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Elementary teachers' knowledge of using language as an epistemic tool in science classrooms: a case study

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ABSTRACT

Language is a fundamental tool for learning science. This study highlights the importance of teacher knowledge in utilising language as a tool for knowledge generation in the classrooms. This case study examines elementary teachers' development of declarative, procedural, and epistemic knowledge related to using language, particularly focusing on how a three-year professional development programme centred around the Science Writing Heuristic (SWH) approach influences the development of these knowledge bases. Our findings indicate that the SWH PD positively influenced the teachers' knowledge development while there were disparities in knowledge development across individual teachers and knowledge aspects. We further discuss the changes in the teachers' knowledge and provide implications for future professional development and research regarding language use in science classrooms.

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Science knowledge generation; epistemic tool; teacher knowledge of language use

Introduction

Science cannot be advanced without some forms of language (Lemke, 1990; Norris & Phillips, 2003). Recognition of this relationship has been highlighted by recent educational movements and standards, including the Next Generation Science Standards (NGSS Lead States, 2013). The new vision of science education calls for a shift in teaching science away from knowledge replication approaches that focus on filling gaps that students do not know to knowledge generation approaches, which emphasise students' active role in the learning process (Hand et al., 2021). This call emphasises a critical need for shifting the view of language from a representation tool to an epistemic tool in learning and teaching science, which means immersing language into a scientific inquiry as an integrated knowledge generation process. This position offers much more potential for learning gains than learning about language separately from the context of its use (Wallace, 2004).

Research has demonstrated that embedding language modes within science practices benefit students' learning across disciplines (Glass & Oliveira, 2014; Hand et al., 2018; Lee

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et al., 2008) as well as help elementary teachers teach science content knowledge more effectively (Dickinson & Young, 1998). This approach encourages students to use different language modes such as writing, dialogue, drawing, modelling, and argumentation as generative tools in their learning process (Fiorella & Mayer, 2016). More importantly, using language as an epistemic tool in science classrooms can encourage students to utilise their epistemic agency to share, discuss, evaluate, and negotiate scientific ideas with peers by using various modes of language (Stroupe, 2014). This approach particularly helped marginalised groups (i.e. individual education plans, free and reduced-price lunches, and English learners) to develop scientific knowledge (Hand et al., 2018).

Building on prior research, the current study aims to shed light on instructional practices of using language in elementary science teaching and learning. Several studies have reported various benefits of the intentional use of language in learning and teaching science (e.g. Fiorella & Mayer, 2016; Stroupe, 2014). To prepare teacher's pedagogical content knowledge, teacher education or preparation programmes need to develop teachers/preservice teachers' awareness of metalanguage to scaffold their pedagogical knowledge on scientific language (Mönch & Markic, 2022). Recent literature has discussed language as an epistemic tool in upper grade levels in K-12 school settings. For example, Hennah (2023) presented a case study that explored chemistry learning through social interaction and language in classroom discourse from a sociocultural linguistic perspective. However, not enough is known about how to prepare elementary teachers to use language as an epistemic tool in elementary science education.

Therefore, we aim to explore elementary teachers' knowledge of using language as a tool to support students' science learning, with a particular focus on the potential impact of the Science Writing Heuristic (SWH) approach (Keys et al., 1999) on teachers' development of knowledge and pedagogical practices. Our goal is to identify and examine the knowledge development teachers need to utilise language as an epistemic tool and provide practical implications for future research and professional development in this area. The current study aims to answer the following research questions:

- (1) What kind of knowledge can elementary teachers develop regarding the use of language as an epistemic tool as they learn to implement a knowledge generation approach?
- (2) How do the elementary teachers' knowledge development differ from one another as they learn to use language as an epistemic tool?

Theoretical perspectives

The current study draws upon three theoretical perspectives: (1) the SWH as a knowledge generation approach, (2) teachers' knowledge of using language as an epistemic tool, and (3) types of teachers' knowledge. The following sections discuss each area regarding science learning and relevant research perspectives.

The science writing heuristic as a knowledge generation approach

The SWH approach, which was designed by Keys and colleagues (1999), is a knowledge generation approach that emphasises the use of language as a tool for science learning. It

encourages students to use language as an epistemic tool to generate knowledge, rather than merely as a means of communication. The language practices in this approach build dialogue and argument as generative tools to engage students in developing scientific knowledge (Century & Cassata, 2016). The SWH approach consists of three phases: Understanding the inquiry, persuading others in arguments, and informing others in summary writing (Hand et al., 2021). By employing these phases, teachers use interactive negotiation to help students build understanding of knowledge and generate claims and evidence to answer questions (Klein & Boscolo, 2016). The processes involve individual and group work, where students are encouraged to use their everyday language to explain scientific concepts and gradually develop scientific language over time. Additionally, the SWH approach integrates eight knowledge-generation strategies (Fiorella & Mayer, 2016), such as summarising, self-explaining, teaching, self-testing, and enacting in science classrooms to help students generate knowledge. This study focuses on elementary teachers' understanding and use of language in science classrooms by using the SWH approach as a context.

Teachers' knowledge of using language as an epistemic tool

Using language as an epistemic tool in classroom instruction means using various language modes to generate knowledge and create meanings. Building on our previous work, we framed three domains to discuss the meanings of using language as an epistemic tool.

(1) Language as an essential tool for learning science

The first domain emphasises that language is an essential tool for learning science, as stated in Norris and Phillips's (2003) assertion that there is no science without language. In order to effectively use language in helping students develop scientific language, science teachers should have prior knowledge of scientific language and be aware of its crucial role (Cabello et al., 2019; Mönch & Markic, 2022). Teacher's knowledge of scientific language includes three levels, namely vocabulary, grammar, and genre (Tang & Rappa, 2021). To frame epistemic practices of science and utilise language as an epistemic tool, teachers should understand that language practices are interconnected with the grammatical and structural features in scientific language, and other linguistic functions, such as dialogue in scientific language and argument about scientific knowledge (Tang & Rappa, 2021). This means that these tools should be utilised together rather than separately in lessons to help students use them flexibly to express and critique their thinking (McNeill et al., 2016). Furthermore, Mönch and Markic (2022) summarised from systematic literature review that teacher education needs to develop teachers' awareness of scientific language and metalanguage to foster pedagogical scientific language knowledge.

