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# Characterizing inquiry-based science classroom learning environments—generative or replicative—using teachers' epistemic orientations: a qualitative study

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This study examines the relationship and influences between teacher epistemic beliefs and their learning environment. Drawing on a multiple case study design, six in-service elementary school science teachers were purposefully selected from a larger, NSF-funded study of teachers' adaptive expertise in the epistemic complexities of science teaching. Methods involved hypothesis, open, and integrative cross-case & cross-strata analyses of epistemic orientation surveys, field observation notes, semi-structured interviews, vignettes, and Teacher Implementation scores, demonstrate that teacher beliefs/orientation type are associated with classroom environment type characterization. Further, results show that struggles of teachers mirrored elementary school science teachers' sense of *control*, *persistence*, and *adaptive expertise*. Major findings from the study reveal that participants who exhibited rigid epistemic beliefs and fluid/flexible epistemic beliefs tended to establish replicative and generative learning environments respectively, albeit on a continuum. And that, while teachers with flexible epistemic belief showed increased teacher adaptive expertise and co-shared classroom *authority/control*, teachers with rigid epistemic belief struggled to release *control* and were generally less adaptive/persistent. Finally, the study discusses pertinent implications for policy, practice, and research. For policy, framers of standards documents, policy makers of teacher preparation, and curriculum developers should consider teacher beliefs and attitudes as foundational for framing future science standards. Regarding practice, the study suggests a reconstruction of belief systems about knowledge and knowing or a total shift in epistemic beliefs for practice. Future research could explore the synergy of all the data sets by adopting a multi-perspective approach for their study.

KEYWORDS

**teacher epistemic orientation, generative learning environment, replicative learning environment, epistemic understanding and development, teacher beliefs**

# 1 Introduction

To support knowledge creation and development, it is important to understand and characterize the influence of teacher belief systems and theoretical orientations and how they impact the establishment of classroom learning environment types. In the field of science education, particularly in the U.S. context, the framework that guides student science knowledge development, the Next Generation Science Standards (NGSS), advocates that science learning centers student engagement in the (epistemic) practices of science. Centering the practices of science requires that science inquiry considers the (learning) environment within which these epistemic factors that promote knowledge generation and validation happen (Newton and Shaw, 2014). Teacher Epistemic orientation (EO), encompasses belief systems that guide the interpretation and explanation of how knowledge is developed, validated, or how one comes to know (Lammert and Hand, 2024; Lammert et al., 2023a,b; Lammert et al., 2022; DeLuca, 2011; Fulmer et al., 2021; Park et al., 2022; Lissitz and Samuelsen, 2007).

While NGSS continues to highlight the *use of epistemic tools* for *science inquiry*, the loud silence of the specifics of (classroom) learning environment types, replicative or generative, that support such science inquiries and knowledge validation, is striking (DeLuca, 2011). Even more deserving of an investigation regards how a teacher could act as a *vehicle*, or an *obstacle*, to science knowledge generation advocacy (Bybee, 2014). Learning environments established for knowledge development could, one hand, optimally support science learning by inquiry. In sharp contrast, some teachers create learning environment types that generally stifle science inquiry and knowledge validation (DeLuca, 2011).

Even as the current NGSS document advocates for science teaching and learning by inquiry— knowledge generation, replicative learning continues to litter science classrooms across the board (Mulders et al., 2020; Cikmaz et al., 2021). Teachers continue to teach learners to memorize and/or regurgitate scientific concepts with the resultant learner objectification (Biesta, 2017) in the instructional process. This is not only a practical concern, but a knowledge gap also exists about how teacher epistemic orientation could influence the creation of either replicative or generative learning environments.

We address these theoretical and empirical uncertainties about teachers' epistemic orientation and its relationship with classroom environment type for (student) science knowledge development. Thus, this study explores and validates all theoretical mechanisms and empirical evidence for assertions about a relationship between teachers' views, beliefs systems, or theoretical orientations and teachers' implementation metrics within a learning environment type in actual classroom settings.

