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RESEARCH ARTICLE

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Characterizing adaptive teaching expertise: Teacher profiles based on epistemic orientation and knowledge of epistemic tools

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Abstract

With an ultimate goal of characterizing teachers' movement toward understanding the epistemic complexity of generative learning environments, this study refers to adaptive teaching expertise (AdTex) as a developmental teaching capacity observable through a teacher's ability to utilize various resources to address the epistemic complexity of knowledge generation practices. The analysis and discussions centered on how teachers develop and utilize epistemic orientation and understandings of epistemic tools for adaptive teaching, making this study distinct from previous research on AdTex. In particular, this study shows a new way to create systematic profiles of AdTex based on the multiple qualitative data sources, including vignettes, interviews, and reflections collected through a multiple-case study with 24 teachers. The qualitative profile analysis suggests that the development of epistemic resources is closely related to teachers' attention to student ideas, student agency, and a balance between flexibility and productivity regardless of context. The analysis demonstrates that the development of epistemic resources can represent the degree of development of AdTex and provide a rich research pathway for future analysis.

KEYWORDS

adaptive teaching expertise, epistemic orientation, epistemic tools, qualitative profile analysis, teacher learning

1 | INTRODUCTION

1.1 | Background and problems

The Next Generation Science Standards (NGSS; NGSS Lead States, 2013) recognize a critical need for teachers to engage students in epistemic practices of science and engineering (Berland et al., 2016). These practices involve social and interactional acts aimed at constructing, communicating, and validating knowledge claims, individually and collectively (Kelly & Licona, 2018). The epistemic practices suggested by the NGSS are neither sequential nor straightforward. Instead, they are characterized by the sophisticated utilization of various epistemic tools such as language, dialog, and argument. The NGSS offers a curricular framework toward which teachers can aim their use of epistemic tools. However, the NGSS does not define the rules governing how these tools intersect, or how they should be utilized to implement epistemic practices during the process of knowledge generation across various learning contexts. In this gap, the relationship between teachers' use of epistemic tools and their students' science learning becomes even more complex and unpredictable when students bring their own unique intellectual resources to the knowledge generation process (Maggioni & Parkinson, 2008).

Thus, the challenge of teaching in ways aligned with the NGSS is clearly great, yet key elements remain undefined. In particular, the complex nature of knowledge generation environments requires a fundamental change in perspectives on teaching. Specifically, teachers must move from routine pedagogy to adaptive pedagogy (Fairbanks et al., 2010; Lampert et al., 2013). In other words, teachers must move beyond the role of routine experts who focus on mastery of knowledge and practices through knowledge replication approaches to become adaptive experts. In parallel form, this enables teachers to construct knowledge generation environments, defined as those in which knowledge is fluid and actively constructed through student participation in scientific practices. As a whole, this movement requires the development of adaptive teaching expertisee (AdTex) (Yoon et al., 2015). Teachers with AdTex defined as those who constantly evaluate the teaching context and utilize their cognitive, epistemic, linguistic, and sociocultural resources to create spaces for knowledge generation are the future of science education.

Research on AdTex has achieved solid grounding in the field (Yoon et al., 2015). We can look to models of effective teaching that demonstrate that teachers who hold adaptive expertise are flexible, innovative, and deliberate throughout the decision-making process (Berliner, 2001; Lampert, 2010). Despite the profound importance of AdTex, little is known about how we can characterize this expertise in ways that address the epistemic complexity of science learning environments across various contexts. Moreover, few attempts have been made to rigorously study this expertise as a necessary foundation for implementing reform-based approaches in the science education field (Bowers et al., 2020), resulting in critical disconnections between a framework of AdTex and the fundamental theories of learning science that underpins the NGSS.

The challenges to studying AdTex are both conceptual and methodological. AdTex goes beyond simply having more knowledge or experience, which is more easily measurable through research, and instead functions as a capacity or ability to adjust instructional decision-making by moving away from the preplanned curriculum (Mulvey et al., 2016). Accordingly, and in agreement with Bereiter and Scardamalia (1993) we concur that teacher expertise should be understood in terms of a *process of growing (developmental)* as something people can change and advance rather than *a thing* or *state* as something they have at the moment. From this perspective, we argue that AdTex is best described as a developmental teaching capacity observable through a teacher's ability to adjust and utilize various resources to address the epistemic complexity of knowledge generation practices. One should note that the phrase "developmental or process of growing" does not mean that there is a single pathway to this expertise, but that this expertise expands over time and through experience. Indeed, we assume that there are multiple pathways to development, and each teacher has his/her distinct profile of this development.

We recognize the methodological difficulty of measuring and/or capturing this process, as opposed to knowledge. However, we argue that continuing to search within well-searched spaces, such as content and pedagogical knowledge, is unlikely to lead to the radical change necessary to enact the vision put forth in the NGSS. As science educators, we acknowledge the vast value of teacher knowledge, but we aim to go beyond what is most obvious by exploring the important underlying resources for AdTex.

1.2 | Goal of paper

The purpose of this research is to characterize teachers' movement towards utilizing epistemic tools and their development of AdTex as an underpinning foundation for implementing knowledge generation approaches. To do this, we first examine how the role of teacher knowledge, and related constructs that influence how teachers use their knowledge, has been understood through prior research.

2 | THEORETICAL FRAMEWORK

2.1 | Adaptive teaching expertise

Classroom teaching is a challenging and demanding activity that requires teachers to address inherently complex and ambiguous situations (Shulman, 2004). Given that classrooms are the places where "particular students interact with particular ideas in particular circumstances" (Ball & Cohen, 1999, p. 10), this requires teachers to be adaptive problem solvers who understand that every situation is different and are able to utilize different professional knowledge and practices to meet the needs of students and the cognitive demands of an instructional situation (Duffy & Hoffman, 2002; Soslau, 2012). Various scholars have provided numerous descriptions and conceptualizations of adaptive expertise since Hatano and Inagaki (1986) proposed the term. Research has particularly focused on how adaptive expertise differs from routine expertise (e.g., Fisher & Peterson, 2001; Mylopoulos & Woods, 2009). The difference between adaptive and routine experts becomes apparent once we see how they address uncertain or unfamiliar situations: A situation in which desired procedures and results are not known in advance, such as knowledge generation environments (Ellström, 2001).

2.2 | Characterizing AdTex for knowledge generation environments

Learning is a generative activity that involves actively constructing the meaning of to-be-learned information by adjusting and integrating it with prior knowledge (Fiorella & Mayer, 2016; Wittrock, 1974). For decades, this vision of learning has been reflected in major reform efforts in science education, including NGSS (NGSS Lead States, 2013), advocating teaching in a way that engages students in the cognitive processes of generating knowledge about the world (Aleixandre & Crujeiras, 2017). Transforming classrooms into knowledge-generation environments requires changing the epistemic underpinnings of learning and teaching practices, such as the use of language, the structure of dialogic interactions, and the process of decision-making around knowledge (Suh, 2016). To understand and address the complexity of the knowledge generation environments, teachers must understand the epistemic underlying of the knowledge generation process and develop the ability to use fundamental tools and practices for it.

The theoretical framework used in this research (see Figure 1) attempts to explain what teachers need to be able to do, know, and fundamentally be to take up the complex epistemic activities necessary to use knowledge generation practices (NGSS Lead States, 2013). Currently, teachers who enact the NGSS vision in science classrooms do so through generative learning approaches (Tytler et al., 2019). In these approaches, students are authors of their knowledge as they utilize their *freedom* to engage in a range of epistemic practices for learning

