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The Use of Epistemic Tools to Facilitate Epistemic Cognition & Metacognition in Developing Scientific Explanation

Kok-Sing Tang

Curtin University

Author Note

Kok-Sing Tang, STEM Education Research Group, School of Education, Curtin University

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Correspondence concerning this article should be addressed to Kok-Sing Tang, Curtin University, GPO Box U1987, Perth, Western Australia 6845, Australia

Contact: kok-sing.tang@curtin.edu.au

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Abstract

Current research in science education and the cognitive sciences has highlighted the importance of epistemic tools in scaffolding learners to think in ways consistent with scientific practices. However, recent studies on epistemic tool have mainly focused on epistemic cognition, but not epistemic metacognition. Epistemic metacognition, which operates at a meta-level targeted at our own thought processes concerning the source, nature, and justification of knowledge, is a crucial component that promotes and regulates epistemic development. The aim of this paper is to illuminate how an epistemic tool mediates and supports epistemic cognition and epistemic metacognition, and the difference between them. Drawing data from a design research study that introduced a specific epistemic tool called PRO (premise-reasoning-outcome) to describe the structure of a scientific explanation, this paper illustrates how PRO was used to facilitate the development of both epistemic cognition and epistemic metacognition. Specifically, epistemic metacognition was developed by using PRO with multiple metacognitive instructional approaches to: (a) highlight the epistemic connections between the various components of an explanation, (b) prompt questions that regulate one's own thought processes, and (c) organize navigational markers that regulate key ideas linking the causality of an explanation. The findings from this study provide insights and evidence for a crucial theoretical link that is currently missing in our understanding of epistemic tools, epistemic cognition, and epistemic metacognition.

Keywords: classroom discourse, epistemic tool, epistemology, metacognition, scientific explanation

The Use of Epistemic Tools to Facilitate Epistemic Cognition & Metacognition in Developing Scientific Explanation

The connection between epistemic and metacognitive development is currently a new area of research in the cognitive sciences (Barzilai & Zohar, 2016; Hofer & Sinatra, 2010). Epistemic thinking generally refers to any cognition that is related to epistemic matters, such as understanding and beliefs about the source, nature, and justification of knowledge (Chinn, Buckland, & Samarapungavan, 2011). For decades, many researchers (e.g., Hofer & Pintrich, 1997; Kitchener, 1983) have assumed that epistemic thinking shapes learners' perceptions of the knowledge learned from a task, and therefore makes metacognitive monitoring of the knowledge possible. Conversely, metacognitive awareness is widely regarded as a crucial component that promotes epistemic development (Khishfe & Abd-El-Khalick, 2002). However, the precise relationship between epistemic thinking and metacognition is still not clear.

A recent development currently being explored by several researchers is the use of epistemic tools to support the development of epistemic thinking (e.g., Christodoulou & Osborne, 2014; Stroupe, Moon, & Michaels, 2019; Windschitl, Thompson, & Braaten, 2008). Broadly speaking, epistemic tools are strategies or resources that purposefully facilitate knowledge production by making thinking visible and available through a shared discourse. In science classrooms, Settlage and Southerland (2019) argue that epistemic tools are more than devices to support inquiry, they also "scaffold the individual learner to think in ways consistent with scientists' practices while they develop discourse and thought processes affording and signalling fuller participation in science" (p. 1114). In the literature, there have been multiple epistemic tools identified as innovative pedagogies that disrupt the traditional knowledge transmission mode of learning, including explanation-driven inquiry (Sandoval & Reiser, 2004), evidence-based argumentation (Sampson, Grooms, & Walker, 2011), model-based inquiry (Windschitl et al., 2008), and knowledge building community (Scardamalia & Bereiter, 2006).

While researchers have explored the link between metacognition and epistemic thinking, as well as the role of epistemic tools in promoting epistemic thinking, what is currently missing is a clear connection between epistemic tool and metacognition. This connection has so far been difficult to examine for two reasons. The first reason is a lack of theoretical understanding that distinguishes between epistemic cognition and epistemic metacognition (Barzilai & Zohar, 2016). Many researchers follow Kitchener's (1983) distinction that treats epistemic thinking as a type of metacognition, thus creating a confusion as to whether epistemic tools mediate cognitive or metacognitive development. The second reason is a lack of empirical studies that illustrate how an epistemic tool supports epistemic metacognition in the classroom. Current literature examining the role of epistemic tools has mainly focused on epistemic cognition, but not epistemic metacognition.

To address these gaps, the aim of this paper is to illuminate a clearer relationship between epistemic cognition and epistemic metacognition, and the use of an epistemic tool in mediating each of them. First, based on a review of research from metacognition and epistemology, I make a distinction between object-level and meta-level cognition as well as between conceptual (non-epistemic) and epistemic cognition, in order to introduce four related constructs: conceptual cognition, conceptual metacognition, epistemic cognition, and epistemic metacognition. I then review several epistemic tools developed to foster scientific practices and how these tools have been used to prompt students' conceptual and epistemic cognition, but not metacognition. The review also includes a specific epistemic tool called PRO (premise-reasoning-outcome; see Tang 2016a) that was used in this study to describe the structure of a scientific explanation. Then, drawing data from a design research study where a group of teachers and students learned and applied PRO in their classroom discourse, I illustrate how an epistemic tool like PRO was used to facilitate epistemic metacognition, in addition to epistemic cognition. Lastly, I argue that this illustration provides evidence for a crucial theoretical link currently missing in our understanding of epistemic tool, epistemic cognition, and epistemic metacognition.

Literature Review & Conceptual Framing

Research on Metacognition

In the most general sense, metacognition refers to "cognition about cognition" (Flavell, 1979). However, this definition is too broad and the field currently lacks a unified theory that encompasses various terms and ideas associated with metacognition (Barzilai & Zohar, 2016). Nevertheless, there is a shared understanding that metacognition generally involves a number of attributes, two of which are central to the definition of metacognition adopted in this study.

First, metacognition differs from cognition in terms of the targeted entity that is being thought about. Nelson (1996) provides a useful distinction of cognitive processes at two different levels: object- and meta-level. In science, cognition at the object-level generally deals with things, events, or interactions in the natural world as well as the associated ideas or concepts related to them. Cognition at the meta-level, or metacognition, deals with our own or other people's object-level knowledge or thought processes, for example, in terms of their comprehensiveness, gap, source, reliability, logic, justification, or truth. At a meta-level, metacognition also monitors and controls cognition at the object-level.

The second attribute of metacognition is that it entails a level of conscious and deliberate processing. Many researchers agree that this level of consciousness is necessary for a meta-level cognition in terms of knowing, monitoring, and evaluating one's knowledge and learning progress (e.g., Nelson, 1996, Thomas, 2012). As Vygotsky (1986) puts it, this involves the consciousness of being aware of the activity of the mind. Drawing from

Vygotsky, Brown (1987) articulates metacognition as an understanding of knowledge that can be reflected in an overt description of that knowledge. Similarly emphasizing the "overt" aspect of metacognition, Thomas (2012) refers metacognition as "a conscious, reflected-upon and deliberate form of thinking that can be reflected upon by individuals" (p. 135).

Following the distinction made by Flavell, Miller, and Miller (2002), many researchers generally acknowledge two major components of metacognition: metacognitive knowledge and metacognitive skills (e.g., Veenman, Van Hout-Wolters, & Afflerbach, 2006; Whitebread et al., 2009; Zohar & Barzilai, 2013). Metacognitive knowledge, also called metacognitive awareness, is the knowledge of one's or other people's thoughts and thought processes in relation to cognitive tasks. It consists of: (a) self-knowledge of one's cognitive activity and knowledge of others' cognition, (b) knowledge of how the nature of a task affects cognitive activity, and (c) knowledge of strategies that can be used to achieve a particular goal (Flavell, 1979). On the other hand, metacognitive skills deal with the monitoring and control of one's cognition, and are sometimes called self-regulation (Fox & Riconscente, 2008). It consists of the regulatory skills of planning, monitoring, evaluating and control involved in learning and completing a task (Veenman, 2011; Whitebread et al., 2009).

As metacognition is often regarded as a useful tool to enable students to learn how to learn, there have been a number of metacognitive interventions that aim to develop students' metacognition in science learning. In a systematic review by Zohar and Barzilai (2013), they identified several categories of metacognitive instructional approaches in science education. The approaches that are most relevant for this study are: (a) *explicit instruction* where metacognitive knowledge and skills are explicitly taught or discussed with students, (b) *metacognitive prompts* where reflective or evaluative questions, cues, probes, or checklists are provided in the course of instruction, (c) *metacognitive modelling* where teachers demonstrate how to activate and apply metacognitive knowledge and skills during instruction or solving a task, and (d) *graphic organizers* where teachers use visual representations to help students represent or organize their thinking.

Research on Epistemic Thinking

Epistemic thinking has often been associated with metacognition even though research in personal epistemology actually emerged from a separate inquiry (e.g., student intellectual development; Perry, 1970). Kitchener (1983) was one of the first who brought the two areas together by proposing a three-level mode of cognitive processes, consisting of cognition, metacognition, and epistemic cognition. Based on this model, epistemic cognition is defined as the reflection by learners on the limits, certainty, and criteria of knowing. Because this definition involves a meta-level of "knowing about knowing" as well as the hierarchy nature of the model, Kitchener's definition of epistemic cognition is effectively a higher form of metacognition (which, in hindsight, should be called epistemic metacognition). Consequently, Kitchener's view has been critiqued by recent researchers as it obscured the distinction between epistemic cognition and metacognition, and limited a broader view of epistemic cognition that may not be metacognitive in nature (e.g., Barzilai & Zohar, 2016; Chinn et al., 2011; Hofer, 2004). This leads to the need for a finer distinction in the constructs of metacognition, epistemic cognition, and epistemic metacognition.