While the relatedness and connections between the epistemic orientation of the teacher and replicative/generative learning environments are unknown, there could be a likely potential relationship that may require further exploration. Dearth literature, however, exists on the relationship between teacher epistemic orientation and classroom environment. Particularly, through the lens of teacher belief systems/teacher epistemic orientation and its association with the classroom environment for knowledge creation. This study explores impacts of teacher epistemic orientation and belief systems on classroom environment types that get established for knowledge development—knowledge replication or knowledge generation.

# 2 Literature review

The following research bases underpin this study: literature on teacher epistemic orientation (EO) and knowledge development, classroom learning environments, learning by knowledge generation, and relationship between EO and classroom outcomes.

## 2.1 Teacher epistemic orientation and knowledge development

Epistemic beliefs and orientations comprise system of beliefs and views held by people about knowledge development and knowing (Hofer and Pintrich, 1997). While knowledge can be viewed as perception gained through experience or education, beliefs are strongly held opinions. Some scholars have theorized a relationship between belief systems and instructional/learning strategies (Hofer and Pintrich, 2012). However, different epistemological views have been found to impact the ways essential instructional decisions are made and the ways teachers think (Bell and Lederman, 2003).

Similarly, other scholars also argue that epistemological worldviews could dictate curriculum choices, pedagogy, and assessment. Correspondingly, consistencies have been reported about the belief systems held by teachers and their decisions about classroom practices which resultantly create a type of classroom learning environment (Bell and Lederman, 2003). Notwithstanding teachers' mediation of many of the effects of schooling on student outcomes, student learning, and classroom environments (Bong, 2001), scholarship that has investigated the relationship amongst teacher beliefs, views, teacher theoretical orientations, classroom environment, instructional practices, classroom orientation, etc. are limited (Talbert and McLaughlin, 1999).

Recognizing the inherent complexities regarding the belief–action association, Rokeach (1972) explained that "beliefs cannot directly be observed; but rather be inferred as best one can… from all the things the believer says or does" (p. 2). Rokeach continued to argue that the actions and activities executed by a teacher may be representative of their beliefs and cannot be divorced from their belief systems, albeit difficult to capture. These inherent complexities in capturing and/studying beliefs have led to one group of scholars contending that beliefs in written prompts are in most cases associated with the classroom learning activities and/or the learning environment—*congruous thesis* (Hashweh, 1996; Abell et al., 2013; Fraser et al., 2014; Lederman and Abell, 2014). Other scholars on the opposite side of the argument also assert that, teacher beliefs do not dictate teacher actions/decisions in the classroom-–*incongruous thesis*, instead they suggest that other contextual factors are mediating teachers' beliefs and translating them to teacher classroom actions (Fraser et al., 2014; Fulmer, 2008).

## 2.2 Learning by knowledge generation

The past two decades have witnessed a dramatic shift in the conceptualization of approaches to science learning. This shift has changed the conceptualization of learning from a traditional and replicative to more generative learning. While replicative learning environments largely locate learning somewhere on the transmission—reception continuum, generative learning characterizes learning as

student-centered engagements that bolster the generation of scientific ideas to foster understanding. Thus, transmissive learning environments characteristically view learning as passive possession of knowledge from an "authority" figure—teacher—in the science classroom (Biesta, 2017, p. 8). Criticizing the replicative notion of learning, Sfard (1998) voiced her disquiet by proposing that this "acquisition metaphor makes one think of the human mind as a container to be filled with certain materials as the learner[container] becomes the owner of the materials" (p. 5). Similarly, Biesta (2017) censured this by proposing that this approach ensures that the "child[ren] or students remain [as] objects of the educator's intentions and activities" (p. 8).

In lieu of the transmissive learning standpoint emerges the generative (learning) environment.