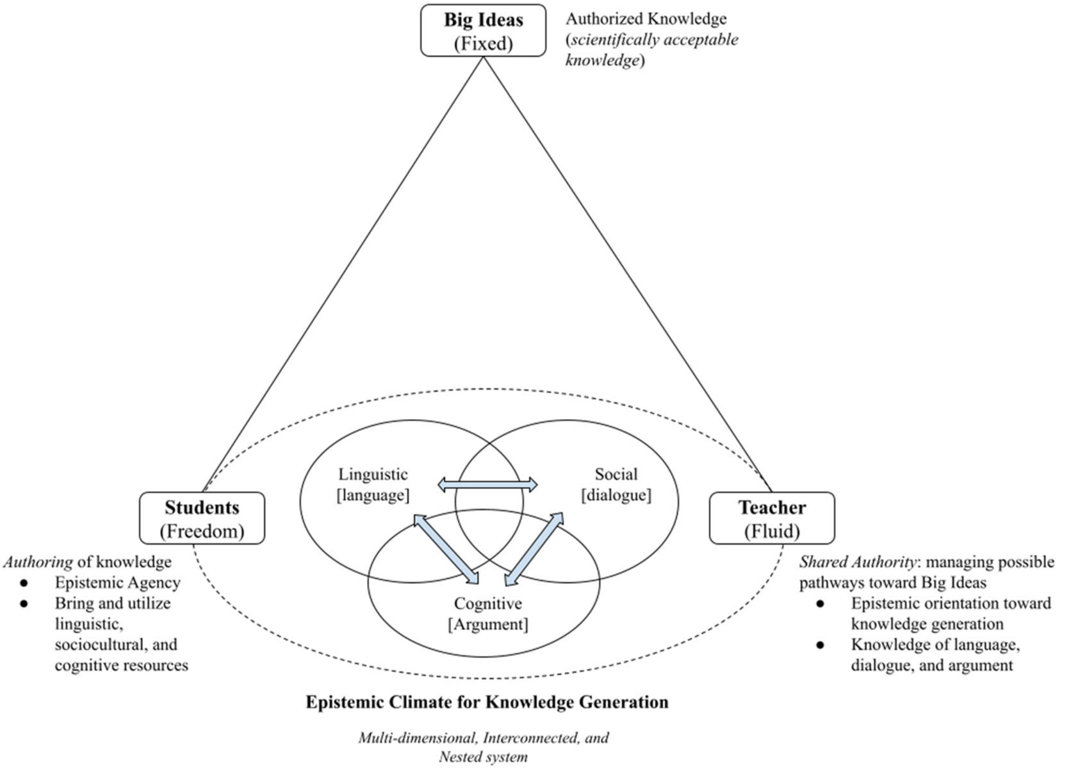

FIGURE 1 Conceptual framework of adaptive decision making.

NGSS-sanctioned big ideas in science. Such settings can be created when teachers are *reflexive* (Schön, 1983) and *fluid* by sharing their authority to manage possible pathways toward authorized big ideas. This suggests that teachers must become adaptive decision-makers who can go beyond being flexible around defined practices and strategies. An adaption is often defined in literature as a deviation from curriculums or lesson plans (e.g., Allen et al., 2013; Beltramo, 2017), which can lead researchers to focus only on actions or decisions in which teachers flexibly switch or modify defined practices or strategies they already had. While we do not dispute that *flexibility* is one of the characteristics of adaptive teachers, we intentionally use the term *fluidity* to better reflect the complex and undefined nature of teaching for knowledge generation environments. Unlike research that focuses on an adaptation of curriculum or lesson plans, we aim to characterize AdTex as the ability of teachers to "adjust their teaching according to the social, linguistic, cultural, and instructional needs of their students" (Parsons et al., 2018, p. 206).

2.3 | Foundation for the development of AdTex

2.3.1 | Epistemic orientation

Knowledge has been viewed as a crucial resource for teaching (Carlson et al., 2019; Gess-Newsome, 2015; Shulman, 1986). In a similar vein, much emphasis has been placed on studying teachers' content and pedagogical knowledge (including pedagogical content knowledge) as a means of characterizing their ability to adapt their instructions (e.g., Lee et al., 2014; Schipper et al., 2017). Teacher knowledge clearly matters, but researchers have questioned whether there are specific knowledge bases that can prepare teachers to address the complexity of learning environments. The first step toward addressing the complexity requires an understanding of the fact that the decision-making process often proceeds nonlinearly and nonsequentially as teachers negotiate with a variety of resources and factors in their responses to student learning (Schildkamp & Poortman, 2015). This means that adaptive decision-making demands more than simply applying existing knowledge and practices; no specific set of content knowledge or pedagogical knowledge can prepare teachers to be adaptive in those decision-making processes (Kennedy, 2006). This is even more true when there is a clear need for shifting science teachers' epistemic stances and views toward knowledge generation (Suh & Park, 2017; Windschitl, 2002). To be adaptive decision-makers aligned with the epistemic underpinnings of the NGSS, teachers must shift their epistemic orientations (EOs) toward generative learning approaches (Suh et al., 2022). In other words, teachers should develop an EO which considers knowledge as unsettled and evolving, learning as a generative activity, and teaching as actions dealing with the complexity and uncertainty of knowledge generation processes (Männikkö & Husu, 2019; Suh et al., 2022).

The importance of an EO has been documented in the literature. For example, Fisher and Peterson (2001) regarded epistemology as one of the four primary constructs of AdTex. De Arment et al. (2013) also claimed that adaptive experts hold an epistemic stance that views the world as complex, messy, irregular, and dynamic. Similarly, Männikkö and Husu (2019) highlight that an *open* orientation to pursue more dynamic and evolving knowledge and skill is a key factor for predicting adaptive expertise. Although the field of education has agreed on the importance of epistemic stances in understanding adaptive expertise, it has often been defined broadly and inconsistently under personal epistemology theories (Hofer & Pintrich, 1997; Sandoval, 2005). Similar terminologies such as epistemic stance, epistemic worldview, and epistemic beliefs have been widely used to describe an individual's theories and beliefs about knowledge and knowledge generation. This inconsistent use of terms and definitions results in hardly providing specific theoretical implications for the fundamental underpinnings of the instructional practices necessary to adapt to knowledge generation approaches (Maggioni & Parkinson, 2008). To address this concern, a previous study conceptualized EO as a more inclusive concept by collectively considering epistemic beliefs and beliefs about learning and teaching within its framework (Suh et al., 2022). The term EO refers to a direction of thinking that determines actions and reactions inside the knowledge generation process (Suh et al., 2022).

EO has powerful implications for characterizing AdTex. First, it functions as cognitive guidance for other resources (e.g., content knowledge and pedagogical knowledge) by driving the processes of selecting and utilizing appropriate resources when deciding how to implement epistemic practices (Park et al., 2022). Second, EO toward knowledge generation directs teachers' attention to the resources students bring to the learning environment. Previous studies demonstrated that teachers tend to value students' ideas more in dialog and promote the utilization of students' epistemic agency to generate knowledge as they shift their EO (Anthony et al., 2015; Lammert, Suh et al., 2022). Third, EO influences how teachers approach the complexity and uncertainty of knowledge generation. While teachers often view uncertainty as undesirable conditions for learning (Beghetto & Karwowski, 2017; Chen & Qiao, 2020), teachers who have an EO toward knowledge generation tend to view uncertainty as a fundamental aspect of knowledge generation. This view enables teachers to utilize more flexibility to solve nonroutine problems. Lastly, EO toward knowledge generation prepares teachers for ongoing, future learning which is an important characteristic of adaptive teachers (Bransford & Schwartz, 1999). Teachers with an EO strongly aligned with a knowledge generation approach believe that knowledge can be changed with new evidence and are willing to change their own ideas and practices through new learning. This enables their continuous learning as they reflect and reform their expertise (Crawford et al., 2005).

2.3.2 | Knowledge of epistemic tools

Using learning tools as epistemic tools for learning science means that the tools are utilized to create social and cognitive spaces for knowledge generation, and they encourage students to think in ways consistent with how scientific knowledge is advanced (Settlage & Southerland, 2019; Stroupe et al., 2019). The importance of epistemic tools has been recognized in science education literature, and this recognition has led researchers to pay specific attention to three foundational tools: (a) argument (Mullis & Martin, 2017; Nussbaum, 2012), (b) dialog (Premo et al., 2018), and (c) language (Hand et al., 2021; Norris & Phillips, 2003). These three tools are essential to addressing cognitive, linguistic, and social aspects of epistemic practices in science. While the roles of these tools are intertwined with each other in knowledge generation processes, each tool has its unique features that inform cognitive, linguistic, and social dimensions of learning environments.

Language as an epistemic tool

Language is a fundamental tool for generating knowledge. As the National Research Council (NRC, 2012, p. 76) framework stated, “Every science or engineering lesson is in part a language lesson…”. For students to engage with language in generative ways requires that teachers understand and encourage the use of language to support learning (Yore & Treagust, 2006), as opposed to using language solely as a communicative tool. This distinction is crucial since there are two opposing perspectives on language use in science: (a) students must learn to use language before learning science, and (b) students can use language as an epistemic tool for learning science. The first positions language as a “by-product of thought, rather than a contributor to it” (Klein, 2006, p. 149); thus, learning scientific vocabulary and syntax is considered a precursor to meaningful engagement in scientific practice. Alternatively, the second view emphasizes that language is learned through its use and scientific vocabulary and syntax should be embedded within the learning experience (Gee, 2004). From this perspective, language learning intersects with scientific ideas inside the scientific practice. This view is aligned with Halliday's (1975) suggestion that the best approach to learning language is through using that language as a person lives it.