In elementary classrooms, language use should be embedded in science teaching and learning (Seah & Silver, 2022). This highlights the crucial role of language in generating epistemic practices of science in elementary classrooms (Hand et al., 2021). To use language as an epistemic tool to scaffold elementary students' learning, teachers should have the knowledge about language functions such as meaning-construction, which connects language structures to meaning-making process (Seah, 2016). Also, teachers with

advanced level knowledge of the language can employ various approaches to develop students' capacity to use multiple modes of language to communicate their thinking, demonstrating their understanding of science content knowledge (Hand et al., 2021).

(1) Using everyday language to develop academic language

In science learning, academic language encompasses not only scientific vocabulary and terminology but also various language modes to use everyday language to learn scientific knowledge (Lynch, 2001). Using language that students are more familiar with in their daily lives can make it easier for them to understand and connect with science content and conduct class interactions in a natural way (Lemmi et al., 2019; Wallace, 2004). Also, researchers found that teachers may struggle with the terms they used in academic or scientific language when transferring the meanings to everyday language (Mönch & Markic, 2022). Science teachers' content knowledge regarding scientific terms and the nuances between similar terms is important for science teaching (Yun & Park, 2018). The inaccurate meaning transfer can lead to a discrepancy between instruction and students' comprehension because students may understand the scientific language differently from the meaning that teachers tried to communicate (Cabello et al., 2019).

Particularly to elementary science teaching and learning, several researchers (e.g. Brown & Ryoo, 2008; Schoerning et al., 2015) have demonstrated the effectiveness of elementary teachers who use everyday language to scaffold students' development of scientific language. This approach has proven beneficial in improving students' understanding in science terminology and content. Understanding the scientific language capabilities of young students enables elementary teachers to better gauge their performance in science and address their need for scientific languages (Seah & Chan, 2021). Therefore, elementary teachers' knowledge and use of everyday language as a critical element of science learning have the potential to assist students in transitioning towards adopting and utilising academic language more effectively.

(1) Language in multimodal representations

Multimodal representations, also known as *multimodality*, involve integrating language practices with multiple modes, such as written texts, print-based texts, visual representations, verbal responses, and interactions (Kress, 2010). From a multimodal perspective (Kress, 2010), visual representations need to be used in the knowledge generation learning process to support comprehension and expression (Fiorella & Mayer, 2016). By using multimodal language formats to support reading and writing, teachers can provide multiple entry points for students to engage with science content and express their understanding (e.g. Cabello et al., 2019).

Multimodal representations have been widely utilised in K-12 content area teaching and learning (Si et al., 2022). Many recent research studies explored how multimodal representations were utilised in elementary classrooms especially in science learning practices. For example, graphical representations (e.g. pictures, photos, drawings, etc.) can help teachers support young students' understanding of complex and abstract concepts in science classrooms (e.g. Glass & Oliveira, 2014; Mctigue & Flowers, 2011). Additionally, writing and drawing can be integrated together into science learning practices to

help elementary students generate, share, and synthesise ideas regarding scientific concepts and topics (West et al., 2016; Wilson & Bradbury, 2016). Also, engaging students with different representations (e.g. pictures, diagrams, various dimensions of language) of scientific concepts and terms are important to support elementary students in knowledge generation in science classrooms (Seah & Chan, 2021). Therefore, elementary teachers need to develop their knowledge about how to engage students with multimodal representations and transform them into languages in science (Yeo & Tan, 2022).

Declarative, procedural, and epistemic knowledge

Metacognition refers to high-level thinking that actively engage cognitive processes in successful learning (Livingston, 2003). From a metacognition perspective, Jacobs and Paris (1987) proposed a framework for knowledge of cognition, which conceptualised teacher knowledge in three dimensions: (1) declarative knowledge, (2) procedural knowledge, and (3) conditional knowledge. These three types of knowledge represent the abilities to know and explain the meaning of things, design solutions and procedures, and code or test the solutions to solve problems (McGill & Volet, 1997). Specifically, declarative knowledge refers to ‘what’ about the things, procedural knowledge refers to ‘how’ to do the things with detailed procedures, and conditional knowledge refers to understanding ‘why’ to do certain things to facilitate cognition and comprehension (Schraw & Moshman, 1995). Declarative knowledge indicates that learners who have more capacity of memory in the cognitive process can learn better than others; learners with more procedural knowledge are more likely to use strategies effectively to solve problems; and learners with conditional knowledge would know why to apply different strategies to promote learning in specific situations. From the above literature (Jacobs & Paris, 1987; Schraw & Moshman, 1995), the procedural knowledge and conditional knowledge overlap on learners’ choices of strategies to solve problems, suggesting those two knowledge types may be unnecessarily separated. Instead, epistemic knowledge can be clearly distinct from procedural knowledge as it influences learners’ justifications for using other knowledge bases for learning (Lammert et al., 2022).

However, there has been a relatively limited exploration of the metacognition perspective and its application to elementary school teachers, particularly within the context of elementary science education. Additionally, the integration of the three dimensions of teacher knowledge (i.e. declarative, procedural, and epistemic knowledge) into this specific language area remains a less-explored territory in academic research. Despite the substantial volume of research exploring how elementary teachers utilise various language formats in their classroom instructions, there is still a need for deeper exploration into the development of teachers’ knowledge of language and its impact on their classroom practices. To address this gap, the current study synthesises the metacognition perspective and teacher knowledge domains into a framework that categorises teachers’ knowledge into declarative, procedural, and epistemic knowledge of using language as an epistemic tool. Specifically, the study explores (1) how teachers define and conceptualise the role of language in science instruction; (2) what processes are involved when both teachers and students using different modes of language in science teaching and learning; and (3) why teachers think language is important for students and/or how language can help students in science learning. This framework provides a useful way to examine how

teachers' knowledge about language influences their classroom practices and students' learning outcomes.

Methods

The current study aims to understand how teachers' knowledge of using language as an epistemic tool was developed (Keys et al., 1999) over a three-year professional development (PD) programme that was designed to help teachers implement the SWH approach. To acquire in-depth descriptions and perspectives (Creswell & Poth, 2016) from the teachers and conduct analysis on how teachers' knowledge would influence their instructional practices, an explanatory case study methodology was adopted. This methodology provides insights into individual teacher's adaptation to knowledge while exploring the effectiveness of the professional development programme (Yin, 2014). Through this case study approach, we aim to provide a detailed understanding of the complex and dynamic nature of teachers' knowledge development and its impact on classroom practices.