Generative learning argues that learners should not be objectified as consumers of information (Biesta, 2017). Instead, learners should be viewed as actively participating epistemic agents who construct their own understanding in a socially negotiated setting. Thus, the learner actively constructs his/her own interpretations of information and draws inferences based on evidence which is socially negotiated. I draw on generative learning premised on socio-cultural constructivism to further parse the current review. Given that, social constructivism hinges on the interpretivist's epistemological framework, drawing on generative learning as an epistemological lens is the best fit for unpacking epistemic talk. Concurring with this proposition, Hyslop-Margison and Strobel (2008) opined that social constructivism is more correctly an epistemological or philosophical explanation about the nature of learning than a learning theory.

At this point, it is important to stress that the principal role of constructivism—allowing student ideas to drive the conversation—is currently the adopted notion of learning in science education. Undoubtedly, this conceptualization has shifted the discussion from the relegation of ideas of students to rendering them as the fulcrum around which teaching and learning revolves. Given that the world is visualized principally around culture that embodies learning, the social and cultural contexts of the knowledge to be constructed become indispensable in the knowledge creation chain. Vygotsky (1978) supported this analogy by suggesting that "every function in the child's cultural development appears twice: first, on the social level, and later, [at] the individual level" (p. 322).

## 2.3 Classroom learning environments

Literature on classroom learning environments continues to diversify. Some scholarship center their explorations on the development and validation of instruments on classroom (learning) environments (Aldridge and Fraser, 2000; Frazer and Twohig, 2012; Fabes et al., 2019), the influence of classroom learning environments on student learning outcomes (Goh and Fraser, 1995; Goh and Fraser, 1998; Wang et al., 2020), juxtaposition of preferred learning environment and actual classroom environment, and the multiplicity of classroom (learning) environments (Waldrip and Fisher, 2000; Fraser, 2014).

Classroom environment, as a concept, has been variously described in literature. For example, while some scholars explained it as the social, psychological, or pedagogical milieu within which learning occurs (Ozkal et al., 2009). Fraser (1981) asserts the centrality of the construct by positing that "the classroom environment is such a potent determinant of student outcomes and that it should not be ignored by those wishing to improve the effectiveness of schools" (p. 1). The study defines classroom learning environment as the climate in the classroom created for free or censored knowledge development and epistemic talk.

Some studies have reported a relationship between teacher beliefs and classroom environments for teaching and general instructional practice. Based on earlier studies (e.g., Meece, 1991; Ames and Ames, 1984; Akuoko, 2024), the influence of teacher beliefs on the practices in the classroom [environment] has been documented in literature (Maehr and Midgly, 1996; McCrum, 2013). For example, MacAulay (1990) found a positive influence of teacher characteristics on classroom environment and student outcomes. He further concluded that teacher qualities like teacher belief systems, teacher views, and theoretical orientations have been found to increase [student] learning outcomes.

The significance of improving the general classroom environment and its inclusion in teacher preparation and education programs has also been explored in literature. Yarrow et al. (1997) reported observed improvements in the classroom environment and increased interest in student learning due to the inclusion of topics of learning environment research aimed at improving classroom environments. In their exploration, 117 preservice education teachers were introduced to the field of learning environment through personal involvement of an action research that sought to improve their university teacher education classes and teaching practice/microteaching. Providing evidence to support this, Fraser (1993) stressed the significance of including assessments of classroom environments in teacher education programs. Corroborating this, Fraser (1993) further contended that pre-service and in-service teacher programs could emphasize classroom research on classroom environments to sensitize teachers and student perception of classroom events.

That said, Tsai and Liu (2005) also examined the relationship amongst teachers and students' scientific epistemological views (SEVs) and teaching beliefs, instructional practice, as well as students' perception towards actual science learning environments. They reported strong coherence between teachers' scientific epistemological views and their teaching beliefs regarding instructional practices. They further contended that their findings are consistent with results about the coherence between teachers' SEVs and students' perceptions towards science learning environments, "suggesting that the constructivist-oriented scientific epistemological views appeared to foster the creation of more constructivist-oriented science learning environments" (Tsai and Liu, 2005, p. 3).