Barzilai and Zohar (2016) provide a critical distinction between epistemic thinking and metacognition as partially overlapping constructs. "Epistemic thinking involves both cognition and metacognition, but not all metacognition is epistemic" (Barzilai & Zohar, 2016, p.417). They reserve the term "epistemic cognition" to refer to the cognitive level of epistemic thinking. Referring to the distinction between object- and meta-level cognition described earlier, epistemic cognition occurs when people consider or engage with the epistemic status (e.g., knowledge representation, reliability) of information concerning things in the world (object-level), but not of their own or other people's cognition (Barzilai &

Zohar, 2016). Epistemic metacognition, on the other hand, occurs at a meta-level of epistemic cognition. In other words, in order for epistemic thinking to operate at a metacognitive level as opposed to a cognitive level, learners would have to either "be aware of their beliefs about the nature, source, structure, and justification of knowledge, and/or be using their beliefs about the nature, source, structure, and justification of knowledge to regulate their cognition" (Hofer & Sinatra, 2010, p.115).

Besides epistemic cognition and metacognition, it is also necessary to distinguish between another pair of constructs – epistemic and non-epistemic cognition. In introducing the *Handbook of Epistemic Cognition*, Greene, Sandoval, and Bråten (2016) note that many authors in the handbook use the adjective "epistemic" in order to refer to "cognition of or relating to knowledge," which is distinctly different from standard (non-epistemic) cognition. While there is a wide range of cognition, for the purpose of this study, I only focus on one type of non-epistemic cognition, conceptual cognition, following the distinction made by Sandoval (2003) between conceptual and epistemic aspects of scientific explanation. In particular, I regard any cognition as conceptual when the thought process involves ideas or concepts about specific phenomena or things in the world.

With these two independent sets of distinction, we can now represent on a two-by-two matrix four separate constructs – conceptual cognition, conceptual metacognition, epistemic cognition, and epistemic metacognition (see Figure 1). To give an illustration, when people think about a specific concept (e.g., density), phenomenon (e.g., hot air rises), and explanation (e.g., hot air rises due to density change), these are all examples of conceptual cognition. When they question the validity of an explanation in terms of its outcome (e.g., does hot air really rise?) or its underlying premise (e.g., is density change the cause?), this is a form of epistemic cognition because (a) it considers the source of information and knowledge claims behind this explanation (epistemic) and (b) the targeted cognition concerns natural events and the ideas associated with them (at object-level, e.g., hot air, density). When they consider their own thoughts concerning the validity of the explanation or strategies to investigate the validity (e.g. how do I know or find out what is the premise or evidence for this explanation?), then this is a form of epistemic metacognition as the cognition is both at a meta-level and toward an epistemic end. Finally, if the questions were "how much do I know about density?" or "how can I know more about density?", then these are non-epistemic (conceptual) metacognition.

	Non-epistemic	*Epistemic*
Object-level	**Conceptual Cognition*** *(e.g., What is density? Why does hot air rise?)*	**Epistemic Cognition** *(e.g., Does hot air really rise? Is density change the cause?)*
Meta-level	**Conceptual Metacognition** *(e.g., How much do I know about density?)*	**Epistemic Metacognition** *(e.g., How do I know or find out what is the premise or evidence for this explanation?)*

Figure 1. Relationships among conceptual cognition, conceptual metacognition, epistemic cognition, and epistemic metacognition

(*While there is a wide range of non-epistemic cognition, for the purpose of this study, it is sufficient to focus on conceptual as one kind of cognition that is non-epistemic.)

Many researchers have acknowledged the challenges of defining a boundary between epistemic and non-epistemic thinking (e.g., Hofer & Sinatra, 2010). This is mainly because the epistemic nature of a thought or action often depends on the situated context in which it occurs. Chin et al. (2011) suggest one way to overcome this challenge is to consider whether the cognition in question is directed toward the achievement of an epistemic end or goal. As Barzilai and Zohar (2016, p. 417) argue, this approach makes it possible to "identify epistemic thinking by the issues or ends it is concerned with rather than its form." In methodological terms, it is not productive to determine whether a thought or action is epistemic simply based on one sentence or utterance. Instead, we have to consider the larger context of the task or conversation to evaluate if the participants are discussing or working toward an epistemic end. This approach in examining the context to determine the epistemic or non-epistemic nature of a conversation will inform the analysis adopted in the study.

Epistemic Tools for Scientific Practices

This study involved the use of PRO as an epistemic tool to support students in learning how to construct scientific explanations based on its epistemic structure. Constructing explanations is one of eight scientific practices identified in the Next Generation Science Standards (NGSS; National Research Council, 2012), along with other related practices such as developing and using models, and engaging in argument from evidence. In science education, there is an increasing emphasis to develop epistemic tools to "scaffold the individual learner to think in ways consistent with scientists' practices" (Settlage & Southerland, 2019, p. 1114). Besides PRO, other epistemic tools designed to promote scientific explanations include *Explanation Constructor* developed by Sandoval and Reiser (2004). For scientific argument, a similar epistemic tool has been used in several studies to teach students the epistemic structure of an argument (e.g., Erduran, Simon, & Osborne, 2004; McNeill & Krajcik, 2008; Sandoval & Millwood, 2005; Wang, 2014). This epistemic tool (called CDW) was designed based on Toulmin's model of argument, consisting of claim (C) – a tentative proposition, data (D) – evidence to support the claim, and warrant (W) – a connection from data to the claim.

The conceptual design of PRO was informed by two theoretical perspectives: a philosophy of science perspective on the logic of explanation and a systemic functional linguistics perspective on the genre of explanation (Rappa & Tang, 2018; Tang, 2016a). In the philosophy of science, a scientific explanation is generally agreed to be a theoretical or mechanistic account of why or how natural phenomena occur the way they do (Achinstein, 1983). It typically involves three characteristics. First, the phenomenon in question has already occurred or is not in dispute within the scientific community. This is a key criterion that distinguishes an explanation from an argument, which always involves a degree of uncertainty over the claim to be argued, without which there would be no argument (Osborne & Patterson, 2011). Second, the account typically involves a causal or probabilistic mechanism that leads to the phenomenon observed. From a linguistic perspective, this mechanism consists of a chain of logical relations (joined by conjunctions, e.g., because, thus, next) that builds up the 'causation' of the explanation (Unsworth, 2001). Third, scientific explanations are often constructed logically based on generalizations derived from and validated through repeated observations (e.g., laws) or a model that connects seemingly disconnected phenomena with a unifying framework or theory (Braaten & Windschitl, 2011).

The above-mentioned characteristics are captured in three terms that are used to describe the epistemic structure of an explanation, namely premise (P), reasoning (R) and outcome (O). A *premise* is an accepted or assumed knowledge[1] that is used as the theoretical basis or "first cause" of an explanation. Common examples of premise include laws of nature, theoretical postulates, scientific rules and principles, and definitions. A *reasoning* in an explanation is the logical sequences that follow from the premise, and they are typically causal (cause and effect) or temporal (time-bounded) in nature. An outcome is the phenomenon to be explained, which can either be directly observed (e.g., hot air rises) or an undisputed and accepted fact within the scientific community (e.g., dinosaurs are extinct).

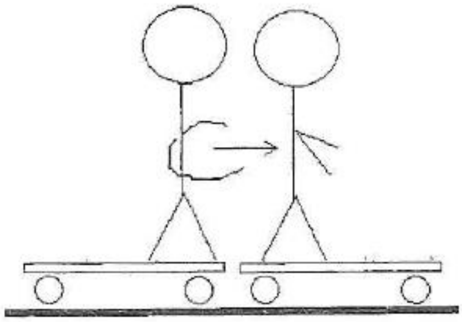
Instructional Scaffolds & Cognitive Prompts

The design of PRO, like many other epistemic tools, incorporated some elements of instructional scaffolds aimed at supporting students to write scientific explanations. As noted

[1] In the context of the explanation, a premise does not need to be "explained". However, this does not mean that a premise cannot be questioned. In the history of science, the strength of a premise is based on empirical evidence, but this will involve a different scientific practice which is argumentation.

by Wang (2014), cognitive prompts are one of the most common strategies used as scaffolds. Cognitive prompts are questions or elicitations that are not only grounded in domain-specific knowledge, but are also used to stimulate thinking in determining relevant scientific principles and reasoning (Bulu & Pedersen, 2010). In this case, cognitive prompts can be used to scaffold both conceptual and epistemic cognition (see the distinction in Figure 1). For example, in one of the first lessons when PRO was applied during the study, a supporting worksheet with a number of cognitive prompts was used (see Figure 2). These cognitive prompts consisted of a P-R-O table, guiding questions, and sentence starters. The generic P-R-O table and guiding questions were useful as epistemic scaffolds, while the content-specific sentence starters were more useful as conceptual scaffolds. Consistent with the notion of fading (Bruner, 1966), these prompts were gradually scaled back and removed in later lessons as the students became more familiar with the use of PRO.

1. In Scenario 1b from Lesson 1, why did both skaters move away from each other when only a skater was pushing?



Principles *(What do you know? What laws/principles involve? What's the concept behind?)*	When the skater was pushing, both of the skaters will move apart from each other
	According to Newton's third law, an equal and opposite force will be exerted on both of the skaters.
Reasoning *(What follows from the principles?)*	Therefore, the skaters being pushed will exert an equal and opposite force on the other skater
Outcome *(What is your conclusion?)*	Thus, both of the skaters will move away from each other.

Principles → When the skater was pushing, a force is exerted on the other skater.

~~Reasoning~~ → According to Newton's third law, a reaction force of the same magnitude but of opposite direction acts on the pushing skater.

~~Reasoning → Therefore,~~

Outcome → Thus, the skater who pushes move backwards and the skater that was pushed move forward.

Figure 2. Supporting worksheet with cognitive prompts used in the first lesson with PRO

In other studies, Sandoval and Reiser (2004) introduced a type of cognitive prompt called *explanation guides* to help students engaged in the epistemic practice of constructing and evaluating a scientific explanation. Embedded within *Explanation Constructor*, the explanation guides consisted of a set of connected prompts that highlighted the conceptual content and epistemic structure of a scientific explanation. As explanation guides prompted students to think about the casual components of a phenomenon or idea such as natural selection, they were also tools for promoting both conceptual and epistemic cognition. In another study on scientific argumentation, Wang (2014) used the CDW framework as cognitive prompts to help students differentiated their claim, data, and warrant in their written argument. Interestingly, Wang (2014) also focused on metacognition in her quasi-experimental study. However, instead of using the prompts based on CDW, a peer evaluation rubric not related to the argument epistemic tool was used as a separate scaffold for metacognitive development.