Three principles for the use of language as an epistemic tool support the theoretical framework used in the current research: (a) Language is essential for student learning; (b) learning can be maximized by utilizing multiple forms of language; and (c) language is a constitutive part of science. First, it is impossible to teach science without using some form of language since knowledge cannot be generated without the use of semiotic systems that allow individuals to represent their ideas (Norris and Phillips, 2003; Oyoo, 2012). Relatedly, multiple science reform initiatives have highlighted the importance of language in science learning (NRC, 2012; NGSS Lead States, 2013). Second, the value of language is maximized when multiple modes of language (e.g., text, video, diagram) and multiple forms of language (e.g., spoken, written) are employed to make sense of natural phenomena (NGSS Lead States, 2013). Rivard and Straw (2000) claim that student talk is vital for sharing, clarifying, and spreading knowledge among peers, whereas writing is essential for translating emergent ideas into coherent understandings. In addition, science instruction “must entail movement from the existing everyday ideas of children towards a more scientific point of view” (Mercer et al., 2009, p. 354). This means that when using language as an epistemic tool, it is crucial that teachers value students' everyday language to help them bridge their experiences to expressions with academic language (Varelas et al., 2008). Last, language is not a simple tool for storing and transmitting science, but rather a constitutive part of science. As Norris and Phillips (2003, p. 226) state, “Constitutive relationships define necessities because the constituents are essential elements of the whole”. This perspective transcends the view of language as a simple communicative tool.

Dialog as an epistemic tool

Dialog is an essential tool for learning science, particularly since one goal of science education is to engage students with social aspects of scientific practices (Ford, 2008; Hand et al., 2019; Premo et al., 2023). Dialog involves constructing, critiquing, and revising ideas, which leads to “a new understanding that is progressively constructed by the participants, move by move, meaning by meaning” (Wells, 1999, p. 4). Social interaction through dialog plays a critical role in knowledge generation processes, and such interactions can benefit student learning (Mercer, 2008; Wells, 2007).

To immerse students in dialog, teachers must create dynamic spaces where students interact in pairs, dyads, or in small or whole group discussions (Baines et al., 2003; Howe & Abedin, 2013). While the groupings can vary, what is essential is that students' private arguments are brought to the public realm through these discussions. This results in the evaluation of arguments by others, which enables the arguments to be re-evaluated and improved. Ultimately, a dialog can validate students' knowledge, and equally, encourage them to rethink previously held positions.

Using dialog as an epistemic tool requires teachers to shift away from teacher-dominated lectures by allowing students to utilize their agency to construct, evaluate, and communicate their ideas. As Premo et al. (2018) highlight, teachers need to understand that student involvement in the social practices of science is centered around issues related to power and agency. This recognition allows teachers to attend to other resources (e.g., conceptual, epistemic, and sociocultural) that students bring to the learning environment (González-Howard & McNeill, 2020; Ko & Krist, 2019; Miller et al., 2018).

Importantly, epistemic tools such as dialog are connected to other epistemic tools. Clearly, it would be impossible to engage in dialog without using some type of language, and dialog is a space in which students' arguments can be refined. Dialogical interactions should provide students with a learning space in which to construct, validate, and communicate knowledge while utilizing a variety of language forms and modes to represent the meanings of their knowledge (Kewalramani & Veresov, 2022; Mercer et al., 2019). This requires teachers to understand ways of using argument within dialog, and how to engage students in multiple language practices for knowledge generation.

Argument as an epistemic tool

Argumentation is defined as an individual cognitive activity and a negotiated social act (Driver et al., 2000; B. M. Hand, 2008). This perspective views argument as being constructed through an individual cognitive process; however, it becomes a process in which meaning is debated through interaction. Students construct arguments and accept public critique to identify weaknesses in those arguments, at which point each student returns to production to strengthen their arguments.

Argument as an epistemic tool represents how science has advanced. In line with the activity of scientists, students should engage in reflective thinking to construct and critique ideas by making claims, generating evidence, and reporting their findings (Duschl et al., 2007; Ford, 2008). Jiménez-Aleixandre and Erduran (2007) asserted that introducing argument in science classrooms has the potential for fostering scientific literacy and understanding of scientific culture. To engage students in argument, teachers must understand how to use arguments for developing scientific knowledge. They must also allow students to become fluent speakers of science within peer group interactions and make sense of newly constructed ideas.

Among various orientations to argumentation (e.g., Erduran et al., 2004; Winn et al., 2016), "only the immersion orientation appears to fully capture the culture, including the epistemic nature of science that is embedded in scientific practice" (Cavagnetto, 2010, p. 352). Immersion-oriented approaches involve students in cognitive processes and social interactions in which they construct scientific knowledge by using argument structures (Weiss et al., 2022).

2.4 | Toward an AdTex view of teaching

The combination of an EO and knowledge of epistemic tools promotes the development of the epistemic foundation for AdTex. In the current research, our focus on the epistemic foundation is distinct from previous research on professional expertise. Achieving a better understanding of how the EO and knowledge of epistemic tools interact is necessary to characterize the development of foundational resources for AdTex to address the epistemic complexity of learning environments. Starting from our conceptualization of adaptive expertise, a multiple case study was conducted to create profiles of AdTex and detail the characteristics of each profile.

2.5 | Summary of the theoretical framework

This research set out to build on an empirical study of teacher learning as the basis for a theoretical framework that articulates the relationship between the EO, knowledge of epistemic tools, and AdTex. Consistent with Figure 1, we have demonstrated how teachers must act with fluidity as they move between the authorized big ideas of science and their students' freedom to construct their own explanations. We have also highlighted epistemic tools play key roles in teachers' ability to act with this fluidity. Specifically, we argue that teachers who hold knowledge of the ways language, dialog, and argument can function as epistemic tools, and who hold EOs toward knowledge generation, are most able to develop and exercise AdTex. To demonstrate how case study profiles support this framework, we now turn to an empirical example.

2.6 | Research questions

The following research questions are addressed in this study:

- How can the teacher profiles created based on their EO and knowledge of epistemic tools (i.e., language, dialog, argument) characterize AdTex for teaching science?
- What characteristics make teachers more or less adaptive in their decision-making for teaching science?

3 | METHODS

3.1 | Participants and context

The basis for this research was a study focused on developing the adaptive expertise of elementary science teachers ($n = 122$) as they implemented a knowledge generation approach called the Science Writing Heuristic (SWH) (Hand & Keys, 1999). The SWH approach emphasizes the use of epistemic tools such as argument, language, and dialog to create immersive classroom environments (Hand et al., 2021). This research provided us with a sample of science teachers whose AdTex was under development. To promote SWH, a 3-year professional development (PD) program was designed based on the conceptual framework shown in Figure 2.

This diagram illustrates how we integrated findings about teachers' knowledge of epistemic tools, EO, and classroom practices to provide a theoretical framework for teachers' AdTex growth. The intensive summer PDs lasted 6 days each year of the study. After the 6-day summer PD workshops in the following semester, participant teachers were additionally supported by a planned visit from a PD consultant in which they discussed their challenges and successes with the approach. The main goals of the ongoing PD workshops were to help teachers better understand the fundamentals of the knowledge generation environment. The summer PDs particularly framed around four main themes: (1) learning, (2) language, (3) dialog, and (4) argument. During the learning sessions, the teachers had discussions about how students learn science, shifting roles of students and teachers in generative learning environments, and creating learning environments that help students utilize their agency to learn science. To help the teachers understand the core ideas, the PD leaders worked with teachers to generate big ideas of generative learning: (1) we negotiate ideas, not people (2) learning is about big ideas, negotiation, and the use of language and (3) learning is focused on being additive, not about what is in deficit (4) we are all learners and learners need to be adaptive. Teachers also learned about language, dialog, and argument as epistemic tools through discussions, modeled activities, and example classroom video analysis. Specifically, we emphasized flexibility in the use of epistemic tools. In addition, teachers were allowed to address their concerns and questions about the SWH approach. Typically, the morning sessions were centered on presentations by guest speakers with follow-up question-and-answer opportunities. The

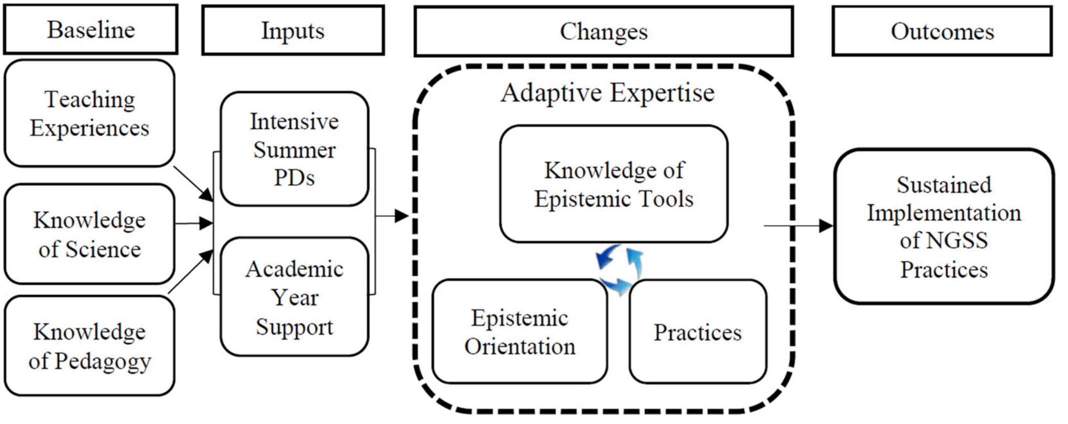

FIGURE 2 Conceptual framework for the professional development (PD) program. NGSS, Next Generation Science Standards.

afternoon sessions consisted of teacher-selected small group meetings with participants as the center of conversions. Thus, teachers experienced the value of dialog for themselves as learners.

