Plausible Mechanism*	42 (67%)	40 (63%)	Δ - 2
Note: '***' = $p < 0.001$; '**'			

Findings from the study

The main finding in this study is that a significant number of students taught by teachers with a reform-based approach switched from selecting a common misconception with a plausible mechanism to a correct claim backed by empirical evidence. The students in classrooms with traditionally oriented epistemology continued to select the misconception for their claim and the plausible mechanism as evidence. We saw this in the data for students with a traditional-orientated teacher focused on content. The students taught through a direct instruction approach and given the correct information by the teacher were found to select the misconception. However, a statistically significant number of students taught by a reform-based teacher did not hold on to the misconception.

These data are interesting because reform-based teachers use different approaches to managing student doubt. These teachers managed doubt through dialogic questioning patterns and allowed students to construct claims through peer-to-peer discussion. This may have impacted the higher percentage of students who shifted to empirical evidence because those students were allowed more opportunities to wrestle through their uncertainty. These teachers asked students to consider multiple ideas when investigating a claim, instead of telling the students which claim the evidence supported.

Also, the results of this study align with the dialogic moves used to manage uncertainty in what Michaels and O'Connor (2015) defined as 'Productive Talk', in which dialogue is described as a fit between the students' ideas and evidence that either confirms or contradicts the student's original claim. In this study, how teachers used dialogue to manage uncertainty resulted in a significant number of their students overcoming the common misconceptions presented in the videos.

The eleven teachers who scored as 'traditional' on the TBI used almost no opportunities for dialogic discourse and instead used more authoritative feedback to reduce doubt. These teachers used a feedback loop of initiate-respond-evaluate (IRE), where the teacher raises doubt with their initial question and then reduces doubt by telling the student if they are 'right' or 'wrong'. In their videos, the teachers allowed minimal opportunity to maintain doubt, and the students were not involved in maintaining doubt at all due to the authoritative nature of the discussion.

The reform-oriented teachers aimed to deepen dialogue by encouraging students to focus on one idea at a time and explore the reasons behind supporting or rejecting a claim. This approach invited critique into the discussion, a talk move that was notably absent from the transcripts of the teachers with traditional orientations.

One key implication for professional development from this work is that supporting teachers with traditional views of instruction in transitioning to more reform-oriented approaches could involve encouraging them to expand their repertoire of talk moves. When teachers are planning their science lessons, our findings indicate that a lesson's aims should also include the development of argumentation skills, whereby students discuss and debate ideas. Teachers who used single aim doubt management strategies relied more on teacher testimony, which might have led to a greater reliance on plausible mechanisms. Understanding and managing doubt is critical for students to learn about the practice of science, which constantly questions assumptions and preconceptions of our knowledge of the natural world. As researchers and practitioners look for ways to improve science instruction, having future teachers think about managing student doubt properly should be considered when developing their pedagogical toolkit.

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