In the literature, studies on epistemic tools have mainly examined the use of cognitive prompts to target cognitive processes (both conceptual and epistemic), but not metacognition. At the time of the research when PRO was first conceptualized, it was natural to design this epistemic tool with the use of supporting cognitive prompts. While the addition of cognitive prompts supported student thinking and writing with PRO, they did little to engage metacognition, which would involve a conscious reflection and explicit discussion on the nature, structure, and justification of knowledge in constructing scientific explanation or argument (Hofer & Sinatra, 2010). Although PRO was not designed with a metacognitive focus in mind, one of the teachers in the study later adopted it to reinforce his metacognitive instruction. As such, this prompted our interest to explore how an epistemic tool such as PRO, can be used as a metacognitive tool to promote epistemic metacognition.

Methodology

Research Context

With the aim of understanding how PRO was used to scaffold epistemic cognition and epistemic metacognition, and the difference between them, there were two research questions (RQs) that guided this study:

1. How did the teacher use PRO as part of his cognitive and metacognitive instruction?
2. What was the nature of epistemic cognition and of epistemic metacognition as they developed and manifested in the classroom discourse when PRO was used?

To address these questions, data were taken from a case study (Mitchell, 1983) where PRO was explicitly taught to and used by a group of teacher and students in a physics classroom. This case study was situated in a larger three-year design research (Collins, Joseph, & Bielaczyc, 2004) that aimed to examine and improve the teaching of science disciplinary literacy in Singapore. The design research had two phases. First, a baseline observation was carried out on four secondary school science teachers (including the physics teacher selected for this case study) in their respective classroom environments over six months. In light of the findings from the baseline observation, the second phase involved an intervention to design instructional strategies and co-develop lesson plans with the participating teachers over two years. In particular, it was reported from the teachers that many students struggled in scientific explanation. As such, one of the foci in the intervention was the development of a heuristic to support students in constructing scientific explanation. Based on our baseline observation and a review of the literature, this was how the research team developed PRO as an epistemic tool (see Tang 2015, 2016a for elaboration).

Through several professional development workshops conducted by the research team, the teachers learned about PRO and discussed how to implement it in their respective classrooms for various physics and chemistry topics, including forces and motion, density, kinetic model of matter, chemical bonding, and electrolysis. During classroom implementation, the teachers had full control and ownership in enacting PRO according to their teaching practices and the classroom situations. At the beginning of the intervention, the teachers tended to rely more on the research team in the lesson planning and direction over how PRO should be used.

Gradually, as the teachers became more familiar and confident in the use of PRO, they began to have more ownership and direction over how it was used with their students in the classroom.

During the joint planning and development of PRO, the teachers anticipated many students would find it difficult to understand the word “premise.” As such, we changed the terms from *Premise*-Reasoning-Outcome to *Principle*-Reasoning-Outcome during classroom implementation. This decision was made to facilitate students’ initial understanding of the PRO strategy, but it created some issues later in the implementation (e.g., see episode 2 in the findings section). This was because the meaning of “principle” is narrower than “premise.” For example, many statements that are not technically scientific principles (e.g., definition, fact, formula) can be used as a premise in a scientific explanation within an instructional context. In this paper, the P in PRO will continue to denote “premise,” but in the reporting and interpretation of data, I will occasionally switch to “principle” in order to quote from and reflect the voices of the participants.

At the time of the research, there was no emphasis or discussion on metacognition. This was because metacognition at the time was not within the instructional scope and analytical focus of the design research. In addition, the PRO framework was developed to be a cognitive tool, rather than a tool for metacognitive instruction. However, during the classroom observation, one of the participating physics teachers, whom we called John, demonstrated some metacognitive instruction during both the baseline and intervention phases. More importantly, it was observed that the nature of his metacognitive instruction changed notably when John applied PRO in his teaching. For instance, toward the later stage of the intervention, John used PRO as a structure for his students to practice asking self-regulatory questions in their mind in the process of constructing an explanation.

This preliminary observation thus motivated a deeper analytical focus on metacognition based on John’s instruction with the use of PRO. As the subsequent analysis focused on only one teacher, I do not make any universal claim about the nature of epistemic cognition and metacognition outside the context of this case study. Instead, my purpose is to explore this under-studied and under-theorized terrain and gain some qualitative insights and understanding. In this regard, the purpose of this analysis is to provide a revealing case study (Mitchell, 1983) to explore and highlight this unknown phenomenon for further study and discussion.

At the start of the research, John had been a physics teacher for three years. He has a degree in physics and a post-graduate diploma in education. Consistent with the typical instructional approach in Singapore's examination-oriented education system, John's classroom teaching was predominantly teacher-directed instruction. However, John also frequently used small group or pair discussions and hands-on explorations to complement his instruction. In the second year of research that generated the data used in this study, John's ninth-grade physics class had 31 students. These students were generally motivated and their academic abilities were about average[2], according to results from a national examination taken at the end of sixth grade. Like most students in Singapore, they tended to be quiet and not speak up in class unless they were called upon by the teacher. In Singapore, all children formally learn English as a first language in primary school and most started earlier in kindergarten. About half of all the young children in Singapore grow up in families that predominantly converse in English.

Data Sources & Analytical Procedures

The primary data source for this study was classroom videos, which covered all the lessons taught within selected topics. A research assistant was involved in recording the classroom events from the back of the classroom. For John's class, a total of 18 lessons (16 hrs & 42 mins) and 29 lessons (30 hrs & 40 mins) was collected during the baseline and

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[2] In Singapore educational system, all students in public schools are streamed into different schools and classes according to their academic abilities, which are measured by their results in national standardized examinations. Based on the results of the streaming, the students in John's class would be considered as having average ability in comparison to the entire student population of the same year in Singapore.

intervention phase respectively. During the intervention phase, the topics covered in the data collection included Newton's laws of motion, moments, density, and kinetic model of matter.

The classroom videos were analyzed in three distinct phases: (a) segmentation and reduction, (b) coding, and (c) discursive interpretation. In segmentation, the continuous video sequence was partitioned into meaningful discrete segments called *episodes* according to Erickson's (1992) ethnographic microanalysis methods. Each episode was determined by prominent shifts that occurred due to the participants' ongoing interaction or the nature of the discussion. On average, each episode was 3 minutes and 14 seconds long. In a previous study (Tang, 2016b), every episode was categorized into different types of literacy events (e.g., whole class talk, student discussion, reading, writing). Within the category of whole class talk, each episode was sub-categorized into review, instruction, explanation, worked solution, and announcement.

For the purpose of this study, episodes involving explanation within whole class talk for John's classes were selected for further analysis. This selection made up about 20% of the time in the recorded videos. This dataset was further reduced by selecting lessons involving the use of PRO as an epistemic tool. From this reduction, there were 17 episodes lasting a total of 68 minutes.

In the next analytical phase, each selected episode was coded at an utterance level for instances of epistemic thinking and instructional scaffold. I drew on an observational tool first developed by Whitebread et al. (2009) and later expanded by Barzilai & Zohar (2016) to identify and assess the participants' epistemic cognition and metacognition in naturalistic settings (e.g., classroom talk). This observational tool, in the form of a coding framework, consists of an operational definition for identifying epistemic cognition (EC), epistemic metacognitive knowledge (EMK), and epistemic metacognitive skill (EMS) based on observable verbal and nonverbal indicators (see Table 1). Examples of EC include justifying a claim, considering the validity or coherence of knowledge, and assessing the source or nature of knowledge. Examples of EMK include knowledge of one's epistemic disposition, knowledge about the nature of knowledge, and knowledge about knowledge construction strategies. Lastly, examples of EMS include the planning, monitoring, and evaluation of knowledge construction strategies and processes.

Table 1

Coding Scheme at the Utterance Level

Code		**Verbal & nonverbal indicators**
Nature of Epistemic Thinking		
EC	Epistemic Cognition	Any verbalization or behavior demonstrating a consideration of the epistemic status of information (e.g., source, knowledge claims, representation) concerning things or events in the world
EMK	Epistemic Metacognitive Knowledge	Any verbalization or behavior demonstrating explicit expression of one's knowledge or beliefs in relation to the epistemic status of information (e.g., source, knowledge claims, representation)
EMS	Epistemic Metacognitive Skills	Any verbalization or behavior related to the planning, monitoring, controlling, and evaluation of strategies and processes of knowledge construction and justification
Nature of Instructional Scaffold		
CP	Cognitive prompt	Any visible use of questions, cues, or probes with the explicit aim of fostering conceptual or epistemic cognition
MP	Metacognitive prompt	Any visible use of questions, cues, or probes with the explicit aim of fostering metacognitive knowledge or skills
EI	Explicit instruction	Any visible teaching of metacognitive knowledge or skills where the development of metacognition is an explicit instructional goal
MM	Metacognitive modelling	Any visible demonstration of how to activate and apply metacognitive knowledge or skills in the course of teaching, in order to model these practices for the students
GO	Graphic organizer	Any visible use of graphic organizers (concept maps, flowcharts) to help students represent their thinking and learning

In the codes for instructional scaffold, an important distinction to highlight in the data is between cognitive and metacognitive prompt. As mentioned earlier, cognitive prompts (CP) are questions, cues, or probes which aim to build conceptual and/or epistemic cognition regarding ideas about the natural world (Wang, 2016). Metacognitive prompts (MP) on the other hand, are questions, cues or probes which aim to foster metacognitive knowledge or skills (Zohar & Barzilai, 2013). In addition to metacognitive prompts, there are other instructional approaches used to foster metacognitive thinking. Drawing on Zohar and Barzilai's (2013) work that was reviewed earlier, I drew on three other codes that are most relevant for this study: explicit instruction (EI), metacognitive modelling (MM), and graphic organizer (GO).