Participants in this study were 122 K-5 teachers from two U.S. states, one in the Midwest and one in the Southeast. We conducted a multiple-case study (Yin, 2014) to understand teachers' decision-making processes and experiences with SWH as a knowledge-generation approach. To identify case study teachers who have a range of orientations possible, we used maximum variation sampling. This sampling method involved evaluating the scores of the survey, called the Epistemic Orientation Survey (Suh et al., 2022), which the teachers completed before the first SWH workshop. After asking for their consent, we conducted case studies with teachers who volunteered for further data collection. Stake (2006) has argued that the key criteria for participant selection in multicase studies are whether each individual case is relevant to the object of study, the diversity of contexts across cases, and whether each case provides an opportunity to reveal complexity. We satisfied these criteria by selecting 24 teachers with maximum diversity in ways relevant to the constructs under investigation (i.e., their AdTex, EO, and knowledge of epistemic tools). Since prior research has suggested that teachers typically require professional support to develop their knowledge of the use of epistemic tools (e.g., González-Howard & McNeill, 2020) we ensured that teachers varied in their years of experience, which ranged between 1 and 30. A table providing information about the participants' context in the multiple case study is included (Table 1). As can be seen in the table, participant teachers had varied instructional modes because of COVID-19 pandemic regulations. There were 11 teachers who kept teaching in person. Five of them taught hybrid, where at-home students zoomed in to the classrooms. Eight other teachers taught both in person and virtually at different times. As shown in Table 1, some teachers had district-promoted curriculums. However, most of them mentioned that they mostly used those curriculums as a resource, and they did not have pressure to implement them step by step. Only one teacher (TeB) noted it limited her flexibility.

3.2 | Data collection

Throughout the 3 years of the study, we collected different types of qualitative data (interviews, observations, and PD reflections) from the same case study teachers at multiple time points as shown in Figure 3. The present study includes reflection, vignette, and interview data collected from 24 teachers during the summer 2020 workshop and 2020–2021 school year, which refers to the project's second year. We used the data collected at that time because the COVID-19 pandemic had created novel contexts where the teachers are required to address nonroutine problems that they had never experienced before (Lammert, Hand et al., 2022). Analyzing the data collected from

TABLE 1 Teacher information.

Teacher	Cluster	Gender	Grade level	Years of experience	Instructional mode			Curriculum	
					In-person	Hybrid	In-person and virtual at different times	District-promoted curriculum	No curricular restrictions
KyB	Midwest 1	Male	5	8	X				X
JeL	Midwest 1	Female	4	13			X		X
GiJ	Midwest 1	Female	3	19	X				X
LiS	Midwest 1	Female	3	13	X				X
SaS	Midwest 2	Female	5	4	X				X
JoB	Midwest 1	Female	5	8	X			X	
LaS	Midwest 1	Female	4	12			X	X	
CaC	Midwest 2	Female	4	17		X		X	
AlR	Midwest 2	Female	4	1	X			X	
KrD	Midwest 2	Female	4	1			X		X
SaJ	Midwest 2	Female	3	17	X			X	
DaK	Midwest 2	Female	3	26	X			X	
KaB	Midwest 2	Female	5	1			X		X
JoM	Midwest 2	Female	4	19			X		X
LaD	Midwest 2	Female	5	30	X			X	
KrL	Midwest 2	Female	4	12			X		X
AnT	Midwest 3	Male	4	2	X				X
TrL	Midwest 3	Female	3	20		X			X

TABLE 1 (Continued)

					Instructional mode			Curriculum	
Teacher	Cluster	Gender	Grade level	Years of experience	In-person	Hybrid	In-person and virtual at different times	District-promoted curriculum	No curricular restrictions
TaL	Southeast	Female	5	2		X			X
RaH	Southeast	Female	5	9		X			X
JeH	Southeast	Female	5	12			X		X
TeB	Southeast	Female	4	17			X	X	
AlH	Southeast	Female	5	15		X		X	
SaC	Southeast	Female	4	26	X			X	

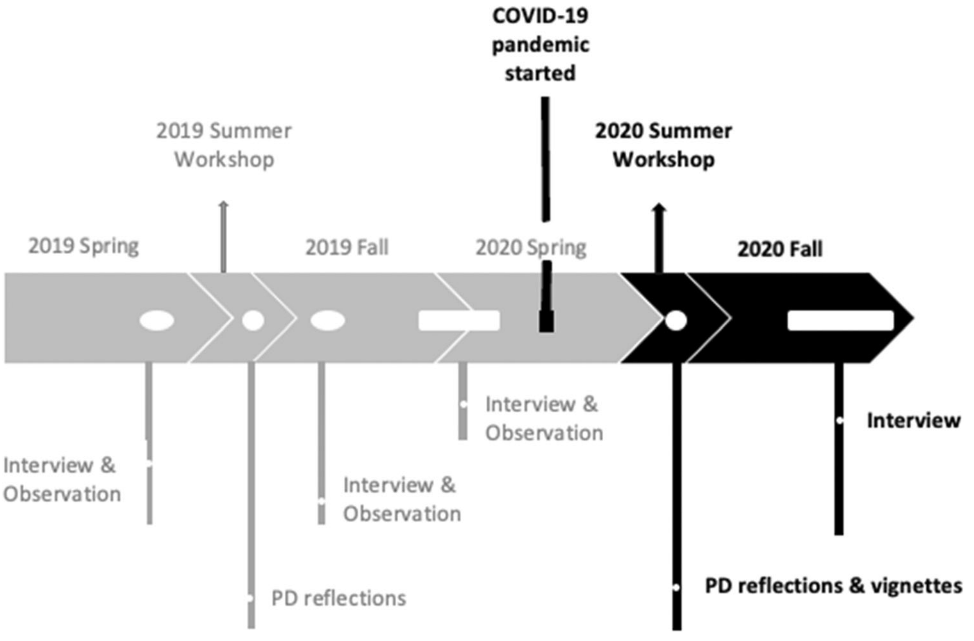

FIGURE 3 Qualitative data collection throughout the project for case study teachers. PD, professional development.

this time enabled us to further understand how teachers' EOs and understandings of epistemic tools functioned as foundational resources to be adaptive across contexts.

3.2.1 | Vignettes

Four vignettes were designed to assess teachers' EOs and their understanding of epistemic tools. The purpose of including the vignettes was to provide a scenario to which teachers could respond in ways that demonstrated their knowledge of epistemic tools and their ability to act in ways consistent with AdTex when faced with a novel problem (Finch, 1987; Stecher et al., 2006). The administration procedure for the first vignette asked teachers to write for 10 min in response to the following scenario: "Thomas has just finished his first Science Writing Heuristic workshop, and now he is uncertain how to prepare for teaching science. He knows he won't be able to anticipate all the different ideas his students will share or where the investigations may go. Please describe to Thomas how he could think about science teaching as he prepares. Include any steps he should take, and make your thinking transparent so he knows why those steps are important." The other three vignettes followed the same structure, and each one included specific prompts to explore how teachers might think about language, dialog, and argument when preparing to teach science concepts. The vignettes were administered individually, online, through a reusable link, one per day, during the third year's PD.

3.2.2 | PD reflections

We collected teachers' written reflections through open-ended questions (a) after each morning session of the PD, (b) after each afternoon session of the PD, (c) after the overall PD. We asked several open-ended questions to get teachers' reflections on the topics covered in the PD. Example questions include the following:

1) What was your biggest struggle with argument as a learning tool? What will you do/try in your classroom next year to support student argumentation?
2) What has been your biggest change in how you think about using language in science?
3) If someone said that the “Big Ideas” of each unit anchor their instruction, what would that mean to you?
4) In the examples you saw today, how were students given “space” to ask questions and negotiate ideas?
5) What skills do you already have that you feel work well with the big ideas of this workshop?