Establishing the connection between classroom[learning] environments and student outcomes, Jeffrey and Troman (2009) examined the relationship amongst classroom environment, antecedent variables, and student outcomes amongst high school students in Australia. Their study found that there is increased "potential for classroom environments to improve student outcomes" (p. 277).

Aldridge et al. (2009) also undertook a similar exploration on classroom learning environments in South Africa. They examined in-service teachers who were schooling through distance education delivery programs. They also adapted the WIHIC (What is happening

in this class) questionnaire as their instrument and administered it to 1,077 students. They found that teachers used the feedback on their belief systems and the WIHIC to improve their classroom learning environments. Likewise, Aldridge et al. (2004) administered classroom learning environment instrument to 1864 grades 4–9 students in 43 different classes, the study reported an enhancement in the constructivists' view of their classrooms.

### 2.4 Relationship between epistemic orientation and classroom outcomes

The relations between epistemic beliefs, views (and orientations), and learning have been reported in extant (science education) literature. While some scholars found a direct impact of epistemic beliefs on [learner] conceptual change (Andre and Windschitl, 2003; Alvermann, 2000), others reported a link between epistemic orientations and both teacher growth and student development of knowledge (Hofer, 2004b). Dweck (2013) notes that teachers whose views and belief systems ascribe to the malleable nature of knowledge and knowing—incremental theory of intelligence—create a (classroom) climate that promotes similar interactions. On the other hand, teachers who hold fixed and unchangeable views and belief systems--the entity theory of learning/intelligence--tend to align their instruction towards positivists and objectivists.

This study aims to examine and characterize the relationship between elementary school science teachers' epistemic orientation (EO) and classroom learning environment type they establish for knowledge generation or replication.

## 3 Research questions

The following research questions were posed to guide the study:

1. What epistemic Orientations (EO) and belief systems do the participating elementary teachers hold about classroom learning environments for knowledge generation or replication?
2. How are classroom learning environments of participating elementary school teachers characterized?
3. How do teacher epistemic orientation (EO) and belief systems relate to and to what extent do teacher beliefs influence the type of classroom environment elementary school science teachers create for knowledge development--generative or replicative?

## 4 Theoretical framework

The study rests on the theory of epistemological development and understanding (Hofer and Pintrich, 2001; Hofer and Pintrich, 2012; Hofer, 2001; Kuhn, 1999; Kuhn et al., 2000; Kuhn and Park, 2005; Sandoval, 2014). Various definitions have been proffered in literature regarding the process of epistemological development, epistemological understanding, and the belief systems that undergird such theories and beliefs. In one of such definitions, it was argued as "ways individuals come to know, the theories and beliefs they hold about knowing, and the manner in which such epistemological premises are a part of and an influence on the cognitive processes of thinking, reasoning, and classroom settings" (Hofer and Pintrich, 1997; Hofer and Pintrich, 2002, p. 46).

In a similar proposition, Salmento and Murtonen (2019) explained epistemological development as encompassing the beliefs systems and theoretical orientations that underpin scientific knowledge, scientific knowing, and its association with scientific thinking. Interestingly, other scholars situate their explanation of the development of epistemology on the positivist–interpretivists coordination continuum. In one of such examples, it was explained as embracing the coordination of objective and subjective dimensions of knowing, knowledge development, and construction (Kuhn et al., 2000; Kuhn and Park, 2005). I define epistemological development as the ensemble of (teacher) belief systems, views, conceptions, and theoretical orientations that frame the process of knowing, how one comes to know, and knowledge development processes within a classroom where these belief systems undergird a type of classroom environment that gets developed—generative or replicative.

Epistemological development has a nuanced history. Three different, but concurrent, and seemingly intersecting models of explorations cut across time in literature. Pioneer studies modeled their exploration along the "degree of structural, developmental sequences" (Hofer and Pintrich, 2002, p. 9) and elucidated on the ways different people digest their experiences in education (Magolda, 2001; Baxter Magolda, 2004; Magolda, 2012; Perry, 1999; Perry, 2014). The second group of explorations examined the procedural role of epistemological assumptions and development on reflective judgements—reasoning processes through argumentation and ways of (scientific) thinking, and knowing (King and Kitchener, 1994; Kitchener et al., 1989; Kuhn, 1991, 1993). For one example in which scholars examined the functional relationship between epistemological development and students/teachers' views of scientific thinking, Salmento and Murtonen (2019) explained that epistemological development comprises the beliefs, views, and conceptions about (scientific) knowledge, (scientific) knowing, and its linkage with scientific thinking.