Context and participants

The study was conducted as a part of a larger project focused on developing the adaptive expertise of elementary teachers ($n = 122$) as they implement the SWH approach. The project included a three-year PD programme designed to support teachers' knowledge and use of the SWH approach. The intensive PDs were held during the summers of 2019, 2020, and 2021 each PD lasted four to five days. The initial summer PD workshop was conducted in a traditional face-to-face setting, whereas the subsequent two sessions were transitioned to a virtual environment due to the constraints imposed by the COVID-19 pandemic. The PD programme was structured around three primary phases:

Phase 1. Negotiating foundational knowledge for generative learning

During this phase, a combination of whole group and small group discussions challenged teachers' conventional perceptions of learning, urging a more nuanced understanding of generative learning. The central question posed in the PD programme was focused on who controls learning. Teachers were prompted to articulate their role in shaping learning within their classrooms. Reflective activities were also integrated to foster a conceptual grasp of language, dialogue, and argument as epistemic tools. For example, teachers collaborated in small groups to define these terms and explore their significance in students' learning processes, as well as the interconnectedness between them.

Phase 2. Exploring pedagogical approaches for generative learning

This segment of the professional development programme was dedicated to assisting teachers in adopting and adapting the theoretical foundations of generative learning into their classroom practices. By sharing their experiences of employing epistemic tools in teaching, teachers and PD leaders engaged in meaningful discussions about pedagogy linked to generative learning. Discussions on language encompassed topics such as encouraging students to use both everyday and scientific language, promoting the generation of multiple representations, and utilising writing as a learning tool.

Phase 3. Repeated cycling through phases as a function of revisiting theory and practice

Significant emphasis was placed on enabling teachers to cycle through Phases 1 and 2. The iterative process allowed teachers to revisit theoretical aspects critical for cultivating a robust understanding of knowledge generation theory. Repeated engagement with the phases facilitated the refinement and development of pedagogical understandings and practices necessary for implementing knowledge generation environments.

Within the scope of this PD programme, teachers received ongoing support through scheduled visits either from cluster leaders or groups of graduate students. These observers provided feedback after observing classroom teaching, aiming to enhance teaching practices. Furthermore, additional planning sessions were conducted annually to encourage flexibility in lesson planning. These sessions were designed to help teachers delve deeper into teaching science's 'big ideas' in ways that encourage students to actively generate knowledge through language, dialogue, and argument.

Participants

Participants of the project were 122 K-5 teachers from two U.S. states, one in the Midwest and one in the Southeast. Before the first PD session, participants were asked if they were willing to participate in an in-depth case study. Among them, 13 teachers consented to be included in the case study for additional data collection through interviews and observations. Among them, 11 teachers completed all the summer PDs and data collection procedures throughout the three years of the project. All 11 teachers included in the current study were female. [Table 1](#) provides information about the participants' demographic characteristics.

Data collection

Data collection was conducted throughout the three-year project at multiple time points (See [Figure 1](#)). The data includes observations, interviews, vignettes, and reflections. For this particular study, we used interviews, vignettes, and reflections collected from 11 volunteer teachers at various time points. This approach helps us to track teachers' changes of knowledge in language use and to triangulate data to increase credibility for the study (Yin, 2014).

Table 1. Participants' demographic information.

Teacher*	Cluster	Grade Level	Years of Experience
Grace	Midwest 1	3	19
Lusia	Midwest 1	3	13
Lorry	Midwest 1	4	12
Chloe	Midwest 2	4	17
Alice	Midwest 2	4	1
Summer	Midwest 2	3	17
Daisy	Midwest 2	3	26
Scarlett	Midwest 2	5	4
Teresa	Southeast	5	2
Rose	Southeast	5	9
June	Southeast	5	12

*All teacher names are pseudonyms.

Interviews

Semi-structured interviews were conducted between the researchers and the participant teachers throughout different time points of the project. The current study used data from four timepoints interviews. The first round of interviews took place in Spring 2019 (time point 1), so we could understand teacher knowledge about using epistemic tools before the implementation of the first PD. Participants were asked about their understanding of learning and their knowledge of epistemic tools, including language, dialogue, and argument. Example questions for language included the following: (1) *In your science classroom, do you encourage your students to use scientific language or everyday language?* (2) *Could you tell me about how you use writing in your science lessons?* (3) *How do you help or encourage your students to interact with visual representations in class?*

Two more rounds of interviews (midpoint of the 2019–2020 school year; Fall 2020) were conducted with teachers after the PDs to further explore their development of understanding of learning, knowledge of epistemic tools, adaptiveness, and planning. Sample interview questions included the following: (1) *How comfortable do you feel with using language, dialogue, and argument?* (2) *Can you tell me how you have been planning the units with the SWH?* (3) *How do you feel about the flexibility and adaptability of this approach?* (4) *How can language contribute to student learning in science and in other content areas? In your mind, what is the ultimate goal of language use?*

Finally, one more interview took place in Fall 2021 after the last workshop of the project. Teachers were asked again about their use and understanding of language. In addition, we asked them to elaborate on the vignette responses they filled out during Summer 2021 PD. All of the interviews were audio recorded and transcribed for further analysis.

Vignettes

Vignettes are commonly used in qualitative studies such as the fields of education and psychology to examine participants' perspectives within a specific phenomenon or situation (e.g. O'Dell et al., 2012). Four vignette tasks were held in order to give teachers a scenario to which they may respond by demonstrating their understanding of epistemic tools. The vignettes were originally adapted from a validated instrument developed by Vogt and Rogalla in 2009, which primarily emphasised adaptiveness. To suit the elementary teaching context, we made several modifications, such as expanding the scope to cover all science topics, not limited to natural science. Furthermore, vignettes were designed with distinct prompts aimed at eliciting teachers' knowledge pertaining to language, dialogue and argument. For the present study, we particularly assessed participants' responses to the vignette related to language use. The language vignette asks '*Naomi completed a Science Writing Heuristic workshop last summer. She thinks her science teaching went okay this year, but she wants to make better use of language. Please describe to Naomi how she could think about language as she prepares. Include any steps she should take and make your thinking transparent, so she knows why those steps are important*'. Teachers provided written responses to this scenario. We carried out the same vignette task twice, in the summers of 2020 and 2021 during the PD workshops.