Including the teachers' individual written responses as a data source allowed us to analyze participants' thinking immediately following the PD and without interaction with a researcher, whereas interviews were conducted later.

3.2.3 | Interviews

In Time Point 4, individual semi-structured interviews took place during the school year after the summer PD. All interviews were audio-recorded and transcribed. The interview questions focused on four main areas: (1) epistemic tools (2) learning (3) adaptiveness, and (4) planning. Sample interview questions included the following:

1) 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?
2) Do you think learning works in mostly similar ways across content areas, or do you think students learn differently from science to english language art, to math, to social studies? What does your view of learning mean in your teaching?
3) How has the uncertainty of your current teaching situation, including in-person, remote, and virtual instruction, required flexibility? What or who have you drawn on as sources of support?
4) How much do you stick to a daily or unit plan, and how much do you deviate? How does this compare to what you have done in the past?

Importantly, to improve the dependability of the interviews' content (Yin, 2014) they were conducted by graduate students and post-docs with no formal authority to evaluate the teachers' abilities. Each interview lasted between 25 and 50 min.

3.3 | Data analysis

We conducted interviews after participants had completed the vignettes and PD reflections. Subsequently, we conducted data analysis specific to each step of the study.

3.3.1 | Step 1: Vignette analysis

Our case study analysis process began with the vignettes since this data source provided insights into each participant's EO and knowledge of epistemic tools. First, we created a Vignette Evaluation Rubric to analyze vignette responses (Table 2). The rubric addressed learning, language, dialog, and argument. We combined all four vignette responses and then used the rubric to determine the teacher's level of orientation toward learning and the level of understanding of each epistemic tool. Each component had three criteria. The criteria were determined based on the literature review on each area. If a teacher's responses addressed three of them, those responses were scored as high. If the response addressed two of the three criteria, we scored that as medium. If the response

TABLE 2 Vignette Evaluation Rubric.

	Low	Medium	High	Target areas
Orientation to learning	At least one area was addressed; responses show limited understanding of the areas or are poorly aligned with knowledge generation.	At least two areas were addressed; responses show a basic understanding of the areas and are aligned with the knowledge generation approach.	Three areas were addressed; responses show exemplary understanding of all three areas and are aligned with the knowledge generation approach.	Response addresses **1.** *Learning process*: What "learning is (learning process)." They may use words like "know" or "knowledge" and discuss the role of students' existing/prior ideas. **2.** *Loci of learning*: Students' "control" and/or "freedom" in relation to learning. **3.** *Attention to learning*: Interests and attention were landing on student learning (not themselves and teaching) engagement, and wellbeing.
Language				Response addresses **1.** The ideas of using language as a learning tool; giving students control over what they talk and write. **2.** Use of multiple forms of language (writing, multimodal representations), and/or everyday language. **3.** Connection between language and other tools.
Dialog				Response addresses **1.** 1. Student-centered/dominated dialog. **2.** Dialogs through different group sizes. **3.** Connections between dialog, language, and argument.
Argument				Response addresses **1.** Argument or negotiation as an essential learning tool. **2.** Negotiation/argumentation cycles (question–construction–critiques) instead of following one-time mechanical processes, negotiations happen all the time. **3.** Private and public negotiations (constructions and critique), managing group size to give more room for negotiation.

addressed only one criterion, it was scored as 1. As the scale transitions from low to high, teachers' understandings become more adaptive, student-centered, and knowledge-generation-focused.

3.3.2 | Step 2: Cross-checking across multiple data sources

After placing teachers on a scale based on their vignette responses and scores, we cross-checked this scale with more open-ended data sources including PD reflections and interviews. Combining these data sources at this step, which considered individual cases, allowed us to generate "tentative assertions" (Stake, 2006, p. 55) within each case. These data sources included teachers' responses based on their own teaching contexts (i.e., the classrooms where they actually taught) as opposed to one presented in a vignette scenario. At this step, we applied the same criteria included in the Vignette Evaluation Rubric to interview transcripts and written reflections from PD. When this provided additional evidence that confirmed the teacher's original placement on the scale, we did not change the teacher's scale score. When this provided disconfirming or contrasting evidence to the vignette-based score, we adjusted the level of orientation to learning and the level of understanding of epistemic tools. For example, if a teacher addressed two criteria of orientation to learning in the vignettes, we first score the teacher as a medium. Then, if we found evidence for the third criteria in the PD reflections and interview responses that was missing in the vignette responses, we added that into our analysis and adjusted the score from medium to high.

To ensure the validity and consistency of coding, two different coders (two graduate research assistants) conducted analysis in Step 1 and Step 2. After completing the coding separately, they compared their scores for teacher epistemic orientations and each epistemic tool. They checked all the disagreements on the codes and tried to reach an agreement. If they could not come up with an agreement, a third coder (a graduate research assistant) was invited for the analysis of that particular case. The scores that the third coder agreed on were kept as the final scores. Finally, we combined agreed scores as one data set that shows each teacher's scores on four constructs: (1) orientations toward learning, (2) knowledge of language, (3) knowledge of dialog, and (4) knowledge of argument.

3.3.3 | Step 3: Creating two-dimensional profiles

Using the scores created in Step 2, we determined teacher levels for two dimensions of the foundational resources: (1) orientation toward learning (high–med–low), and (2) knowledge of epistemic tools (high–med–low). This process fulfilled the need to engage in triangulation across cases, rather than just within cases, which is a hallmark of cross-case research (Stake, 2006). We determined an overall score for the knowledge of epistemic tools by looking at the scores of each area (language, dialog, and argument) that we obtained in Step 2. If the teacher scored high on at least one of the epistemic tools and if the teacher scored as a medium for the other two epistemic tools, we coded that as high for the overall knowledge of epistemic tools. For example, if a teacher was scored as high in language and medium in both dialog and argument at Step 2, that teacher coded as high for the overall knowledge of epistemic tools at Step 3. If the teacher had no more than one area scored as low at Step 2, we coded that teacher as medium for the overall understanding of epistemic tools at Step 3. If the teacher had two or more areas scored as low at Step 2, then we coded this as low for the overall understanding of epistemic tools at Step 3. After completing scoring, each teacher was placed across the scale (high, medium, and low) on the basis of two dimensions: (1) orientations toward learning and (2) knowledge of epistemic tools, which allowed us to create profiles. Among nine possible profiles of adaptive expertise, our analysis revealed six profiles as shown in Figure 4.

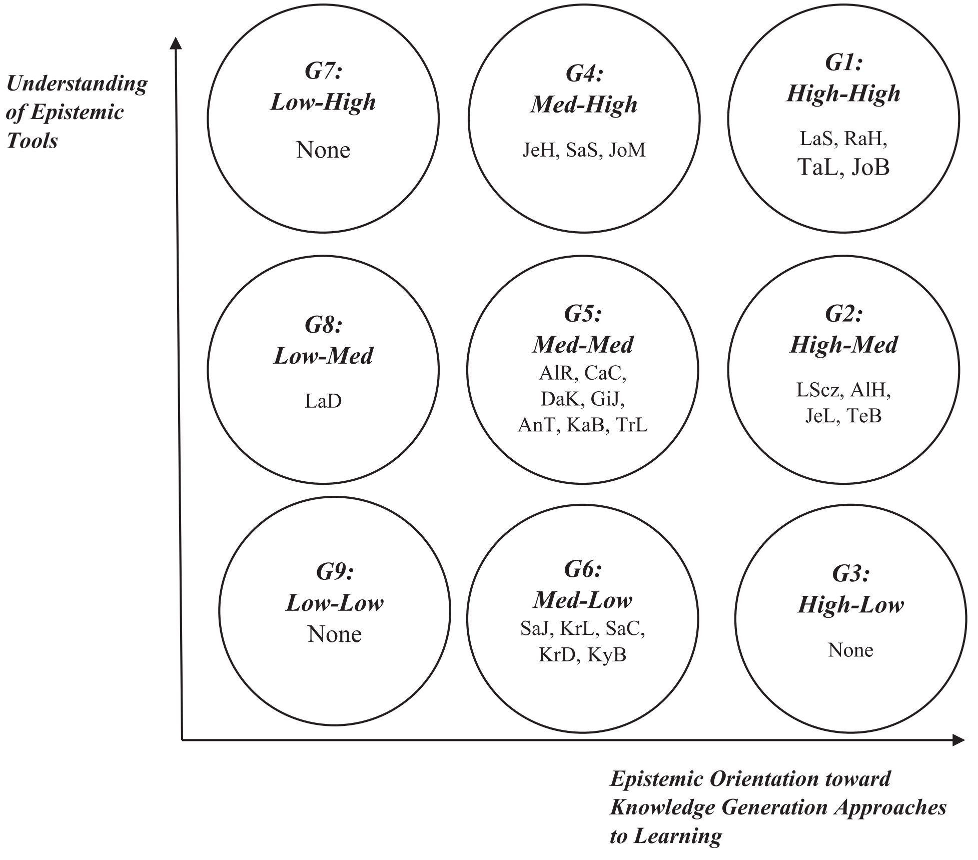

FIGURE 4 The two-dimensional diagram of teacher profiles.