The purpose of the coding at an utterance level was not to provide an isolated evidence of epistemic cognition or metacognition from a single utterance. As mentioned earlier, whether an action can be considered epistemic or metacognitive cannot usually be determined based on one utterance alone, but must be interpreted within the larger context of the conversation. Instead, the purpose of the coding was to facilitate an evidence-based interpretation in the final phase, which was to interpret the codes with greater discursive details within the context of the episode. Specifically, the codes for CP, MP, EI, MM, and GO facilitated the interpretation for RQ 1, while the codes for EC, EMK, and EMS facilitated the interpretation for RQ 2. This contextual interpretation included a discourse analysis (Gee, 2010) that takes into account the participants' turn-by-turn interactions and meaning-making process. The codes and interpretations were subsequently compared within and across episodes to look for generalizable patterns and themes within the case study. In an iterative manner, assertions were then generated in response to the specific RQs and the theoretical constructs of epistemic cognition and metacognition based on the literature.

One of the methodological challenges concerning the validity in this study was the use of videotaped observations to examine epistemic cognition and metacognition. Unlike more commonly used methods in metacognition that involve self-report measures (e.g., questionnaires, interviews, think-aloud protocols), observation methods rely on directly observable behaviours and require a high degree of inference from the analysts. Acknowledging these methodological challenges, Whitebread et al. (2009) took methodical steps to address issues of validity as they developed and validated their coding framework based on 96 hours of video data of children working in the classrooms.

In the application of Whitebread et al.'s (2009) and Barzilai & Zohar's (2016) coding frameworks, I took additional steps to increase the credibility and trustworthiness of the interpretations. First, two analysts were involved in the coding process in order to discuss and confirm each other's codes and interpretation. Any ambiguity was discussed and resolved until a common interpretation was established. Second, we searched for confirming and disconfirming evidence to check and revise our codes and emerging claims during the analysis. Finally, we paid attention to the linguistic details of the participants' utterances and actions at a micro-analytic level, which is an important element of validity for discourse analysis and interpretation (Gee, 2010). These details also provide a rich "thick description" (Denzin, 2002) for readers to evaluate and ascertain for themselves whether our interpretation is credible and applicable in their context.

Notwithstanding the limitations of observation methods, Winne and Perry (2000) and Whitebread et al. (2009) argue that these methods have many advantages over self-report measures. First, observation examines what the participants actually do based on their words, gestures, gazes and other multimodal actions, instead of what they remember or perceive themselves doing. Second, observation occurs within a naturalistic setting and takes into account of the context of the situation, and therefore presents a more authentic interpretation of the task involved. Third, it does not rely on the language abilities of the participants to articulate their thinking, which is a challenge for most research on children.

Findings

From the analysis of the data, the main argument in this paper is that an epistemic tool such as PRO can be used to facilitate the development of both epistemic cognition and epistemic metacognition involved in constructing scientific explanations. Specifically, in the case of the teacher John, epistemic metacognition was developed by using PRO with multiple metacognitive instructional approaches to: (a) highlight the epistemic connections between the various components of an explanation, (b) prompt questions that regulate one's own thought processes, (c) organize navigational markers that regulate key ideas linking the causality of an explanation.

To illustrate these assertions, six episodes will be presented next. Among the 17 episodes that involved the use of PRO to scaffold explanation construction in John's whole class talk, these six episodes were selected for an illustrative purpose of representing a chronological development in terms of how John and his students became more familiar with using PRO and subsequently adapting it from a cognitive to metacognitive tool. Episode 1 occurred in the beginning of the intervention phase when the students just learned about PRO as a heuristic and applied it to explain a phenomenon involving a pair of action-reaction forces. Episode 2 occurred a few months later, when PRO was applied to explain the "dancing raisin" phenomenon where a raisin repeatedly rose and sunk in carbonated water. Episode 3 to 5 occurred within the same lesson in the third cycle of the intervention (within the same academic year) and they demonstrated a marked transition toward the instruction and development of metacognition as compared to episodes 1 and 2. The question that drove the explanation in episode 3 to 5 was, "Why air blown into a balloon inflates it?" Finally, episode 6 occurred a few days later and the discussion question was, "Why does hot air rise?"

All six episodes occurred within the second year of the design research with the same group of students.

The manifestations of epistemic cognition/metacognition in relation to the use of instructional scaffolds will first be shown and explained through each of the six episodes. Subsequently, the role of PRO as an epistemic tool will be discussed in another section.

Episode 1: Using PRO to Identify Principle (Premise), Reason, and Outcome

In the lesson where this episode occurred, the instructional objective was to learn about Newton's Third Law of Motion through a series of demonstrations and discussions. Two student volunteers were asked to perform the demonstrations by interacting with each other while standing on a skateboard. In the second demonstration (called scenario 1b), only one skater exerted a push while the other remained standing. The students observed the resulting motion and they were then asked to formulate a preliminary explanation in pairs with the help of a supporting worksheet. As shown in Figure 2, the worksheet included three types of cognitive prompts: (a) a P-R-O table, (b) guiding questions, and (c) sentence starters to guide the students in completing their written explanation.

After most of the students had completed their worksheets, John projected the worksheet on the screen and used it to facilitate his whole class discussion. As he elicited the responses from the students, he wrote them down to complete the sentence starters on the worksheet, which was made visible to the whole class. The following discussion shown in Table 2 ensued.

In all the transcripts that follow, John is denoted by "J." Specific identifiable students are represented by "S1," "S2," and so on; while unidentifiable voices are represented by ''S'' or "Ss" for individual voice and multiple voices, respectively. Two dots ".." indicate there was a substantial pause (more than 2 seconds) while three dots " . . . " indicate the omission of utterance that is not relevant to the analysis. Nonverbal actions are shown within parenthesis. Codes for epistemic thinking (EC, EMK, EMS) and instructional scaffold (CP, MP, MM, EI, GO) are shown alongside the occurring utterances. **Bold** and *italics* in the transcript denote cues or phrases that influence our interpretation of why the utterance was an instance of epistemic thinking and instructional scaffold respectively.

Table 2

Transcript and Codes for Episode 1

No	**P**	**Utterance**	**Epistemic Thinking**		**Scaffold**
			Students	**Teacher**	**Teacher**
1	J	In scenario 1b from lesson 1, why did the skater move away from each other when only a skater was pushing.. You realise in exam right, they will just give you this statement, a skater is pushing another skater from behind, explain what do you observe. **So there is actually 2 parts. There is one you need to state your observation. The other one is to explain your observation**. **And we will use this structure to answer the question which is our P R and O.** Our principle, our reasoning and then our outcome. So let's try, so let's see what else did you write down?		EMK	MM
2	J	S1, what did you write down in your so called worksheet? (*Read from sentence starter next to Principles*) *When the skater was pushing*, what did you write down?			CP
3	S1	The skater moved eh backward			
4	J	The skater moved backward?			
5	S1	**Because we saw him moving backwards what**	EC		
6	J	**Yah, but that one does it belong to the principle, the reason or the outcome?**		EC	
7	S1	**Outcome**	EC		
8	J	**So what you said is in the outcome part.**		EC	
9	J	*Thus,* (started writing on board *after the sentence starter next to Outcome*) the skater who pushes actually moves backwards and the skater that was being pushed move forward.			CP
10	J	**But this is your outcome. What is the principle that we had learnt according to Newton?**		EC	
11	S2	Third law			
12	J	Third law of motion. *Obviously here* (*pointed at "Principles"* on screen) is third law of motion.			CP
13	J	And **accordingly to third law of motion, a what force?** I did not introduce this word but there is a word here		EC	
14	S3	Reaction force?			

There are two parts in this episode that are relevant to the analysis. The first part occurred in line 1 where John was giving a monologic commentary about the nature of the task they were doing. Such commentary was frequently observed in John's whole class talk in order to set up the context of the explanation that would be subsequently developed in the later discussion (Tang, 2017). This commentary is coded as an instance of epistemic metacognitive knowledge (EMK) for two reasons. First, it reflected John's knowledge of the nature of knowledge required, which consisted of two parts: "state your observation" and "explain your observation." Second, it indicated a knowledge of the strategy (i.e., PRO) to provide a "structure to answer the question."

John's commentary was provided as a form of metacognitive modelling (MM) where he made his thinking visible for the students by talking aloud what they should "realize in exam" and articulating what they needed to do (e.g., "we will use"). This "think-aloud" procedure is commonly used to model metacognitive thinking by many teachers (Fisher, 2002). In this utterance, although John considered and talked about the epistemic status of an explanation (which justified it as a form of EMK and MM), it is important to point out that he regarded it from the perspective of the information required in an examination, rather than as a form of scientific practice. However, the later episodes would show a contrasting perspective.

The second analytical part of this episode illustrates instances of epistemic cognition (EC) and cognitive prompt (CP) from line 2 onward. As John was using an Initiate-Response-Feedback (IRF) interaction pattern (Mortimer & Scott, 2003) to elicit students' ideas to construct the explanation, an interesting exchange occurred from line 3 to 7. When John asked S1 what she wrote down after the sentence starter – "When the skater was pushing," S1 replied, "the skater moved backward" in line 3. This response was not conceptually wrong. In fact, most of the students wrote down similar answers in their worksheets. However, in line 4, John's repetition of S1's response in a rising intonation signalled a doubt in her answer. This immediately led S1 to voluntarily give a justification of her claim in line 5. S1's justification based on her observation was an instance of EC.

John's follow-up comment continued this epistemic conversation. In line 6, John agreed with S1 over her observation with a "Yah," but he questioned whether her identification of this observation should "belong to the principle, the reason, or the outcome?" In other words, John was not concerned with whether S1's answer was correct *conceptually*, but more *epistemologically* along with the PRO framework. John's actions from line 2 to 8 were prompted and mediated by the worksheet, which clearly juxtaposed the sentence starter next to "Principles" in the left column of the table (see Figure 2). If S1's response occurred while John was filling in the blank next to "Outcome," then her response would be regarded as correct, both conceptually and epistemologically. Therefore, at this point, John wanted the students to identify the principle instead of the outcome. In line 10, John then went on to elicit from the students what should be the principle "according to Newton."

In terms of the cognitive prompt, there were two different types from the worksheet that mediated the classroom talk. First, there were the sentence starters which John read out as he called upon selected students to answer and fill in the blanks as he elicited their responses, as seen in line 2, 9, and 12. These sentence starters prompted responses targeted at conceptual cognition, which is neither epistemic nor metacognitive (e.g., skater moved backward, a force is exerted). However, the second type of cognitive prompt is the P-R-O table which subsumed and incorporated the sentence starters in one of the columns (see Figure 2). The P-R-O table was designed to help students determine the epistemic structure of the explanation in terms of knowing which responses "belong to the principle, the reason or the outcome?" (line 6). As discussed earlier, the conceptual versus epistemic emphasis between the sentence starters and P-R-O table led to a brief conflict between S1 and John from line 3 to 7.