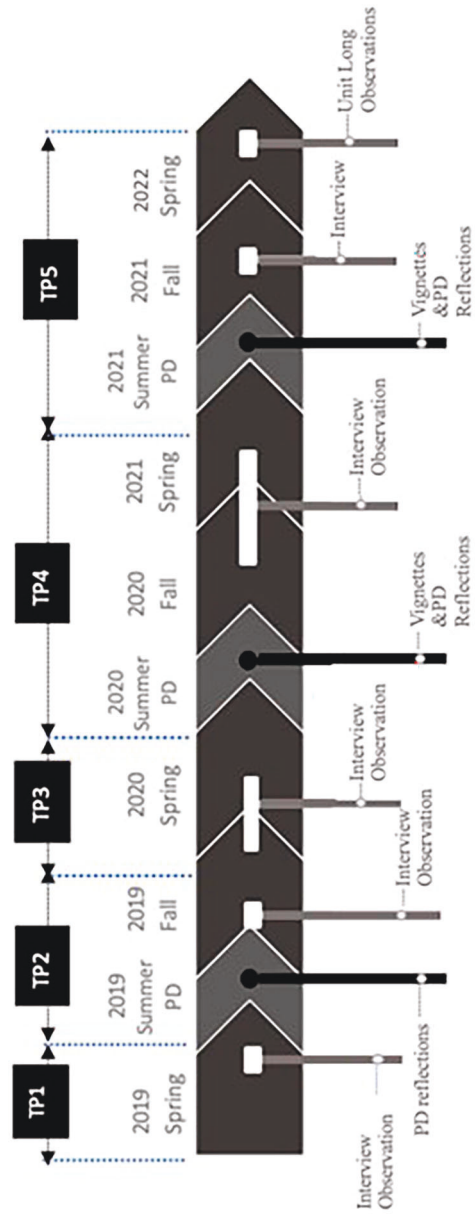


Figure 1. Data collection procedure (Adapted from Suh et al., 2023).

Reflections

We collected teachers' written reflections throughout the PDs in Summer 2020 and Summer 2021. We posed several open-ended questions to get teachers' reflections on their use of epistemic tools and changes in their knowledge and practice. Examples of reflection questions related to language knowledge include: (1) *What does 'using language as a learning tool' mean to you?* (2) *What has been your biggest change in how you think about using language in science?* (3) *How would you like to grow in your practice of using writing as a tool for learning science?* (4) *How often and why do you use academic language in your teaching?*

Data analysis

To analyse the data, we first coded the transcribed interview data into the three dimensions of teachers' knowledge of using language: (a) declarative knowledge, (b) procedural knowledge, and (c) epistemic knowledge. This involved examining how teachers understood language, what examples and procedures they provided for using language in teaching, and how they believed students could use language to support science learning. After coding the interviews, we further coded the vignettes and reflections from two different time points, specifically looking at language use with the same coding scheme. We summarised the data separately for each time point to identify adaptive patterns over time. Table 2 provides the coding scheme, definitions, and example codes used in analysis. This rigorous coding process ensured that the analysis was thorough and reliable, allowing us to gain a detailed understanding of how teachers' knowledge of using language as an epistemic tool developed over time.

To assess the evolution of teachers' knowledge across various knowledge categories over different time points, we developed a rubric for a thorough examination of their understanding of language as an epistemic tool (see Table 3). This rubric was meticulously developed by drawing upon prior research on teachers' knowledge of language as an epistemic tool (Hand et al., 2021; Lammert et al., 2022). We systematically identified

Table 2. Interview coding scheme and example codes.

Knowledge Type	Definition	Example Codes
Declarative knowledge	• Define what language is. • Explain what she/he knows or thinks about language.	'I guess I would just say that language is the words or the vocabulary that you are using when you're talking about something.' (Alice, interview)
Procedural knowledge	• Explains how he/she implements strategies to promote language use. • Give examples from his/her practice to explain the process of using language.	'Every student has a journal and sometimes I will put a question, like a focus question on a piece of paper and they will glue it in and respond in their journal. Sometimes it is through a worksheet or sometimes it is just some reflecting in their journal, but that is where most of their science writing goes: in their journals.' (Lusia, interview)
Epistemic knowledge	• Addresses why he/she uses language as a tool in classroom instruction. • Explains how language helps students to learn or construct knowledge.	'I know their needs and know that science vocabulary is and be able to use it, but they have to be able to use it in their everyday language in order to understand it. I can give them a term, and it could be something, but if they don't understand it and don't use it in their own words then they don't ever understand it.' (Chloe, interview)

Table 3. Teacher knowledge rubric results.

Dimension	#	Item	Timepoint 1	Overall
Declarative Knowledge (4 items)	D1	• Language has multiple modes including writing, drawing, talking, etc.	7	11
	D2	• Language is a tool for knowledge generation.	0	5
	D3	• Students should use everyday language to explain scientific concepts.	6	7
	D4	• Students need to use academic language to explain scientific concepts.	5	9
Procedural Knowledge (5 items)	P1	• Provide opportunities for students to make them talk and write about their ideas.	5	10
	P2	• Encourage students to use multimodal representations (e.g. written texts, drawings, graphs, and verbal interactions).	7	10
	P3	• Encourage students to use everyday language and scientific language.	5	9
	P4	• Make students write in different styles (argumentative writing, summary writing) for different audiences.	1	3
	P5	• Let students choose how they want to represent their learning.	0	1
Epistemic Knowledge (3 items)	E1	• Using everyday language helps students have ownership over their language/understand better/meaning-making.	2	6
	E2	• Different modes of language help students to show their learning in different ways/communicate their understanding.	4	7
	E3	• Language helps students show their thinking/learning process/ understanding.	0	6

indicators of teachers' language knowledge as discussed in the existing literature, and categorised them into three essential knowledge types: declarative, procedural, and epistemic knowledge of language. Ultimately, the rubric encompasses 12 distinct indicators of teacher knowledge regarding language, distributed across three key areas: (1) Declarative Knowledge of Language (4 indicators denoted as D1, D2, D3, D4), (2) Procedural Knowledge of Language (5 indicators labelled as P1, P2, P3, P4, P5), and (3) Epistemic Knowledge of Language (3 indicators designated as E1, E2, E3).

We used the rubric to explore the distribution of teachers' knowledge in each dimension at each time point, starting with the Spring 2019 interview as a baseline. We checked how many teachers demonstrated knowledge of each item at time point 1 and across all time points, including interview, vignettes, and reflections. We also calculated each teacher's total scores at time point 1 and overall time points separately. To account for any duplicate responses, we only counted each item once in the rubric. Based on the whole dataset, we summarised the teachers' knowledge in each dimension and explored how their understanding of language use as an epistemic tool changed over time. We expected the teachers to expand their understanding and practices across time points, building on the knowledge they developed during the professional development programme. Table 3 shows the full rubric used in the analysis.