3.3.4 | Step 4: Identifying decision-making patterns for each profile

At this step, we looked at the cases in each profile in depth to understand common patterns in their decision-making. For example, four teachers were represented in high–high profile, which means they scored as high in their orientations toward learning and knowledge of epistemic tools. We looked closely at their data (vignettes, interviews, and reflections) to identify common decision-making patterns among those four teachers. We repeated the same procedure for the other five profiles.

4 | FINDINGS

This section describes the characteristics of AdTex shown in each of the six groups with membership. These characteristics are presented in order from highest (i.e., most oriented toward knowledge generation) to lowest (Figure 4).

4.1 | G1: High–high profile

Four teachers represent high–high profiles: LaS, RaH, TaL, JoB. These teachers showed three common decision-making patterns: (1) flexibility in planning and utilizing epistemic tools and practices across contexts; (2) prioritizing students' agency across contexts; (3) focusing adaptations on translating the knowledge generation system rather than simply adjusting individual learning tools.

First, flexibility and open-mindedness were central, particularly when they had to deal with the uncertainty of learning. In an interview, TaL recommended:

> You can take what you need them to learn, what they want to learn, and their misconceptions, and make a plan for how the unit will progress. Keep in mind that this plan will change as students learn more. Keep an open mind and stay flexible.

LaS also stated that "you have to be flexible to go over to guide them back towards the big idea, but yet let them have input and interest on what it is they're learning" (Interview). RaH and JoB also stressed the importance of flexibility. JoB said, "There's a lot of times I don't have to do some of the stuff that I thought I would because they just come at it at a different way… So I just have to be flexible with that, and I have to provide myself time to think about sometimes how to challenge them" (Interview). RaH also mentioned that she needed to remember herself to be flexible. Their flexibility was further highlighted when they had to change the instructional mode from in-person to remote. Despite some restrictions they encountered, they quickly adjusted by finding new ways to utilize language, dialog, and argument as epistemic tools in new settings.

It was evident that their flexibility stemmed from their EO. They believe knowledge is unsettled, and they are willing to learn from novel experiences. TaL emphasized this by stating that "I am living in where I've got I have to look at virtual data every day and in-person data every day and make instructional decisions" (Interview).

Second, they heavily emphasized the importance of utilizing student agency in the learning processes. They used several practices to provide students an opportunity to investigate their own questions of interest. JoB wrote "provide resources, but let students manipulate and use them. Don't create a recipe. They need ownership to have their own investment in their learning" (Vignette). Similarly, RaH stressed that learning should be controlled by students and students need to decide their questions and whether they are going to test or research about it. TaL also mentioned that she always tried to find a way to give students more freedom in knowledge generation processes (Interview). LaS suggested "Always allow opportunities for students to discuss, elaborate, and question each other" (Vignette). She was using a scripted, district-promoted curriculum, but she mentioned that she was using it as a resource to modify when needed. She said "We might pick and choose some of the investigations. We might modify them. We just like or we let the kids modify them after watching part of it on" (Interview).

Third, when the instructional context changed, they translated knowledge generation practices rather than simply adjusting each epistemic tool. For example, when TaL planned for virtual teaching, she identified digital tools and platforms for students to generate questions, investigate, and negotiate ideas. RaH also identified new ways to translate epistemic practices into a virtual setting by considering language, argument, and dialog together. JoB said, "language, negotiation, and dialog is something that we can do for everything. It's one thing that COVID doesn't stop" (Interview).

4.2 | G2: High–medium profile

Four teachers, LiS, AlH, JeL, and TeB, showed high EO and a medium understanding of epistemic tools. Three patterns applied to this profile: (1) Instructional adjustments were made to promote student agency, (2) changes in contexts limited their flexibility, (3) dialog and language practices were favored over argumentation.

First, similar to G1, these teachers valued student agency. They highlighted that students should understand that they control their learning by asking questions and negotiating with peers. For instance, AlH wrote, "I have tried to focus more on adding on to what the students know and want to know instead of just planning what to teach" (PD Reflection). Similarly, TeB said, "I leave it up to them to see where they want to go in their research as long as they cover the big idea" (Interview). JeL stated that teachers need to be "question askers" rather than the one who controls the learning environment by arguing that "It is much easier for the teacher to involve themselves in dialogic interaction if they too take on the role of the learner" (Vignettes). LiS also wrote about allowing students to talk about their current understanding and letting them ask questions to help them build on their learning.

Second, the COVID-19 context limited these teachers' flexibility in using epistemic tools, especially student questioning, and dialog. For example, JeL mentioned that she had to post everything on Google classroom for remote students, which restricted flexibility in questioning. She said, "now it's like every single thing has to be posted in. Every question that I ever would ask has to be written and posted. And I think that's the hard part" (Interview). AlH was teaching both remote and face-to-face students at the same time. Due to social distancing policies, she also had to keep in-class students in rows, which made it a struggle to invite dialog and have questioning drive student learning. Like AlR, TeB, and LScz complained about restricted student dialog because they were not allowed to do group work in their classroom.

Third, most of the teachers in this group were able to explain why language and dialog were learning tools for knowledge generation in science. However, argument was rarely mentioned. For example, JeL thought that language leads to learning, and she mentioned that students and teachers would use language to negotiate their understanding and learning. Similarly, LiS thought language is important in learning since it requires people to share ideas and clarify their thinking. In the interview, she said, "I think that language plays the role in the sense that kids need to be able to communicate their thinking, whether it's in writing or sketches or with their words. And they need to be able to understand other people's thinking."

Similarly, AlH addressed the importance of different forms of language, including talking, drawing, and writing as a way to promote dialog and to gain a better understanding of science (Vignettes). TeB emphasized scientific language by stating that students need to add new scientific vocabulary to their writing, discussion, and presentations. She also addressed the importance of audience awareness when using language and dialog as learning tools. She said, "They need to remember who their audience is when they are writing or speaking. This way I can make sure that they comprehend what they are learning" (Interview).

4.3 | G4: Medium–high profile

Three teachers, JeH, SaS, JoM, scored medium in EO and high in the utilization of epistemic tools. This group represents three patterns: (1) Inconsistently emphasizing student agency; (2) understanding the interplay of epistemic tools; (3) attempting flexible responses to new contexts.

Similar to the G1 and G2 groups, all G4 teachers addressed the importance of student agency. However, they sometimes struggled with it. For example, SaS said, "I let them guide their thinking a little bit more, and what they want [to know] and how they want to solve that. So that's gotten a little better. Not perfect, but I've stepped back a little bit" (Interview). JeH mentioned that students have control over the language they use in negotiations around key concepts; however, she stated that she struggled to apply this when teaching virtually. JoM also mentioned some challenges with student investigations during the pandemic, such as sharing supplies during in-class activities and providing supplies to remote students.

This group of teachers understood how three epistemic tools work together to improve student learning. In her vignette, JoM highlighted the interplays of these tools by stressing that "You need language and dialog to have argumentation." Similarly, JeH and SaS emphasized the importance of argument and dialogs in developing key scientific concepts and language.

Based on their knowledge of epistemic tools, these teachers attempted flexibility in using these tools across contexts despite the difficulties the COVID-19 pandemic brought, such as wearing masks. SaS said "I guess I just I still do the same things, I feel like I really haven't changed much of anything" (Interview). However, such trials were not always successful. For JeH, it was challenging to help remote students engage in investigations, dialog, and negotiations. She allowed students to engage in negotiations online through recorded videos and an online discussion platform, but students' engagement was low.

4.4 | G5: Medium–medium profile

Seven teachers, AlR, CaC, DaK, GiJ, AnT, KaB, and TrL, had a medium EO and medium utilization of epistemic tools. Patterns across the cases were: (1) Valuing student agency but taking limited action due to low understanding of epistemic tools, (2) understanding the interrelated function of epistemic tools, but using the tools separately, (3) constraints in flexibility due to external factors (e.g., school curriculums, COVID-19 -restrictions, and more).