Episode 2: Using PRO for Non-Linear Reasoning

In this lesson which occurred about two months after episode 1, John wanted his students to apply the concept of density to explain why a raisin in carbonated water would sink and float a number of times. The students, in pairs, performed this "dancing raisin" demonstration using hands-on materials and subsequently observed the phenomenon. They were then asked to write an initial explanation. Prior to the following transcript, John had discussed with various groups of students regarding their ideas and connecting those ideas to the concept of density. After the small group discussions, he went on to discuss their answer as a class using the PRO framework, as shown in Table 3. As he elicited individual students' responses, he wrote them on the board next to a vertical line of "P:", "R:", and "O:" prompts (see Figure 3).

Table 3

Transcript and Codes for Episode 2

No	P	Utterance	Epistemic Thinking		Scaffold
			Students	**Teacher**	**Teacher**
1	J	Okay, let's discuss the answer please… Can you look up here? (pointed at the board with PRORO written; see Figure 3) **Okay, usually by principle right, we have a very nice principle to use like Newton's first law, Newton's second law of motion. But in this case, when we talk about principle, we do not have specific name for it. But what you can do here, you can state the formula or definition of density.**		EMK	MM
2	J	So we write down (*started writing **next to P***) Due to density equal to.. Sorry, let's put it into words. Density is mass per unit volume.		EC	CP
3	J	Okay, now what did you first observe? Let's write down the observation. The raisin, the moment you put it in, actually most of them actually?			
4	S1	Sink			
5	J	Sink. So.. (*started writing **next to O***) **outcome is** the raisin sink**.**		EC	CP
6	J	So why do you think the raisin will sink?			
7	S2	Due to fact that they are more dense than water			
8	J	Correct. So.. *(started writing **next to R***) the density of the raisin is higher or you can just use what Alvin said, that the raisin sink is more dense than water. Higher than water. And so your raisin sink.		EC	CP
9	J	After that, what do you observe? The raisin actually?			
10	S3	Float			
11	J	Float. Why did the raisin float?			

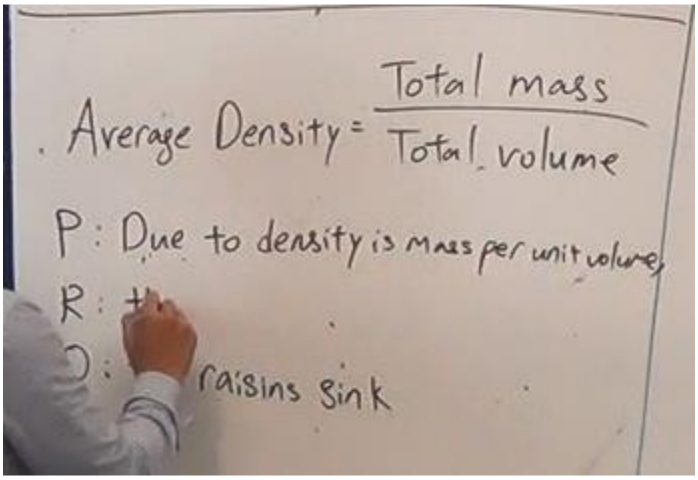

Figure 3. Using PRO as cognitive prompts in the lesson on density

Analytically, this episode has the same two-part structure we saw in episode 1. It began with a lengthy commentary that served as a metacognitive modelling for some form of EMK in line 1. This was then followed by a similar IRF interaction pattern to build the explanation through a series of cognitive prompts from line 2 onward. However, there were some notable differences that are important to highlight.

First, although John's comments in line 1 in both episodes were instances of EMK, they were quite different in nature. In this episode, John remarked that most of principles they had applied using PRO in previous lessons were scientific laws (e.g., Newton's Laws). For this explanation however, they could simply use "the formula or definition of density" as the P. This is an interesting remark as it revealed John's knowledge of and emphasis on the epistemic nature of a scientific premise, instead of emphasizing the information required for examination purpose as he did in episode 1. (John's justification of using a formula or definition as a premise was necessary because the students learned P as "Principle" instead of the more inclusive term "Premise." As explained in the methodological section, the choice of "Principle" was a pedagogical decision made during the design research, which on hindsight was not the right decision.)

The second difference was there was less scaffolding provided in the cognitive prompts. Compared to episode 1, the sentence starters had been removed (consistent with the notion of fading), and the prompts consisted of just the letters P, R, O written on the board. Thus, instead of using the sentence starters to probe his students as in episode 1, John organized his questioning using the P-R-O prompts. He started with commenting on P in line 1 and 2, asked what the first observation was (i.e. raisin sinks) from line 3 to 5, and then asked for the reason from line 6 to 8. He did this repeatedly for the next observation (i.e. raisin floats) from line 9 to 11, and so on. In this way, John was using the P-R-O prompts to scaffold a non-linear reasoning (i.e. P-O-R-O-R) to construct the explanation. This non-linear reasoning emphasized the epistemic structure and pattern of a scientific explanation instead of the conceptual (causal or temporal) sequence of an explanation. Correspondingly, identifying the various parts of the explanation as P (in line 2), O (in line 5), and R (in line 8) were instances of EC.

Comparing episodes 1 and 2, we can see a small shift in the use of PRO to focus more on the epistemic aspects of a scientific explanation, and less on the conceptual content. This shift was not unexpected given that the students and teacher became more familiar with PRO. However, the discussion on epistemic matters was still very implicit and teacher-centered. In addition, metacognition was only limited to the teacher's modelling and there was no explicit attention or prompt toward epistemic metacognition.

Episode 3: Using PRO to Teach Scientific Reasoning (Opening Stage)

The next three episodes (3 to 5) occurred within the same lesson focusing on the kinetic model of matter, specifically "why air blown into a balloon inflates it?" What was particularly revealing in this lesson is the use of PRO to *explicitly* foster metacognition involved in constructing an explanation. This instructional goal was directly stated by John when he expressed his intention in line 17 to teach his students to "think of your thinking process. It's called metacognition."

Table 4

Transcript and Codes for Episode 3

No	P	Utterance	Epistemic Thinking		Scaffold
			Students	**Teacher**	**Teacher**
1	J	Explain.. using the kinetic model of matter.. why gas, or air, sorry, air.. blow into a balloon.. inflates it. (Wrote the question on the board as the words were uttered) **Notice, it's again an explain question.**		EMK	MM
2	J	Now, yup, sorry, you were saying?			
3	S1	**PRO**	EMK		
4	J	Very good, PRO, so **we want to use** our PRO again		EMK	MM
5	J	So now, since you say PRO.. (Wrote "P" on top and "O" on bottom of board) **What's my P then?**		EMS	MM/CP
6	S2	Due to kinematic model of matter.			
7	J	(Pointed to S2. Then wrote "Due to kinematic model of matter" on the board next to P)			
8	J	**What's my outcome?**		EMS	MM/CP
9	Ss	Balloon inflated			
10	J	So, or as, or so.. the balloon.. is inflated. (Wrote "Balloon is inflated" next to O)			
11	J	Notice almost all the students here are very good. All can give me P. All can give me O…			
12	J	So, *what is the difficult part?*			MP
13	Ss	**Reasoning**	EMK		
14	J	Reasoning. So now, today hopefully I can **teach you how to do scientific reasoning**.. How do you all think we can do scientific reasoning?.. Let's say now huh, I am going to do, I am going to come up with the reasoning. **What must I do first on my own?**			EI
15	S3	Think			
16	S4	Think			
17	J	Think. When you are thinking, what are you actually thinking?.. **Think of your thinking process. It's called metacognition**			EI

At the beginning of the discussion, John was giving his usual commentary about the nature of the task, "notice, it's again an explain question" (line 1). Similar to the previous episodes, he was using think-aloud to model metacognitive thinking involving a scientific explanation. This time however, a student S1 interrupted him and initiated the use of PRO as a strategy to tackle the task. By initiating this response, S1 demonstrated EMK in terms of a situated awareness of what strategy to use and when to use it in relation to constructing a scientific explanation.

Building on S1's suggestion, John then used PRO to divide and organize the whiteboard space. Similar to what he had done previously in the dancing raisin density lesson, he used P and O as cognitive prompts to elicit what was the premise and outcome respectively (line 5 and 8). Although John's actions in line 5 and 8 were similar to the instances of epistemic cognition coded in episode 2, in this context I argue that his questions of "what's my P?" and "what's my outcome?" also served as an epistemic metacognitive function for the purpose of metacognitive modelling. One reason for this interpretation is based on what occurred later when John expressed an explicit intention to foster the students' metacognition in this lesson. Seen in this context, his questions in line 5 and 8 served as a metacognitive modelling to the kind of questions one must mentally ask him/herself in developing an explanation; as seen from the teacher-students exchange from line 14 to 17, "What must I do first on my own? Think." This mental self-reasoning also explains why he used the pronoun "my" twice in his questions, instead of a generic "the" or "your." More specifically, John was demonstrating to his students the epistemic metacognitive skill (EMS) of planning an explanation, by modelling how to regulate his *own* thought process in planning the beginning (P) and end (O) of the explanation.

After this preliminary planning involving P and O, John then moved to the main emphasis of this discussion which centered on the reasoning R from line 11 to 17. In particular, the discussion focused on the difficult part of linking P and O through scientific reasoning and the necessity to "think of your thinking process" or metacognition (line 17). In line 12, when John asked the students "what is the difficult part" of PRO, this was a metacognitive prompt (MP) because the response it generated was not about object-level events or ideas (e.g., balloon inflated, kinetic model), but about the nature of PRO strategy in addressing the epistemic task. This helped to raise the students' awareness or EMK of the challenges involved in constructing scientific reasoning. After raising this awareness, John then proceeded to state his explicit instruction to "teach" them how to address this challenging aspect of "scientific reasoning" (line 14) by using "metacognition" (line 17).