Recent studies on epistemological development, however, have centered their exploration on epistemological ideas and conceptualized it as a system of beliefs, views, and theoretical conceptions/orientations that people hold and how those constructs relate with and/or impact classroom instruction, classroom learning, classroom climate, and general cognition for academic tasks (Hofer and Pintrich, 1997; Hofer and Pintrich, 2001).

Zooming in to personal epistemologies and how it impacts the classroom environment, this study frames epistemological development, personal epistemologies, and epistemological beliefs through two lenses. On one hand, personal epistemology is framed as an emerging developmental construct predominantly shaped by education (Bendixen and Rule, 2004). On the other hand, it is conceptualized as an epistemological belief construct, a characteristic of an individual—a trait-like feature of individual differences that influence(s) teaching and learning (Greene et al., 2018; Merriam and Baumgartner, 2020) by creating or altering the classroom environment. Viewing it within the character-trait framework, beliefs, views, and theoretical orientations are conceptualized as potential determinants of conceptual change, classroom environment, student achievement, learning outcomes, etc. (Salmento and Murtonen, 2019).

Specifically in this study, the theory of epistemological development and understanding has been drawn on to identify and elucidate the belief systems and theoretical orientations held by elementary school science teachers. Also, the different levels of personal epistemological model were utilized to characterize the type of classroom environments exhibited based on different teacher's EO. This is particularly important given that the theory of epistemological development and epistemological beliefs provide us with a conceptualization within the character-trait framework, which can also conceive beliefs and theoretical orientations as potential influencers of outcomes such as conceptual change, classroom environment, student achievement, learning outcomes, etc. (Salmento and Murtonen, 2019).

The development of epistemological understanding (Kuhn et al., 2000) provides us with a framework to map out how individuals see knowledge, and the processes involved in the acquisition of knowledge. Notably, views about knowledge, beliefs about knowledge and knowing, and conceptions about how one comes to know what they know, have been identified as determinants of individuals' cognitive functioning. Żyluk et al. (2018) argue that one's views and beliefs about knowledge and knowing determine the level of epistemological development and understanding. Kuhn (2000) proposes a four-tier epistemological framework that underpins one's conception of nature of knowledge (certainty of knowledge), nature of knowing, nature of learning and instruction, and the resultant atmosphere— classroom climate—to be created.

Drawing on the four-tier epistemological development and understanding–realists, absolutists, multiplists, and evaluativists (Kuhn, 2000)—teachers' conceptions, views, and belief systems about certainty of knowledge, nature of knowing, and nature of learning/instruction are interrogated to unpack the relationship between epistemological development (understandings) and the resultant type of classroom learning/instructional environment. While both realists and absolutists view knowledge as an objective— certain commodity—wholly knowable and accessible, they differently treat assertions as copies of objective reality and facts of the objective reality, respectively (Hofer and Pintrich, 2002; Mason and Boscolo, 2004; Żyluk et al., 2018). Similarly, while both multiplists and evaluativists argue that knowledge is uncertain and subjective and that knowledge can be sourced from many founts, evaluativists additionally consider the empirical evidence and/or persuasive argumentation that provide a better justification (Heiphetz et al., 2014) within the competing propositions as valid knowledge.

Within the purview of this framework, it can be argued that the type and level of epistemological development and understanding could be a foundational premise that guides the type of classroom environment that will be created. Thus, a teacher's level of epistemological development and understanding—suggested by the epistemic orientation of the teacher—provides us with a great starting point to unpack the relationship(s), if any, that could be connecting the two constructs.