All teachers in this group underlined the importance of student agency. They stated that student talk was common in their classroom, and they were comfortable allowing students to lead dialog. For instance, AlR said "we're having a lot more discussions and talking about, like the vocab and stuff than what I have in previous years like more of them leading the conversation than me" (Interview). Similarly, DaK stated, "It is essential for the students in your classroom to talk, and talk, and talk. The students should be doing most of the talking and leading the discussions" (Vignettes). Although they were aware that student agency held importance in student learning, teachers in this group had difficulties in utilizing student agency in their classrooms. For example, CaC expressed her concerns about student-led investigation by stating that "just letting the students go to do whatever investigation they want makes me nervous purely in the sense of having the materials that are needed and/or wanted available to the students" (Interview). Also, most of the teachers in this group (AlR, CaC, KaB, DaK, AnT) mentioned some struggles with student-led argumentation and their lack of understanding of argument contributed to these struggles. KaB said, "My biggest struggle with argument was getting kids to really have good conversations without me dominating and controlling the conversation" (Interview). DaK wrote "it [argument]is not a quick and easy process. It takes time," (Vignette).

These teachers understood how epistemic tools function together. For example, both AlR and DaK mentioned student writing as a communication tool and a resource for their dialog. AlR and AnT viewed language as a tool that helps students engage in argument. KaB discussed the connections between dialog and other epistemic tools. She wrote:

> I used to think dialogical interaction was interacting with others through conversation, but now my ideas have change because it isn't just conversation, it is moving around the room, discussing and negotiating ideas, and challenging others thoughts and idea. (Vignette)

Although these teachers self-reported that they understood the connections between epistemic tools, most also said that they tend to use them individually. For example, AlR, CaC, and DaK focused on including more writing and dialog, but as separate practices. KaB mentioned that she still trying to understand how she can apply notebooking, and mentioned that she planned to use student argumentation after investigations (Interview). Only TrL and GiJ mentioned some practices that incorporate different epistemic tools together. TrL used video recording tools to facilitate student dialog and argument, and GiJ explained that her students had a dialog about their writing, and then discussed how their ideas had changed after their talk.

Finally, some of the teachers in this group listed factors that limited their flexibility in using epistemic tools. For example, due to the COVID-19 pandemic, AlR had a combined class where students had not previously met. She said, "it's hard not to get frustrated during that time, because I'm already not good at science." Both GiJ and DaK struggled with COVID- 19 regulations. These nonroutine regulations restricted their flexibility in using epistemic tools, including collaborative student dialog. She said, "previous small group discussions have been replaced with whole class sharing and writing" (Interview). GiJ also said, "Usually, it would be on the carpet the conversations, I could hear them more. Well, now that they're at their desks, I can't get to everyone as often" (Interview). GiJ and

AnT were impacted by the lack of instructional time for science, which occurred since their schools promoted reading and math during the limited instructional time allowed.

4.5 | G6: Medium–low profile

Five teachers, SaJ, KrL, SaC, KrD, and KyB, showed medium orientation to learning and low in the utilization of epistemic tools. Patterns were: (1) Stressing "student-centered/controlled" practices without strong connections to knowledge generation; (2) struggling to understand how epistemic tools function together and difficulty using epistemic tools in practice. (3) Limited flexibility.

Although teachers in this group emphasized student agency, they did not elaborate much on students' learning processes or how students can control their use of language, dialog, and argument. For example, SaJ stated that her classroom involved, "lots of students doing the talking….I need to work getting my kids to talk more and me talk less" (Interview). She did not explain further how student talks help students learn. SaC connected student learning with student excitement. She said, "when the light bulb turns on and the kids are excited. That's learning for me" (Interview). Similarly, KrL suggested that the teacher allow students to take ownership of the room (Vignettes). However, she also wrote that the teacher needs to use the vocabulary she wants students to use. Following the PD, KrD wrote, "letting the students be the ones that drive the learning is a hard thing for me to do" (PD Reflection).

Second, these teachers lacked an understanding of how language, dialog, and argument interact, and they had difficulty using these tools into practice. For example, KyB mainly focused on student talk as a form of language. He said, "The language part I found is probably the most challenging thing, just because it's really hard to get in front of a whole group discussion" (Interview). To attempt this, she mentioned that she put students in small groups (in person) and breakout rooms (virtually) to support dialog. SaC emphasized the importance of small group work to make students feel comfortable sharing their ideas, but also stated that she could not make students negotiate on big ideas as much as she wanted (Interview). SaJ emphasized student writing to improve their learning. She wrote, "They constantly need to be putting their thoughts down" (Vignette). However, she reported that it was sometimes challenging for her to get students to talk about their thinking. KrL suggested making students write scientific vocabulary down on sticky notes or in their journals so they can think about words relating to the big idea. She also suggested that a teacher needs to make sure that she is using the vocabulary that she wants the students to use. She said, "As long as she is using it, it should transfer to the students" (Vignette). Unlike the other teachers in the group, KrD made connections with language and other learning tools. She said that language is a learning tool when teachers and students collaborate, negotiate, and talk about big ideas. She said she tried to promote student drawing and encouraged students to use the vocabulary they observed in science videos. However, she gave examples from her class that she used the epistemic tools separately, and connections between the tools were missing.

Third, the flexibility of these teachers was limited by different concerns. For example, SaC said, "I am probably not engaging the kids enough in big ideas. Just because honestly the fear of a shutdown, and the fear of me not being here." She said she addressed big ideas efficiently when students attended in person. SaJ also mentioned her struggles in promoting student dialog. SaJ said, "Just getting that conversation going and getting them to talk has been a struggle… we've been off for a long time" (Interview). KrL also explained that she has had to, "figure out how to adapt everyday lessons, and how to do SWH for a virtual learner. That's been really tough." She stated that she was recording the lesson and wanted virtual learners to watch it, but she believed these students' experiences were subpar.

4.6 | G8: Low–medium profile

One teacher, LaD, showed low orientation to knowledge generation approaches and medium utilization of understanding of epistemic tools. Generally, (1) her orientation was minimally aligned to knowledge generation, (2) she understood how epistemic tools could function together but did not do so, and (3) she only made superficial adaptations based on contextual constraints.

LaD thought that teachers need to create an environment where students feel comfortable with dialog. She mentioned that students should lead dialog but failed to explain how to use dialog for knowledge generation. She said, "I have to be better about getting out of the way and letting the kiddos do the talking" (PD Reflection). She also focused on language practices, but she did not describe how language helps students' knowledge generation. She said, "writing things down and talking about it helps knowledge cement in students' heads better" (Interview).

She mentioned that some challenges were minor, such as limited group work due to social distancing, and less time for science because of COVID-19-based schedule changes. In response to these difficulties, she included more writing opportunities. However, she often adhered to the scripted district-provided curriculum while adding additional components, such as asking students to record important terms they heard in the provided science videos.

5 | DISCUSSIONS

This study was driven by our desire to prepare teachers for adaptive teaching that addresses the epistemic complexity of knowledge generation environments in science classrooms. Specifically, we were interested in characterizing the fundamental resources teachers utilize when they engage with complex and nonroutine problems to maximize student learning in various contexts. In light of the importance of addressing epistemic complexity, we characterized AdTex as developmental teaching capacity observable through a teacher's ability to utilize epistemic resources—that is, EO and knowledge of epistemic tools. The findings of this study contribute to addressing both conceptual and methodological challenges for characterizing AdTex.

5.1 | Conceptual discussions

The profile comparisons revealed four prominent patterns that provide conceptual implications for education research and teacher education programs aiming at developing AdTex. Figure 5 illustrates the process of AdTex development, summarizing these patterns.

The analysis shows that an EO toward knowledge generation approaches is related to the degree of teacher attention to student learning and student agency in the classrooms. One of the critical distinctions of the high–high profile (G1) teachers from the lower profile (G4, G5, and G6) teachers was how much they were able to maintain their attention on the maximization of student learning regardless of contexts. As EO shifted more toward knowledge generation, teachers tended to prioritize students' ideas and their agency of generating knowledge. In a new context, such as a virtual teaching environment created quickly out of necessity during the COVID-19 pandemic, the teachers who had strong EOs found new ways to help their students take action for knowledge generation using the resources they had. This suggests that EO toward knowledge generation directs teachers' attention toward potential affordances for knowledge generation and leads them to make more adaptive decisions aligned to knowledge generation approaches in various contexts. The importance of maintaining close attention to student ideas and learning processes in teaching has been highlighted in literature for the last several decades (e.g., Furtak, 2012; Sherin et al., 2011; Windschitl et al., 2011). However, little was known about how this tendency relates to EO, epistemic tools, or AdTex before this study. Given that EO directs teachers' attention toward knowledge generation, we believe EO, as an emerging framework (Suh et al., 2022) has the potential for explaining how and why teachers can best attend to student learning.