Episode 4: Using PRO to Teach Scientific Reasoning (Developing Stage)

Immediately after setting up the instructional goal in episode 3, John went on to the developing stage of constructing the explanation through a series of metacognitive prompts and modelling in this episode (See Table 5). There were two unique aspects of metacognition in this episode that were mediated by the use of the PRO: (a) teaching students to ask their own regulatory questions and (b) regulating key ideas from different parts of an explanation.

Table 5

Transcript and Codes for Episode 4

No	P	Utterance	Epistemic Thinking		Scaffold
			Students	**Teacher**	**Teacher**
18	J	*When you see your O.. what question do you want to ask yourself before you form your R?*			MP
19	S5	**Why?**	EMS		
20	J	Why. Why what?			
21	S6	**Why is this the outcome?**	EMS		
22	J	Ah, okay, so why is this the outcome, so you want to ask yourself why is this the outcome. Sorry?			
23	S7	**What properties cause the outcome?**	EMS		
24	J	Ah, what properties cause the outcome?			
25	J	So we have all these questions like what properties.. or what cause the outcome?.. What properties cause the outcome?...			
26	J	**Questions we ask ourselves. So S7 said that he will want to ask himself…** So what cause the outcome?...		EMS	MM
		(*Wrote students' questions on board; See Figure 4*)			GO
27	J	So now that **S7 has helped you all start to reason,** in asking what caused the outcome, can someone tell me, what caused the outcome?...		EMS	MM
28	S8	Is it related to gas pressure?			
29	J	Yes. So we have to do with pressure. (Pointed to S8) **She has already come up with this question**, because back then in chapter 6 when we talked about pressure, only when there's movement right, when we cause something to inflate and deflate is due to pressure difference.		EMS	MM
30	J	So now we have this keyword that we want to use here called pressure.			
31	J	So probably.. **what key ideas caused.. the outcome?** (Wrote "what key ideas cause the outcome?")		EMS	MM
32	S9	Because the air inside is it compressed?			
33	J	The air inside is it compressed? Wait, you hold to that idea first. Let me write down what she said so that we are all on the same page.			
		(**Gestured space between the P and O statements**)		EMS	MM/GO
34	J	So **over here** she (pointed at S8) said there is a pressure **somewhere** (Wrote "pressure" *inside the space*)		EMS	MM/GO

No	P	Utterance	Epistemic Thinking		Scaffold
			Students	Teacher	Teacher
35	J	So **somehow we know** that the key idea is the pressure. **We have answered this.** (Pointed to the question "what key ideas cause the outcome?" on the board)		EMS	MM
36	J	*What is the next question you ask yourself* when you come up with this key idea already?			MP
37	Ss	**Which pressure is higher?**	EMS		
38	J	Which of the pressure is higher. Very good. So which of the pressure is higher to cause it to inflate?			
39	S10	(Inaudible)			
40	J	Okay. So pressure inside.. balloon.. is higher.. than outside (Wrote statement on the board)			
41	J	Looks good right? So pressure inside the balloon is higher than the outside. So the balloon is inflated. Looks pretty cool			
42	J	Now.. **we still have yet to answer**.. what key ideas, ah sorry, what, *what other question would you want to ask yourself* regarding this, this keyword here. (T points to the keyword 'pressure' on the board)		EMS	MM MP

In the first aspect of John's metacognitive approach, he got the students to ask themselves regulatory questions to guide their thinking process. This was seen several times in line 18, 36, and 42. Instead of the usual teacher asking a question leading to a student's answer, John had his students form their own questions in order to guide them through the explanation. The subsequent questions raised by the students (line 19, 21, 23 & 37) were EMS because they were regulatory and strategic questions that were deliberately premeditated to link R to O in the explanation, rather than questions with a conceptual answer in mind. These self-regulatory questions were first prompted by John in line 18 through the question "when you see your O, what question do you want to ask yourself *before* you form your R?" Such questions were targeted to help students plan their own questions as a metacognitive strategy to tackle the epistemic task. As such, these questions that prompted the students' regulatory questions served as a form of metacognitive prompts (line 18, 36 & 42).

Besides metacognitive prompt, John also modelled how to ask good regulatory questions himself in line 26, 27, 29, and 31. He did this mostly by paraphrasing the questions given by the students and refining them in the process. A good example occurred in line 28 when the question asked by S8 was not a regulatory question. But John used this response to model the question that prompted S8 to think about "gas pressure" and eventually derived the regulatory question of "what key ideas caused the outcome?" in line 31.

The question "what key ideas caused the outcome?" in line 31 can be read as either a cognitive question or a metacognitive question depending on whether the focus was on the "key ideas" part (object-level) or the regulatory question itself (meta-level). In the following utterance, S9 answered that question with a key idea (i.e. air inside is compressed). However, it was apparent that was not what John had in mind as he asked S9 to "hold to that idea first" (line 33). John was more interested in the regulatory question rather than the answer or "key idea," and this was aligned with his goal of teaching scientific reasoning and metacognition, as he stated in episode 3. Thus, the question in line 31 served as a metacognitive question to regulate the reasoning process.

Furthermore, in line 34, John paraphrased S8's previous response in line 28 that the idea has something to do with "gas pressure." John's focus was not on "pressure" as the conceptual answer, but rather that this idea should be located "somewhere" (line 34) within the space between P and O (See Figure 4), thus showing visually that the idea of "pressure" forms somewhere in the chain of reasoning from the premise to the outcome of the explanation. This also justified John's action in line 34 as an instance of EMS as he was modelling how to plan and organize these conceptual ideas within the PRO structure of the explanation. Then in line 35, he went on to model EMS of monitoring whether the question raised in line 31 has been answered, "So somehow *we know* that the key idea is the pressure. *We have answered this*." He then continued in line 36 this metacognitive line of reasoning with another metacognitive prompt to link to the "next question."

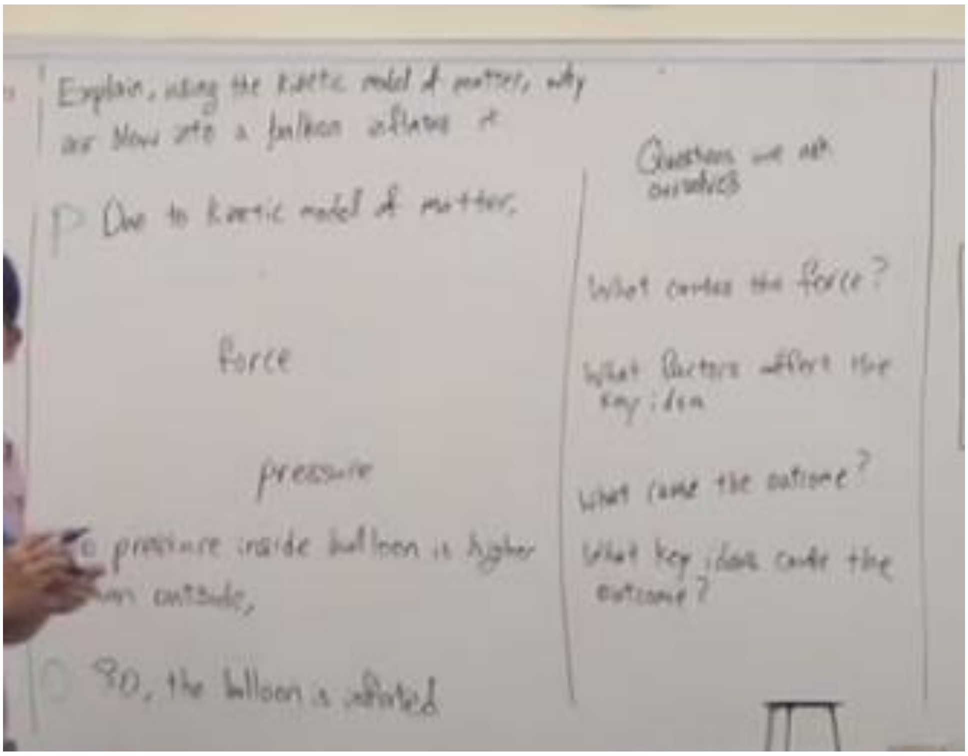

Figure 4. Use of graphic organizer to show the key ideas (left column) and regulatory questions (right column) raised by the students within the space between P and O

In the second aspect of regulating key ideas from different parts of an explanation, John also demonstrated how to construct the explanation using a non-linear approach from P to O to R and back to P. Using the P-R-O as markers, John used a graphic organizer to show a visual space between the P and O statements at the top and bottom of the whiteboard respectively. He also wrote the key ideas elicited from the students at strategic positions within that space, juxtaposing them next to the regulatory questions he elicited from the students (See Figure 4). As mentioned earlier, when John wrote or pointed at the key ideas (e.g., pressure) written on the board, he was less concerned with answering the conceptual questions than modelling EMS to the students on how to plan and regulate the sequence of the questions and key ideas within the P and O in a visible way. From the spatial positions of these ideas on the board, John also modelled EMS in terms of how he monitored whether he had “answered” (line 35) or “yet to answer” (line 42) his own questions and ideas.

Episode 5: Using PRO to Teach Scientific Reasoning (Reviewing Stage)

Toward the end of the whole class discussion in episode 4, John summarized and reviewed in this episode what they had learned "about scientific reasoning" (line 99) from this explanation.