There seems to be a consensus amongst scholars about what notion of epistemological beliefs embodies. Scholars agree that epistemological beliefs encompass beliefs about knowledge and how one comes to know (Briell et al., 2010; Briell et al., 2011; Wiley et al., 2020). Elen et al. (2011), however, points out that epistemological beliefs should also be conceptualized as "an encompassing system of beliefs" (Schommer-Aikins, 2002, p. 197; Duell and Schommer-Aikins, 2001).

# 5 Materials and methods

We adopted a qualitative methodological approach (Denzin et al., 2023; Harding, 2018; Merriam, 2002; Willig and Rogers, 2017; Denzin and Lincoln, 2011) to explore the relationship between teacher epistemic beliefs and classroom learning environment types. The choice of this approach allowed for comprehensive examination of a "messy construct like beliefs" (Pajares, 1992, p. 128).

## 5.1 Study design

Extreme abstractness of belief systems presents a huge task of design choice within the qualitative paradigm. That said, given that teacher epistemic orientations (EO) and belief systems are abstract concepts that inherently lend themselves some levels of difficulty to capture (Kagan, 1992; Luft and Roehrig, 2007; Chan, 2003; Hofer and Pintrich, 1997), a multi-case study design was selected to explore how teachers beliefs impact the learning environment type they establish for knowledge development and knowing (Charmaz, 2014; Yin, 2012; Yin, 2014).

## 5.2 Context of the study

The current study was part of a larger NSF-funded project that tracked elementary school science teachers' adaptive expertise in the epistemic complexities of science in Midwestern and Southeastern states in the U.S. As part of the NSF-funded study, series of teacher professional Developments (PDs) (Akuoko and Gardner, 2025) workshops were conducted with the view to aligning and/or shifting teacher instructional practices, theoretical beliefs, and orientations towards science learning through socially constructive processes that utilized generative learning approaches—Science Writing Heuristics (SWH) (Hand and Keys, 1999). SWH has also been described as an immersive generative approach (Cavagnetto, 2010) that allows students to negotiate their versions of fixed curricula knowledge through argumentations, dialogue and language use. Thus, the participating teachers wanted to deepen their conceptual and practical understanding of learning theories and new pedagogical approaches.

Starting summer of 2019 through to 2021 (the time frame for which data used in this current study was drawn), data were collected at various time points during the series of PD sessions and workshops. Two formal three-to five-day workshops were conducted during the summers of 2019 and 2020. In the summer of 2019, teachers from the two sites–Iowa and Alabama–attended the workshop separately. However, due to the incidence of COVID-19 and its attendant social distancing restrictions, teachers at both sites attended the workshop remotely together in summer 2020. Every 6 months, during the PD workshops, epistemic orientation surveys were administered to participating teachers. The adapted epistemic orientation score survey (A-EOS; Suh, 2016) was used to track teacher beliefs and theoretical orientations about epistemic nature of knowledge (ENK), epistemic

alignment (EA), classroom authority (CA) regarding knowledge creation, and student ability (SA).

## 5.3 Sampling procedures and participants

Selecting respondents in multi-case studies (Hollweck, 2015; Stake, 2013; Yin, 2014) can be challenging, particularly in the light of the "case—quintain dilemma" (Stake, 2013, p. 7). This, according to Stake (2013), comes up when the (individual) cases being studied contend with the quintain for the researcher's attention. This is particularly important given that heeding too much to the individual cases could mask the innate complexities in the quintain. In the same vein, too much attention to the quintain could cloak the circumstantiality, specifics, or situationality of the cases (Stake, 2006) (Table 1).

The current study utilized *intrinsic case study* within multiple case study frame. A total of six (6) participants ($n = 6$)—two (2) from each of the 3 stratified subgroups (Table 2)—were purposefully sampled to participate in the study. To introduce variety, *stratified purposive sampling* was utilized to sample the cases (Anderson et al., 2014; Baxter and Jack, 2008; Stake, 2013). The recruitment criteria were that first two respondents with the highest EO scores in each of the three subgroups—high EOS teachers, medium EOS teachers, and low EOS teachers—were purposefully sampled for the study. Thus, 2 respondents with the highest EOS and implementation scores in each subgroup were selected.