Reliability and validity

To ensure the validity and reliability of this study, we carefully designed the data collection and analysis procedures. Specifically, we took steps to ensure that our data collection tools accurately measured the construct of interest: elementary teachers' knowledge and use of language for science teaching. We employed various triangulation methods,

including data triangulation, methodological triangulation, and investigator triangulation to enhance the validity and reliability of our findings (Denzin, 1970). For data triangulation, we collected data at different time points and through multiple resources, such as interviews, reflections, and vignettes. This involved designing an interview protocol and engaging in team sessions to identify and address any potential sources of confusion for participants. Also, a previously validated vignette instrument (Vogt & Rogalla, 2009) had been modified to align the scenarios with the specific context of our research. Specific language, dialogue, and argumentation cues were incorporated to emphasise their relevance within the vignette context. Furthermore, we conducted a pilot test of the vignettes. The pilot test involving in-service elementary teachers experienced in SWH implementation and graduate students familiar with the context provided invaluable feedback. For instance, ambiguities regarding certain scenario elements were identified, leading to revisions that clarified these elements, thereby enhancing the vignettes' relevance and coherence within the SWH framework. In addition, the rubric used to evaluate teacher knowledge underwent iterative refinement, aligning closely with the dimensions and core content covered in the professional development sessions. Validation involved expert review, ensuring the rubric's accuracy and effectiveness in assessing different facets of teachers' comprehension and application of language within the science classrooms.

For methodological triangulation, we employed multiple data collection tools and procedures such as self-report data, objective/observation data, and writings. By collecting data from diverse sources at various stages of the three-year professional development programme, we effectively captured the evolving changes in teachers' understanding and utilisation of language as an epistemic tool. This approach ensured data saturation which refers to collecting a sufficient amount of data from various sources and stages of the professional development programme until we had a thorough grasp of how teachers' understanding and utilisation of language as an epistemic tool changed over time.

Furthermore, investigator triangulation was achieved by involving several researchers in both the data collection and analysis processes. During the qualitative data analysis, at least two researchers, including graduate students and a postdoctoral scholar, worked collaboratively to analyse the data and engaged in a dialogue to reconcile any discrepancies and arrive at agreed-upon codes and themes. To ensure the consistency and reliability of coding, two coders coded the data separately then checked the differences between the coded documents. We first found more than 90% agreements on the coding regarding declarative knowledge and procedural knowledge, but a lower agreement (78%) on the coding of epistemic knowledge. Then, two coders checked all the disagreements on the codes and discussed the codes and coding scheme to reach total agreements on 100% for all the codes. Finally, the agreed-upon codes were combined into one file, indicating the teachers' knowledge categories at each time point.

Findings

To answer the first research question: *What kind of knowledge can elementary teachers develop regarding the use of language as an epistemic tool as they learn to implement a*

knowledge generation approach? The following section describes teachers' knowledge developed over the PDs on the three dimensions.

Teachers' knowledge descriptions

Table 3 compares the teachers' knowledge at time point 1 and the overall dataset. The number of each item indicates how many teachers demonstrated their knowledge of that particular item. From the results of timepoint 1, more than half of the teachers demonstrated their knowledge of using different language modes and multimodal representations in classroom instruction in addition to scaffold students to use everyday language to explain scientific concepts (i.e. item D1, D3, P2). However, the teachers showed limited understanding regarding language as a tool to generate knowledge and helping students to use different modes of language in their learning and thinking process (i.e. item D2, P5, E3, P4). From the numbers of overall data, we see that gradually the majority of teachers ($n = 9$) developed their knowledge of helping students use different language modes in learning process and utilise both everyday and academic language in science learning (i.e. item D1, D4, P1, P2, P3). More than half ($n = 6$) of the teachers gained knowledge on helping students to use everyday language and multiple language modes in communicating and understanding the scientific content (i.e. item E1, E2). Additionally, almost all teachers ($n = 10$) still struggled with the ideas about encouraging students to choose how they want to represent their learning by using different modes of language (i.e. item P5) at the end of the project.

Declarative knowledge

From the data, all the 11 teachers demonstrated their declarative knowledge of using multiple language modes (e.g. writing, talking, drawing) in science class at the last time point interview. For example, Grace addressed the importance for students to use scientific language in multiple language skills, she said 'thinking about vocabulary, we really want them to be using that when they are speaking and writing, not just matching (definition and vocabulary) (timepoint 3, interview).' The teachers also understood that developing scientific language is an important part of science learning and students need to understand the definitions of scientific terms and be able to apply them in relevant contexts: 'I don't think students have to memorise vocabulary. I think it is more important that students can take the word and define it by themselves.' (Alice, timepoint 3, interview). Additionally, multimodal literacies awareness is also shown from their understanding of language modes. The teachers thought that visual representations (e.g. drawings, graphs, diagrams), especially technology-based platforms (e.g. Google products, Seesaw), are good supportive resources for students' comprehension and expression. Rose explained that 'if you weren't given these visual representations, then a lot of times students struggle with it, and it's a part of our standards that they understand visual representations (timepoint 4, interview).' However, we notice that only five teachers had a clear understanding of language as a tool to generate knowledge (item D2) based on the later time point interviews or vignette responses. For example, Alice expressed in her vignette to regard language as knowledge generation, 'It's not just about spoken language; it's about expressing ideas and communicating them through drawings, pictures, models, writing, graphic organisers, etc. (timepoint 3, vignette)' It

indicates that even though the teachers understand using different language modes to help students practice various skills in science classroom, they need to develop more knowledge on using language as part of a science content knowledge generation process.