Table 6

Transcript and Codes for Episode 5

No	P	Utterance	Epistemic Thinking		Scaffold
			Students	Teacher	Teacher
96	J	Okay, then let me summarise this part.			
97	J	We all know that kinetic model of matter states that large particles, blah, blah, blah, moving in continuous random motion, keyword, continuous random motion.			
98	J	And then, we start to learn about scientific reasoning.			
99	J	We all **start with our PRO**, P and O is easy to identify, **the issue is the R**, and R is the reasoning, we need to have scientific reasoning.		EMK	EI
100	J	**How to have scientific reasoning? We need to ask ourselves question.**		EMS	EI
101	J	Think about it. Now it's easy to craft because I'm the one who keeps asking the question. You guys actually always have the answer, but I'm the one asking the question. What if I'm not there?.. Because I cannot help you during your exam and I cannot help you from, after your secondary school. So what must happen is you must develop this skill of reasoning.			
102	J	So you need to start to ask yourselves questions.. **How to ask yourself question?**		EMS	EI
103	J	**From the outcome, you work backwards. Ask yourself, what are the key ideas that cause the outcome?**		EMS	EI
104	J	(**Pointed to the questions written on the "questions we ask ourselves" column**) Once you identify the key ideas, what causes the key idea? What are the factors? Usually like pressure, the factors will be? Force and area. If it's moment, then it will have force and a perpendicular distance so on and so forth		EMS	GO
105	J	Then after that you **continue to ask yourself question until you cannot ask anymore question. Then you know, you should have reached the principle.**		EMK	EI

This episode showed a number of explicit instruction (EI) where John stressed upon the epistemic metacognitive knowledge and skills that were discussed in the previous episode, such as the EMK of knowing "issue is the R" (line 99), the EMS of "ask ourselves question" (line 100) and "from the outcome, you work backward" (line 103). More importantly, John also highlighted his rationale of why he wanted to focus on metacognition. In line 101, he explained that it was important to "develop this skill of reasoning" because he could not always be the one to "keep asking the question" for them (line 101). The explicitness of stating metacognitive development as an instructional goal and providing the rationale for it was an important component of his metacognitive instruction.

From line 102 to 105, John also communicated his view concerning the epistemic status of a scientific explanation. Line 105 was particularly revealing as it showed his EMK with regard to the source and structure of an explanation. He explicitly mentioned that when every question has been recursively asked till a point where no further question can be asked anymore, then the students "should have reached the principle," and this is how they would "know" (in a metacognitive sense) they had completed the explanation. In effect, this highlights that a scientific explanation depends epistemologically on an accepted premise that serves as the "first cause" of an explanation (Tang, 2016a). Compared with episode 1 where a scientific explanation was mainly a type of answer required for an examination question, this episode showed a more developed view where the justification of the explanation hinged on the epistemic function of an accepted premise.

Note that in this episode John was still concerned with examination as he talked about him not being there to ask the question that will "help [the students] during [their] exam" as seen in line 101. From a practical point of view, the focus on examination is not unexpected from most classroom teachers operating in a school environment. However, this episode shows that learning the epistemic structure of scientific explanation is not necessarily contradictory to the purpose of preparing students for high-stakes examination.

In sum, episodes 3 to 5 showed more epistemic and metacognitive elements in the way the teacher used PRO as an epistemic tool as compared to episodes 1 and 2. Although the epistemic and metacognitive emphasis were still quite teacher-directed, these episodes presented a clear transition toward how metacognition was developed and manifested in the classroom discourse. There was also an evident shift in the teacher's use of PRO with metacognitive prompts to elicit students' epistemic thought processes at a meta-level as opposed to cognitive prompts to elicit students' ideas on the explanation at an object-level. In the last episode, the students subsequently took more initiative and ownership in the thinking process, and demonstrated a wider range of metacognition.

Episode 6: Using PRO to Evaluate Scientific Explanation

The question that drove this episode was raised by a student who asked "why hot air rises?" John took this opportunity for the class to practice regulatory questioning, much like what we saw in episode 4. He started with identifying the P and O, then got his students to ask themselves questions "to form this logical flow of reasoning" (lines 1 & 2; see Table 7).

Table 7

Transcript and Codes for Episode 6

No	P	Utterance	Epistemic Thinking		Scaffold
			Students	**Teacher**	**Teacher**
1	J	Okay, so (wrote "Due to kinetic model of matter" on the board). So this is my P. **I have already stated my P and my O. The problem now is to form the flow of reasoning**. Or the logical flow of reasoning.		EMK	MM
2	J	Now then *what question would you ask yourself to form this logical flow of reasoning?* I already have density decreases. Sorry?			MP
3	S1	What happens (inaudible)			
4	J	What happens when?			
5	S1	**When temperature increases?**	EMS		
6	J	Ah..what happen when temperature increases. **That is this question you ask yourself before you answer right?**		EMS	MM
7	S2	I was thinking of the comparison between the density of the cool air and the density of hot air. So when you compare, hot air will rise because lesser density. Normally when you compare, you will say the denser one will sink… (class sneered and interrupted) I was thinking of comparing the normal air density and the hot air density. So when you compare, normally you always say the denser one will sink. So since hot air rises, means the density of the hot air is lower than the density of the normal air. Since normal air is having, is denser. So it will sink. So when it sinks, the hot air rises due to the density is lower. It's like you compare with a liquid and a cork…. (class laughed and interrupted) CORK. The bottle cork. So when you see the example where you take the water as the.. So the cork will always float due to the lower density. When you take the metal piece and put inside, it will sink because it has a larger density (S3 raised his hand to speak) as compared to the cork.			
8	J	Okay, that's his reasoning right. So his main point is that. Ultimately his main point is, he straightaway think of the outcome, hot air rises. **He think of himself there must be something that cause it to rise or sink,** that is due to density difference. He has asked himself a question, and after that, oh, so the answer is density difference. That's why he went on to say density decreases like what S7 said		EMS	MM

No	P	Utterance	Epistemic Thinking		Scaffold
			Students	**Teacher**	**Teacher**
9	J	Now, but before the density decreases, how do you explain density decreases? (Pointed to a student who wanted to chip in). I am very sorry but S3 wants to say something first			
10	S3	**What's the principle?**	EMS		
11	J	Yah, it's already stated here (Pointed to the written P)			
12	S4	**But it's not related to..**	EMS		
13	S5	**It's not link to any principle**	EMS		
14	J	Correct **he has another principle**.		EMS	
		Do you know what's the principle he was talking about just now?			MP
15	Ss	Density difference			
16	J	Yes, density difference. That was his principle. Now S6 you were saying something?			
17	S6	**If you want to reason, you have to ask why does the density decrease, then go backward.**	EMS		
18	J	Yes, so you head backward. Once you have the outcome, you start to head backwards. So now S7, can you tell us why you think density decreases? How does density decreases come about?			
19	S7	Cause hot air has higher temperature than normal air. That's why there will be increase in kinetic energy of particles which lead to a higher increase in distance between particles which results in an increase of volume. That's why density decreases.			
20	S8	Teacher, **but how high does this hot air actually rise? Because when like.. cause I been thinking for some time**. When hot air rises (pointed finger upwards), it goes all the way up right, let's say Mount Everest that cold right, then it will start to dropping back down what… if like throughout all the way to space right, **then why is like outer space got vacuum?**	EMS		

For this episode, an interesting turn began in line 7 when a student S2 began to verbalize his thinking process for this explanation. What was impressive in this unusually long stretch of talk had 2 cognitive components. The first component was a logical reasoning formed by a long chain of causal connections involved in the explanation (i.e., cooler $\rightarrow$ denser $\rightarrow$ sink, and vice versa). The second component was an analogical reasoning in comparing "cool air and the density of hot air" in relation to "a liquid and bottle cork."

Subsequently, other students begun to join in the discussion after S2's lengthy reasoning. From line 10 to 13, three students (S3, S4, S5) responded that the reasoning given by S2 was not linked to the principle that was established in line 1. This critique demonstrated the students' EMS in evaluating how the explanation was progressing according to a PRO structure. In addition, the critique from these students were not directed at the conceptual accuracy of S2's explanation in terms of whether the content or logic was correct. Despite the impressive thinking and conceptual depth demonstrated by S2, they took issue with the epistemic nature of the explanation in terms of lacking a reasonable premise. Thus, this provides an evidence of epistemic metacognition as they were using their knowledge about the nature and structure of scientific explanation to regulate their cognition of the ongoing discussion (Hofer & Sinatra, 2010).

Subsequently in line 17, another student S6 then added his evaluation that it was important to ask questions that would link the reasoning "backward" to the premise. This was a direct appropriation from John's metacognitive instruction just a few days ago, as shown in Episode 5. As S6 knew that he could still ask a question on why density decreases, this was how he knew that S2's suggestion of density difference could not be the fundamental premise of this explanation. In this sense, S6 demonstrated a similar epistemic metacognitive view where the justification of a scientific explanation hinged on the epistemic function of a more fundamental premise. That is, he would only know he had completed the explanation when he could not ask any more question.

Building on this discussion, S8 asked some thought-provoking questions that queried the completeness of the explanation thus far: "But how high does the hot air actually rise?" and "why outer space got vacuum?" As shown in line 20, he reflected on these questions by "thinking for some time" that since there is vacuum in outer space, hot air will not rise forever and must eventually cool and fall at some point. The remarks by S6 and S8 demonstrated EMS in terms of monitoring whether they had completed the explanation by answering all the questions they had raised (for S6) and whether the current explanation was fully complete by addressing other questions they had in mind (for S8).

Discussion of Findings

The students' epistemic metacognition as well as the teacher's metacognitive instruction during the six episodes is summarized in Table 8. In this section, I discuss the role of PRO in mediating and supporting these epistemic and metacognitive activities.

Table 8.

Summary of Findings & Interpretations

Episode	Manifestations of: Students' epistemic metacognition	Manifestations of: Teacher's epistemic metacognitive instruction	The role of PRO as an epistemic tool
1	Not visible	MM – to model EMK related to knowledge required in an examination	Identified P, R, and O and used with sentence starters to fill in the blanks
2	Not visible	MM – to model EMK related to the nature of a premise in an explanation	Identified P, R, and O in a non-linear way
3	Some degree of EMK in knowing what strategy to use, when to use it, and the difficult part of the PRO strategy in constructing explanation	MM – to model EMK and EMS related to task requirement and strategy used MP – to prompt reflection on strategy EI – to state metacognition as instructional goal	Mediated thought processes involved in planning the structure of an explanation using PRO
4	Some degree of EMS in asking regulatory questions to guide the development of ideas between R and O in constructing explanation	MP – to prompt self-regulatory questions MM – to model EMS in asking and monitoring self-regulatory questions GO – to visually regulate sequence of ideas within P and O	Prompted questions to regulate one's own thought processes from O to P Provided navigational markers to monitor key ideas and regulatory questions in a non-linear way
5	Not visible	EI – to review and reiterate EMK and EMS that were manifested in episodes 3 and 4	Communicated epistemic status of an explanation as depending on an accepted "first cause" in the P
6	Significant degree of EMS in: (i) evaluating a peer's explanation for lacking an epistemic component despite its conceptual accuracy (ii) reflecting own thought processes, monitoring progress of constructing the explanation, and questioning beyond the explanation	MP – to prompt self-regulatory questions MM – to model EMS in asking and monitoring self-regulatory questions	Highlighted the epistemic connection between the reason and an accepted premise Evaluated the justification of an explanation based on the epistemic function of a more fundamental premise

As exemplified in episodes 1 and 2, when PRO was still a relatively new epistemic tool for the teachers, it was mainly used with cognitive prompts to support students' object-level thinking in developing an explanation. This was the expectation during the implementation of the design research and from previous studies of epistemic tools in scientific explanation and argument (e.g., Erduran et al., 2004; Sandoval & Reiser, 2004). As a cognitive prompt, PRO was used to support both conceptual and epistemic functions. A conceptual function emphasized the ideas and content that were required in an explanation while an epistemic function emphasized the source, structure, or validity of knowledge. Interestingly, both of these functions came into conflict in episode 1 between John and a student. While the student gave a response that was conceptually correct, John was expecting a response that was more epistemically aligned with the PRO structure.