In addition, EO appears to affect how teachers approach their own learning, as previous studies suggested (Lammert, Suh et al., 2022; Suh & Park, 2017). Teachers with higher profiles in EO presented more willingness to

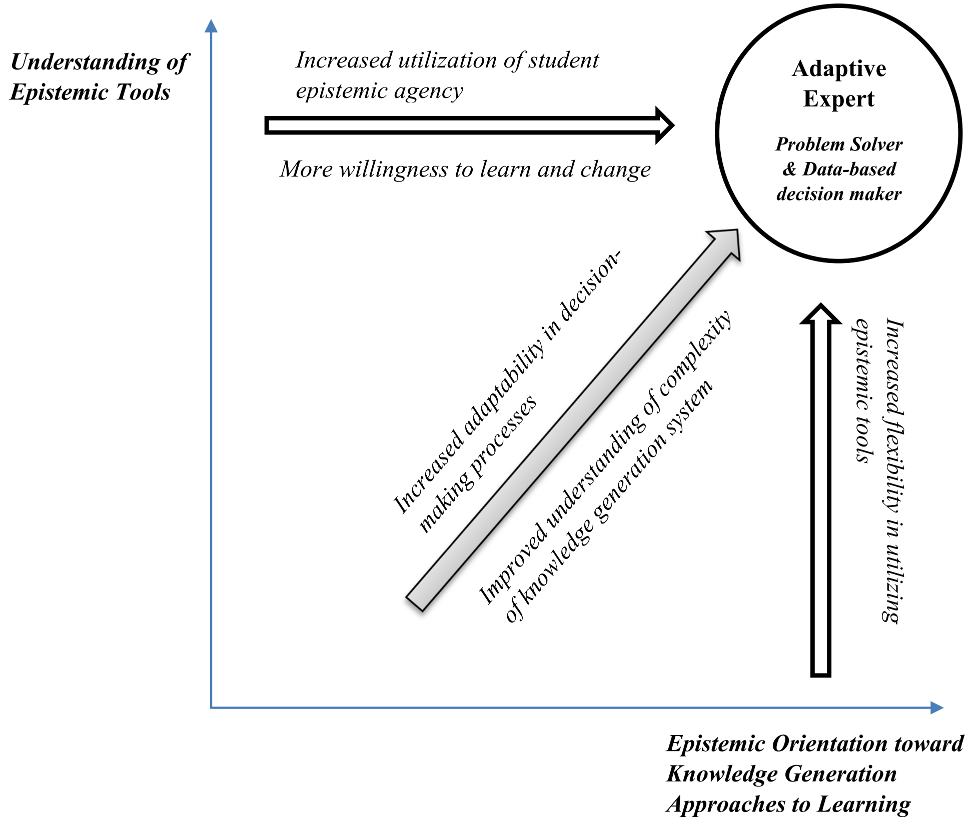

FIGURE 5 Patterns of adaptive teaching expertise development emerged from the profile analysis.

change their existing knowledge and practices based on their experiences and/or the data collected from their classrooms. This characteristic became important when they aimed to address new contextual challenges. As they were willing to learn and explore new ways of using the resources they had, they showed more intentional flexibility in decision-making processes. Noticeably, their flexibility in decision-making is often driven by the data collected from the learning environments. The higher profile in EO used more data (from both students and their environments) to reflexively adjust their practices when they reflected on teaching (Schön, 1983). Given that strong EO informs the tendency of considering knowledge as evolving with new evidence (Suh et al., 2022), such characteristic is naturally presented in high EO group (Bohle Carbonell et al., 2014). This finding is consistent with the previous studies that highlighted the importance of epistemological beliefs in teacher learning and their decision-making (e.g., Brownlee et al., 2001).

This research also indicated that higher profiles in the knowledge of epistemic tools represented a higher capacity of adjusting the tools in practice. We argue that as teachers developed a deeper understanding of each epistemic tool, they tended to value each tool more, use each tool more often in their classrooms, and through experience, feel more comfortable flexibly adjusting the way each tool functioned. More importantly, the teachers showed a deeper understanding of how the tools can be interplayed together for creating generative learning environments as they moved up to the higher profile. Interestingly, among the three epistemic tools, argument was the most challenging tool for the teachers to develop and flexibly utilize. Only high-profile group (G1) showed a strong understanding of argument and a certain degree of flexibility in using the tool across contexts. This is not surprising as literature has reported that elementary teachers are underprepared to use argument (e.g., McNeill et al., 2016; Osborne et al., 2019). While dialog was the tool most teachers valued, and attempted to utilize most often regardless of contexts, only a few teachers in high- and medium-profile groups were able to find innovative ways to create interactive dialog when the instructional mode changed to virtual during the COVID-19 pandemic.

Finally, the cross-case analysis revealed that the development of epistemic resources determines a degree of adaptability aiming at knowledge generation. This suggests that teachers' adaptability is expressed in a sensible balance between flexibility and efficiency/productivity. Unlike flexibility which is often defined as merely using tools, adaptability encompasses an appropriate, meaningful, thoughtful selection of resources for the maximization of student learning (Verschaffel et al., 2009). As the teachers developed stronger EO and a deeper understanding of epistemic tools, they showed a better understanding of the complex relationship among epistemic tools, practices, and big ideas. Not only did they try to be more flexible in utilizing the tools, but they also focused on productively helping students connect between their own ideas and the fixed or predetermined big idea(s). This suggests that our framework of "epistemic resources" that embeds EO and knowledge of language, dialog, and argument has a potential for characterizing AdTex in a way that addresses the epistemic underpinning of the NGSS.

5.2 | Methodological discussions

The present study also provides some methodological implications for educational research aiming at characterizing AdTex.

First, this study shows one possible way to represent the capacity of AdTex development by creating systematic profiles based the multiple qualitative data sources. We argue that the complexity of AdTex development can be characterized by profile analysis as it helps researchers to identify and analyze patterns of profile groups on the basis of multiple variables that need to be considered for understanding the complexity (Stake, 2006). While quantitative analysis provides various ways of analyzing profiles based on scores (e.g., latent profile analysis), there is no set rule or method to analyze qualitative profiles. The multicase profile analysis presented in this study was mainly concerned with the degree of the alignments between the epistemic resources each teacher developed, and the epistemic underpinnings of knowledge generation approaches. While there may be an ideal state or condition of AdTex, the research methodology we adopted led to the identification of multiple pathways toward AdTex. By analyzing that which was observable in qualitative data at a certain timepoint, we attempted to determine how much the development of each resource is closely aligned with the epistemic underpinning of NGSS Lead States (2013). In the end, the profiles created through the analysis demonstrated that the development of the epistemic resources could represent the degree of development of AdTex and provide a rich research pathway for future analysis.

Second, the present study shows the potential value of using vignettes to understand AdTex. Vignettes, which are commonly used in fields such as medicine and business, generally include brief scenarios requiring action or a judgment to which participants are invited to respond (Finch, 1987). The use of vignettes in qualitative case study education research is rare, perhaps because there is some degree of inauthenticity in asking participants to respond in writing to a scenario. Obviously, a response to a vignette is unlikely to perfectly match an individual's actual behavior should they encounter a similar situation in real life (Stecher et al., 2006). However, the use of vignettes helped us understand the developmental trajectories of teachers' AdTex. Stronger and weaker responses were identifiable, and these showed differences in how teachers used their intellectual resources to describe their own vision for adaptive teaching. Furthermore, classroom observation opportunities were limited during the COVID-19 pandemic, so the vignette filled an important space in giving us information about participants' practices (Lammert, Hand et al., 2022). Since the vignettes invited the teachers to describe how they would make decisions or take actions to address challenges described in the scenarios, they present one possibility of measuring and/or capturing AdTex. We believe this is an undeveloped resource for studying AdTex.

5.3 | Limitations and future directions

The present study used only the data set from one-time point within a large data set that has multiple timepoints. To fully understand the developmental aspect of AdTex, further investigations of how teachers develop epistemic resources across multiple timepoints would be helpful. The lack of classroom observations was another limitation of this study. Although we initially planned classroom visits, because of COVID regulations, school administrations restricted classroom access. Also, the findings of this study are not directly generalizable to other contexts, although we have aimed to provide a thick description of the context of the current research to support the transferability of our theoretical model. While the two-dimensional analysis potentially yields nine-profile groups, the present study shows the characterization of the six groups only and some of those groups had one or two members. A particular consideration is state-level curricular contexts. While these teachers came from two U.S. states, one state had adopted the NGSS Lead States (2013) and the other state adopted state standards which were developed based on recommendations in the NRC Framework for K-12 Science Education. It remains unclear how these results would have differed had it occurred where state-level content standards differed from the vision presented in the NGSS Lead States (2013). By adding more cases to each profile group or tracking longitudinal data sets, researchers will be able to provide richer descriptions of the differences among the groups. More importantly, an examination of the relationship between teacher profiles and student learning outcomes is necessary to depict a complete picture.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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