Procedural knowledge

From the data, the teachers demonstrated their procedural knowledge of language and provided details of how they helped students to use language in science learning. Specifically, ten teachers provided opportunities for students to talk or write their ideas in class. For example, June noted at her later time point interview, ‘I’ve been trying to increase my student’s dialogue, in particular their writing, like claim and evidence writing as they work on assignments. I’m trying to let them do more of the leading and investigating. (timepoint 4, interview)’ Also, ten teachers demonstrated their process of encouraging students to use multimodal representations such as written texts, drawings, graphs, and verbal interactions. Grace said,

Sometimes we put concept maps in there or drawings. Trying to get students to maybe label some things ... Students are learning how to read something and look at the text structure and take notes depending on the text structure. Some of them are talking about global warming, and sometimes it might be in a writing notebook. (timepoint 2, interview)

Moreover, nine teachers encouraged students to use both everyday and scientific language in class. Alice indicated that ‘students were introduced to some science vocabulary and language. For example, biome, habitat, and adaptations. I wanted them to at least attempt to put that language back into their written responses. (timepoint 3, interview)’ However, almost all the teachers were still struggling with helping students to write in different styles (i.e. argumentative writing, summary writing) for different audiences, while not appearing to provide enough flexibility for students to choose language modes to represent their learning. As such this indicates that teachers generally encourage students to use multiple modes and representations in learning practices, but have limited understanding of authorising students to freely represent their learning with such modes.

Epistemic knowledge

Compared to declarative and procedural knowledge development, the teachers’ epistemic knowledge of language has been developed less thoroughly. From Table 3, around half of the teachers ($n = 6$) understand how to use everyday language to help students utilise science practices and make better meanings with multiple modes of language. For example, Lorry expressed her belief about everyday language and academic language,

I think students use their own everyday language, but I also don’t think there is anything wrong with them learning what scientific terms are. I think it is absolutely okay that they use their own vocabulary and expand on that when you present to them new terms and new concepts. (timepoint 3, interview)

Furthermore, Lusia said,

Some students don’t want to speak up in front of the class. I think providing writing opportunities for them is important ... I don’t believe giving them a list of vocabulary words or

posting that necessarily helps them use it. I try to do it more in conversation. (timepoint 3, interview)

Even though the teachers demonstrated declarative and procedural knowledge on integrating multiple language modes in science teaching and learning, evidence of epistemic knowledge developing is still lacking from almost half of the teachers ($n = 5$) on their interviews or vignettes. Specifically, from their data, they did not demonstrate their understanding on how students can use such modes to show their thinking, learning, and communicate their understanding.

In summary, the teachers' declarative knowledge, procedural knowledge, and epistemic knowledge development regarding language as an epistemic tool did not develop uniformly across the knowledge areas throughout the PD process.

Changes of teachers' knowledge

To answer the second research question: *How do elementary teachers' knowledge development differ from one another as they learn to use language as an epistemic tool?* We categorise the teachers' knowledge changes into two groups based on their overall scores of teacher knowledge items: (1) substantial changes group (eight teachers), which demonstrates above 5 (more than 50%) out of the total 11 scores at the final time point; and (2) basic changes group (three teachers), which demonstrates below 6 scores (less than 50%). Table 4 shows the two groups based on teachers' total scores at the final time point within each dimension and provides their score at time point 1 for comparison.

Substantial changes group

Based on the data analysis, eight of the 11 teachers (73%) demonstrated substantial changes across the three types of knowledge on using language to help students learn science effectively. We summarised the changes of knowledge development into five categories as follows.

Knowledge generation. The teachers understand that language can be an epistemic tool for students to generate knowledge and create meanings. For example, Alice noted in her interview that students can apply the academic vocabulary in talking and writing, 'they'll

Table 4. Teacher knowledge scores based on the dimensions.

Teacher Name & Group	Declarative Knowledge (4 items)	Procedural Knowledge (5 items)	Epistemic Knowledge (3 items)	Scores at Final Timepoint (Total 11 scores)	Scores at Timepoint 1 (Total 11 scores)
Substantial Change Group (8 teachers)					
Teresa	3	5	3	11	5
Alice	4	3	3	10	7
Rose	4	3	3	10	5
June	3	4	2	9	2
Lorry	3	3	3	9	6
Daisy	3	3	2	8	3
Grace	2	4	1	7	5
Lusia	3	3	1	7	3
Basic Change Group (3 teachers)					
Summer	2	2	1	5	3
Chloe	3	1	0	4	2
Scarlett	2	2	0	4	1

learn it, they'll retain it better and they can put it into their own words (timepoint 2, interview)' and use it in conversations rather than just give the meanings to students. The teachers tend to consider language as a combination of expression, communication, and visual representations rather than merely spoken language. Specifically, Alice wrote in her vignette, 'It's not just about spoken language; it's about expressing ideas and communicating them through drawings, pictures, models, writing, graphic organisers, etc. (timepoint 3, vignette)' Similarly, Rose believed that 'writing is a kind of way to solidify our learning so that we don't forget (timepoint 2, interview)', so she tried to let students use multiple language skills to scaffold their academic language and to build meanings through writing and talking. She also explained that 'language is essential to learning. Language is how we build meaning and express it. (timepoint 2, interview)' Teresa also expressed her understanding of language as a meaning-creating tool in her vignette, 'Think of language as any communication your students use throughout learning (timepoint 3, vignette).' She believed that teachers need to provide a comfortable environment to promote students' meaning-making, such as establishing a polite norm in class for sharing ideas and discussing disagreements, planning time for students to talk about what they are learning, and letting students contribute to answering questions or adding new ideas.

Multiple language modes combination. The teachers showed an understanding of the importance of combining multiple language modes to support students in science learning. The teachers understood the importance of multiple language skills, one said, 'language can take different forms such as speaking, dialogue, writing, drawing, diagrams, pictures, etc. (Lorry, timepoint 3, interview)'. One teacher said, 'Training students to use these different forms of language is the first step to effectively using the heuristic approach.' (Grace, timepoint 3, interview). Also, Alice mentioned that her students integrated academic language in writing and talking with visual representations to support expression. She gave her example of the endangered species project that demands students to combine written texts and a diorama, then present it to their family,

It was a good way for them to gain some written skills, but also be creative and kind of use the knowledge that they gained and apply it hands-on, but they also had to use some presentation skills, so I had to kind of rope a lot of things into one. (timepoint 3, interview)

Additionally, Rose expressed in her vignette, 'provide students with multiple opportunities to use language through listening, speaking, writing, and reading. Language skills are not limited to ELA (timepoint 3, vignette).' Overall, teachers tend to believe that students need to use academic language in various learning contexts such as conversations, journals, reflections, and practice different language skills such as writing, speaking, reading, and listening, and teachers should provide opportunities for students to use different language modes as a combination to fulfil tasks.