When used as a cognitive prompt to highlight an epistemic function, John's main approach was to identify the individual parts of P, R, and O (e.g., What is the principle? What did you observe?). This approach had some positive effect in fostering students' epistemic cognition in terms of justifying and thinking about various ideas involved in an explanation, particularly when the ideas were developed using a non-linear reasoning instead of following a linear sequence of explaining. Such use of PRO is a notable instructional goal that is worth emulating in many science classrooms (Tang, 2015). However, the main critique raised in my analysis was not that John's instruction in episodes 1 to 2 (and other similar approaches in the literature; e.g., Wang, 2014) were not pedagogically effective, but rather these instructions were not targeted at epistemic metacognition. It is important to show this distinction in order to untangle the confusion between epistemic cognition and metacognition. Furthermore, it is necessary to highlight in the analysis how an epistemic tool like PRO can be used to scaffold epistemic metacognition, in addition to epistemic cognition which has already been documented in the literature.

A major difference between episodes 1-2 and 3-6 is the use of PRO as a cognitive prompt versus a metacognitive prompt. As summarized in Table 8, metacognitive prompts elicited students in this study to think about (a) the nature of the task and strategy in constructing a scientific explanation (i.e. EMK) and (b) how to plan and monitor their own questions to guide their thinking process (i.e. EMS). These were notably different from cognitive prompts that elicited conceptual and/or epistemic thinking regarding object-level events or ideas instead.

More specifically, the analysis provides more nuances in how John used PRO to frame his metacognitive prompt. As a cognitive prompt, PRO was used to identify *individual components of P, R, and O,* and linking those components to object-level events and ideas (e.g., outcome is the raisin sink). As a metacognitive prompt, PRO was used to emphasize the *epistemic connections among the P, R, and O components* instead. An interesting approach devised by John was to get his students to ask themselves questions in order to regulate and monitor their cognition from O, to R, to P. Using the P-R-O terminology, this made it possible for students to ask questions that would link their observation to their reasoning, as framed by John's metacognitive prompt in line 18 of episode 4: "when you see your O, what question do you want to ask yourself before you form your R?"

It is important to note that using metacognitive prompts with PRO alone is not sufficient to make the transition from a cognitive to metacognitive emphasis. As shown in the analysis, other techniques such as metacognitive modelling, explicit instruction, and graphic organizer are also crucial in John's repertoire of metacognitive instruction. There are several lessons that can be learned from the way John had integrated these metacognitive instructional approaches with the application of PRO in his teaching. For instance, metacognitive modelling and explicit instruction were critical for John to make his metacognitive thinking visible in the classroom discourse as shown in episodes 4 and 5.

Using the graphic organizer (e.g., Figure 4) also helped the students to visualize the non-linear reasoning between the end points of P and O and the sequence of regulatory questions in juxtaposition to the corresponding conceptual ideas. Some of the students' responses in episode 6 later provided evidence that John's metacognitive modelling and instruction were appropriated by those students.

Limitations of Study

There are a number of limitations in this study which will be discussed in this section. First, the epistemic cognition and metacognition explored in this study is limited to the nature of explanation as a scientific practice, which implies our research questions and findings must be contextualized within this disciplinary-specific epistemic goal. This limitation explains why the scope of the epistemic discourse revolved only around explanation, and not other practices such as argumentation. For example, with the use of PRO, John and his students had developed an epistemic view in which the justification of a scientific explanation hinged on a premise as an accepted knowledge where no further question can be asked. Although this was a more sophisticated view compared to answering an examination question in the beginning, more could be done to help them understand that the accepted premise itself can and should be questioned. While a premise (e.g., law, theory) by its definition cannot be explained, it can be argued, corroborated, or falsified, and the normative way to do so in science is through empirical evidence. However, this kind of questioning will involve scientific argumentation, which is another distinctive practice with a different epistemic goal (Osborne & Patterson, 2011). Thus, for the teachers and students to engage in this type of epistemic discourse, it will require a different epistemic tool, such as the CDW model that had been used in the literature.

Nevertheless, although the specific nature of the epistemic discourse will be different had the teachers and students used a different epistemic tool, such as CDW for scientific argument, it is highly possible that parallel findings would emerge with regard to the role of epistemic tool to scaffold cognitive and metacognitive development, all other things being equal. The same could perhaps be said for other scientific practices (e.g., investigation, modelling) as well as practices from other disciplines, such as mathematical proof, engineering design, computer programming, or drama story telling. It will be interesting for future research to explore these connections and possibilities.

Another constraint in this study is the cultural norms and practices in most Singapore classrooms where the participants are used to the teacher as the main authority and deliverer of knowledge. This made it challenging for the research purpose of collecting data that sufficiently captured the students' voices. However, John's authoritative teaching style does not negate the data collected from the classroom as well as the main argument presented in this paper. Instead, the case study focusing on his teaching reflects the contextual reality of a design research that introduced an inquiry-based pedagogy in a high-stakes examination environment typical in Singapore. It also reveals how a classroom teacher, despite the constraint in such an environment, could adopt and extend PRO into an instructional tool that supported both the objective of preparing for examination (e.g., episode 1, line 1; episode 5, line 101) and his own agenda of promoting scientific reasoning and metacognition (e.g., episode 3, line 14-17). As we saw in the case study, these two objectives were not mutually exclusive, and it is revealing to see how a practicing teacher was able to weave both objectives into his classroom discourse.

Conclusion & Implications

In conclusion, this study has shed new understanding on how an epistemic tool mediates and supports epistemic cognition and epistemic metacognition, and the difference between them. For some time, researchers have emphasized the importance of engaging students in the epistemic tools as used by scientists in the construction of scientific knowledge (Settlage & Southerland, 2019). However, current research focusing on the use of epistemic tool (e.g., Christodoulou & Osborne, 2014; Sandoval & Reiser, 2004) has only shown corresponding results in epistemic cognition, but not epistemic metacognition. This study has made a critical distinction to illustrate how an epistemic tool can be used to scaffold each of them.

This illustration has both theoretical and pedagogical implications. Theoretically, this study provides an empirical basis to support the necessity of demarcating epistemic thinking into its cognitive and metacognitive component, as initially proposed by Barzilai and Zohar (2016). As exemplified in the coding scheme applied throughout the six selected episodes of this study, the finer distinction in epistemic cognition (EC), epistemic metacognitive knowledge (EMK), and epistemic metacognitive knowledge (EMS), in relation to the distinction between cognitive prompts (CP) and metacognitive prompts (MP), has allowed a more nuanced analysis to understand the cognitive and metacognitive development and instructional actions taken by the students and teacher respectively. Furthermore, the analysis from this study has the added benefit of aligning the research in epistemic cognition with metacognition research.

In addition, the study also supports a better understanding of the role of an epistemic tool in fostering scientific practices. Many previous studies in epistemic tools (e.g., Erduran et al., 2004; Putra & Tang, 2016; Tang, 2016a; Wang, 2014) have mostly used cognitive prompts to identify or differentiate the various epistemic components of an explanation or argument (e.g., premise, claim, data) in order to make conceptual connections from those components (e.g., causal or temporal relationships). This study highlights an additional potential in using epistemic tool along with metacognitive instruction to facilitate epistemic metacognition. A key approach in transitioning to metacognition is to use the epistemic tool to make explicit the thinking involved in connecting the various epistemic components, through multiple scaffolds like metacognitive prompts, think-aloud modelling, explicit instruction, and graphic organizers. Working toward epistemic metacognition is an important endeavour because it is a crucial component that promotes and regulates epistemic development (Khishfe & Abd-El-Khalick, 2002).

Besides advancing current theoretical understanding, this study has also provided pedagogical examples of how metacognition of epistemic matters can be manifested and developed through classroom discourse. Through the case study, I have documented and showed how the teacher shifted from a cognitive to metacognitive emphasis in his instruction as well as how various metacognitive instructional approaches were embedded in the classroom discourse. I also showed how this enactment in classroom discourse was mediated through the use of the PRO as cognitive and metacognitive prompts. This case study will be useful for teachers and teacher educators who are looking for practical metacognitive instruction that can promote the epistemic thinking and practices in the classroom.

Although research in epistemology and metacognition has been around for many years (Hofer & Sinatra, 2010), it remains a great challenge to operationalize the theoretical ideas at the classroom level. One of the challenges is that teachers do not have the language to talk about the language of scientific epistemology, let alone reflecting on it to regulate their cognition. This language is not the same as scientific language consisting of specialized vocabulary, register, and genre, but operates at a meta-level of providing the words we use to describe the (often implicit) nature of scientific work (Norris, et al., 2008). This meta-level language, or *metalanguage*, provides a more explicit way of talking about the epistemology of science through a deliberate and conscious use of epistemic terms, such as *premise*, *reasoning*, *outcome* in this study or *claim*, *data*, *warrant* in argumentation studies. As metalanguage allows us to make the implicit explicit, it has the potential to facilitate overt reflection of our thinking and practices, which is the key essence of metacognition. This intertwined relationship between metalanguage and metacognition, as well as the potential of metalanguage in fostering epistemic metacognition, will be an interesting focus to explore in future research on metacognition and epistemic thinking.

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