Engage thinking and interpretation. The teachers demonstrated that they engaged students in thinking and interpreting the science concepts with scientific language. For example, Daisy believed that concept maps helped students to interpret big ideas, so she used an online platform to do concept maps with students. She said that 'when a student asks a question, answer it with a question. This gets them thinking and becoming engaged in their own learning. Once they are engaged, students will want to communicate what they have learned or know or questions they may have. (timepoint 2,

interview)' They also believed that language should be given in a context and the interpretation of language is a good way to show understanding. June said, 'every child brings in their own interpretation of language and that the most important part of introducing new language is to negotiate understanding based on what each child already has in their brain (their resources). (timepoint 3, interview)' Moreover, Grace understood that language is about written and verbal responses from students to show their understanding of academic language. She said that 'when kids use that either written or verbally you can tell if they really know. You can tell if they really understand it or not and so I think that is the important piece. (timepoint 3, interview)' Therefore, both everyday and academic language helped students engage in thinking and interpreting.

Ideas expression and communication. The teachers showed their understanding in utilising multiple language skills, especially writing and talking, to facilitate students expressing their ideas and having conversations with peers on scientific topics. Specifically, Daisy mentioned that she engaged students to communicate with her and peers by using everyday language and academic language to answer questions and explain their thoughts, 'once they are engaged, students will want to communicate what they have learned or know or questions they may have. (timepoint 2, interview)' Also, Lorry expressed in her interview that students can use notebooks to share their ideas with others, especially for those reluctant to speak or have special needs. She addressed that 'when they're talking about things together, they can build their language. And language isn't just words, it's their thoughts. (timepoint 3, interview)' Additionally, Grace said that 'they write first and then we share out, then going back to do more reflective writing. (timepoint 3, interview)' To support students' communication, June thought that teachers should 'create the classroom environment that fosters the free exchange of language in many forms. (timepoint 3, interview)' Moreover, teachers (e.g. Lusia, Rose, Teresa) believed that students should use multiple types of language to scaffold their academic language and to build meaning, such as conversations, science journals, and reflective writing. RaH addressed that she would 'continue to encourage speaking and writing. This will help make thinking audible and visible to all, including the students. (timepoint 4, interview)' In summary, teachers demonstrated their knowledge of supporting students' interactive skills with everyday and academic language.

Visual representations cohesiveness. The teachers understood that visual representations (e.g. print-based texts, digital platforms, drawings, etc.) are good supportive resources and should be cohered in students' learning process. For example, Alice let students use visual representations to support their expression, she believed that language is 'about expressing ideas and communicating through drawings, pictures, models, writing, graphic organisers, etc. (timepoint 2, interview)' Daisy also incorporated drawings and Jam board in her science class. Lorry believed that visual representations could help students to comprehend and articulate ideas, she expressed in her interview that students can use drawings, diagrams, illustrations, and labels to show their comprehension of the scientific language and articulate themselves better. Furthermore, at the last time point interview and vignette, teachers addressed the importance of technology-based multimodal tools (e.g. Seesaw, Padlet, Jam board, Google classrooms) in science teaching, especially during the pandemic. For example, Lusia believed that the online platforms

engaged her students a lot in language practices and students could post diagrams or pictures on the platforms and share them with peers. Similarly, Rose believed that online platforms allowed students to respond to questions in different ways, which students would have more flexibility in learning. Therefore, teachers utilised multimodal representations to help students share ideas and demonstrate their comprehension in interactive and collaborative ways, which are more attractive to students.

Basic changes group

Based on the overall scores, three teachers demonstrated basic changes in their understanding of using scientific language in multiple formats and practices, however, they had implemented limited practices in class and still lacked the knowledge on how students would be benefiting from such practices. We summarised the changes into two categories as follows.

Academic language practices. The teachers have the knowledge of using academic language in their classrooms with students and understand that students need to comprehend and be able to apply it rather than merely memorising the meaning of vocabulary. For example, Chloe mentioned that she helped her students to use everyday language to explain scientific language with visual representations. Also, Summer thought that understanding academic language can be shown by explaining it with everyday language. Scarlett provided several examples of practices such as using concept maps and writing down academic language in journals. However, these teachers did not demonstrate how their students applied academic language into different language modes in learning and lacked the knowledge of why language can engage students in science learning.

Multiple language modes. The teachers demonstrated an understanding of the importance of helping students use language in multiple modes such as writing, talking, and visual representations. For example, Chloe engaged her students in writing and journaling, integrating diagrams into writing. Scarlett found that concept maps were helpful for students to share ideas and understand the unit, and she encouraged students to use academic language in summary writing and to negotiate their ideas with peers. Summer noticed that her students became more interested in writing as she emphasised that it was a learning process rather than focusing on getting everything right. However, these teachers did not provide procedures or details on how their students practiced using these modes in science learning. Moreover, their data lacked a strong rationale for why language was important in supporting students' expression and comprehension of scientific concepts.

In summary, while all 11 teachers showed changes in their knowledge of language use influenced by the SWH approach over the three years, there were differences in the extent of their development. Overall, the teachers improved their declarative and procedural knowledge of using scientific language in multiple modes such as talking and writing in the classroom. However, some teachers still needed to enhance their epistemic knowledge of using language to support student learning in science.

Discussion and implications

The present study provides valuable insights into the knowledge of elementary teachers by investigating their declarative, procedural, and epistemic knowledge

concerning language use in the context of three domains: (1) language as an essential tool for learning; (2) use everyday language in learning; and (3) learning with multi-modal representations. The study revealed that the SWH approach and participating in PD programmes designed to support this approach hold significant potential to enhance teachers' understanding of using language to support students' learning (Yaman, 2018). Nonetheless, the results also indicate considerable discrepancies in the teachers' development across the three knowledge domains and among individual teachers. In this section, we discuss the overall teachers knowledge improvement and the changes specific on the three domains of language use. We also reflect our findings to recent research on elementary teachers' knowledge and instruction, and we provide implications and suggestions for future elementary teacher education relevant studies.

Overall, 73% of the teachers (8 out of 11) demonstrated a substantial improvement in their knowledge development regarding language use over the course of the 2-year PD programmes (see Table 4). The findings reveal that the majority of the teachers in the substantial change group showed development in all three knowledge dimensions (i.e. declarative, procedural, and epistemic knowledge) related to effective language use in science learning, while the basic change group only showed development in declarative knowledge related to language modes and use everyday language in science classrooms. The findings are consistent with our previous work (Hand et al., 2021) and suggest that the PDs intentionally designed to promote understanding of a knowledge generation approach can have a notable influence on the development of elementary teachers' knowledge of language as an epistemic tool (Lee et al., 2008). Specifically, the participant teachers demonstrated their improvement of understanding on using language as a tool to support students in scientific knowledge generation with different modes and representations of language. However, merely half of the teachers showed their understanding of students can take ownership of learning science, and use languages in different ways to communicate their thinking still needs further development. Even though the participant teachers can use language in different modes to help students learn science, they still need to expand their knowledge on language can be tools for students to actively lead their own learning and demonstrate comprehension in various modes of language.

Next, our study explored the elementary teachers' knowledge on three language domains. Our findings suggest that the teachers' knowledge about using language as an essential tool for learning science showed uneven development across the knowledge dimensions. Some teachers showed a clear understanding of epistemic knowledge about the role of language in science learning while others did not. To deepen their understanding of language beyond talking and writing modes, it is imperative for elementary teachers to consider language as a meaning-making process when learning and validating new knowledge (Brown & Ryoo, 2008; Hand et al., 2021). Align with a recent study in preservice teacher education, the more opportunities preservice teachers are provided to conduct sustained writing and talking on science-related topics, the more likely they improve the quality of construct arguments and develop representational competencies (Yaman & Hand, 2022).

Furthermore, our study found that only three teachers described how they encouraged students to practice different writing styles for different audiences despite the importance

of writing in generating knowledge. Previous studies in science education have emphasised that different writing formats, such as journals, observation notes, answering questions, argumentative writing, and summary writing, are necessary for students to generate knowledge in the science classroom (Fiorella & Mayer, 2016; Keys et al., 1999; Lee et al., 2008a). The SWH approach were found effectively improved science pre-service teachers' understanding on scientific argumentation and the quality of argumentative writing (Yaman, 2018). Developing knowledge of language modes and formats equips elementary teachers with means to help students in multiple ways of scientific knowledge generation (Seah & Chan, 2021). Additionally, although the elementary teachers used various language modes in science class, our findings suggest that they did not provide enough opportunities for students to freely choose the language modes they mastered to dominate their own learning process. Therefore, future professional development should pay more attention to developing teachers' knowledge of using language as tools to help students and encourage them to choose different language modes to represent their learning and understanding (Yaman, 2018).

Moreover, the present study found that the teachers recognised the importance of both academic and everyday language in science learning and encouraged students to use everyday language to explain scientific concepts. This finding aligns with a previous study that found the participant teachers understand that everyday language is important for students to build meanings in science learning and different formats of language such as writing, speaking, and representations are helpful to interpret and comprehend scientific language (Nagy & Townsend, 2012). The development of teachers' knowledge on using everyday language is necessary for elementary teaching and learning. Using everyday language is essential for elementary teachers to match the language to their students' understanding level, and ensure the meaning communication is on the same level between teachers and students in science classrooms (Seah & Silver, 2022). This is even more crucial for linguistically diverse students because it scaffolds students' academic language in content areas learning (Warren et al., 2001). Therefore, further research is recommended to focus on elementary in-service and preservice teachers' understanding of scientific terms that have similar meanings and their language knowledge of transferring the scientific terms into everyday language with accurate meanings (Yeo & Tan, 2022).

Last but not least, from the findings, all 11 teachers have demonstrated their declarative and procedural knowledge of language in multimodal representations in science instruction and practices, in which they combined multimodal formats of writing, talking, drawing, and print-based texts to teach science. This finding reinforced a previous systematic literature review that summarised multimodal representations utilised in various elementary instructional settings to support students to gain knowledge and skills in different content areas (Si et al., 2022). Even though the teachers widely utilised multimodal representations to support meaning communication, from our findings, five teachers still lacked epistemic knowledge of why different modes and representations of language can help students learn in scientific knowledge. During the COVID-19 pandemic, the teachers reported relying more on technology-based tools for teaching, and they anticipate continuing to use these tools even when schools return to face-to-face instruction (Francom et al., 2021). To meet the needs of young students on technology-based learning, we recommend professional development should equip teachers

with more knowledge about technology-based tools in classroom instruction, as the younger generation is learning via digital tools over traditional mode, and would be more appreciated if teachers can incorporate modern technology-based tools into their curriculum and classroom learning (Szymkowiak et al., 2021).

Limitations and future directions

Despite the study's valuable findings, it is essential to acknowledge the limitations posed by the ongoing COVID-19 pandemic. The challenges it presented, such as constraints on data collection and the willingness of teachers to participate, may have influenced the accuracy and generalisability of the study results. More observation data at different time points would better demonstrate the teachers' classroom instruction. Additionally, the study's small sample size may limit the generalisability of its findings (Creswell & Poth, 2016). It is worth noting that teachers' experiences and perspectives regarding language use in science education can vary significantly based on factors such as their location, teaching experience, and demographics of their students. As a result, the summary of substantial changes and underdeveloped domains among the participating teachers may differ if a more extensive pool of participants successfully completes the PD programme.

The study only included teachers who showed continuous participation to the PD and who provided data at different timepoints, which may not represent the full range of experiences and perspectives of teachers regarding language use in science education. The study's representation might not be entirely comprehensive, as it excludes the experiences and opinions of teachers who did not complete the PD. This exclusion might raise some concerns, such as the possibility that the participating teachers who agreed to be part of the study might hold more positive views. However, the findings showed the participant teachers varied in terms of their understanding and transition to generative learning practices concerning language use. In addition, all the participants in our sample were female teachers. Although there is limited literature explicitly addressing the influence of teacher gender on their comprehension and utilisation of language as an epistemic tool, some studies have indicated gender differences in the use of information and communication technologies (e.g. Bang & Luft, 2013). Involving male teachers in the study could have offered distinct perspectives, particularly in exploring the shift towards comprehending and employing technology-based multimodal tools. Thus, it is important to conduct future research with a larger and more diverse participant sample from multiple sites to provide a broader perspective and more varied experiences and teaching settings.

Conclusion

The study's findings provide valuable insights into the development of teachers' knowledge of language use in science education. However, it is essential to recognise the limitations and acknowledge the need for more diverse groups of people, such as marginalised groups, English learners, and students with multi-abilities, and larger participant samples and additional observation data in future research. These efforts would allow for a more comprehensive and accurate understanding of the role of language in science education

and how to better support teachers in their efforts to promote effective language use in the classroom.

Ethics statement

This research has been approved by the University of Alabama's Institutional Review Board (#18-07-1325).

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