## 5.4 Data sources, collection, and selection criteria

Semi-structured interviews, vignettes, participant observation field notes, and Implementation scores were the main data sources. Teacher Implementation scores, which was found to be linearly correlated with EO score in another study, were selected for data analysis (Suh, 2016). Each of these data were purposefully selected to constitute the dataset (Suri, 2011, 2013). The goal was to deepen our understanding of the influence of teacher beliefs in written prompts on classroom learning environment types created for knowledge development. One each of vignettes, semi-structured interview transcripts, and observation notes were selected from a pool of data collected.

The main criteria used for selecting from the pool of dataset was the use of the upper and lower boundaries of the respondents in low, medium, or high strata as shown in Table 2. For example, within the lowest implementation score stratum with, 1.1 to 1.67 range, the respondent with the lowest and highest limits of the boundaries were selected. In line with this, the semi-interview transcripts, vignettes, and participant observation notes for the respondent's implementation scores of 1.1 and 1.67 were purposefully picked. Afterwards, the semi-structured interview data, vignettes, observation notes transcripts were mapped, traced, and selected from the pool of data that constitute the data for respondents in the low implementation score stratum. The results were that 2 semi-structured interview transcripts, 2 vignettes, and 2 field observation notes were obtained from each of the three different strata.

Similar modes of selection were applied to the other two strata—medium and high implementation score bearers. Given that each stratum produced 6 datasets (1 each for interviews, vignettes and observation notes for the two respondents that were selected from each of the strata), a total of 18 sets of data from semi-structured interviews, vignettes/reflections, and observation notes were analyzed. Validation and reliability checks as dimensions of and equal discrimination of items had been explored with some sections of the data on vignettes in a different study for the project (Fulmer et al., 2021). This is consistent with some scholars who propose that reduction in bias of qualitative research data increases its analytic rigor (Grodal et al., 2021; Morse, 2015). Two other researchers, who were not shown the data we selected, repeated the data selection procedures and selected same data set for analysis. This provided credence to blind data selection strategy (MacCoun and Perlmutter, 2015).

Cresswell (2013) asserts that the development of complex, detailed understanding of teachers' beliefs can best be established by talking directly to teachers, going to their school to take field notes through participant observations, and/or allowing them to tell their stories to get inner experiences. The interview protocol and the questions that were used for conducting the planned semi-structured interviews were drawn from the four thematic areas of teacher epistemic orientation (EOS) items: Epistemic Nature of knowledge (e.g., Source of knowledge, certainty of knowledge, nature of knowledge, nature of knowing, etc.), Epistemic Alignment (evidenced-based argument, justification for scientific knowledge, ways of learning/the learning process, how to learn, how to teach), Classroom authority (locus of control, source of knowledge (authority), role of teacher, Student Ability).

## 5.5 Characterization of teacher implementation scores

Classroom implementation encompasses the epistemic climate created by the teacher for knowing and knowledge development. It provides the framework to check the indices of a learning environment created for instruction and learning, that similarly draw on the 8 criteria explained in Table 3 and on data collection/implementation score protocol in Supplementary materials that guided the creation of an immersive, epistemically rich, learning environment. We used simple frequency counts to average implementation scores at four different time points of data collection. Respondents were stratified into 3 subgroups–low, medium, and high. The range of implementation scores spanned 1.1 to 2.8, with 1.1 and 2.8 representing the minimum and maximum values, respectively.

To ensure equitable and unbiased stratification, the difference between maximum and minimum values of Implementation Scores (IS) was computed, yielding a result of 1.7, i.e., [2.8–1.1 = 1.7]. The difference obtained, 1.7, was further divided by 3 (the number of strata or subgroups) to get 0.56, the quotient. Thus, each stratum was obtained by adding the quotient to the minimum value. For example, the low implementation score range was computed by adding 0.56 to 1.1, the minimum value of all implementation scores. This provided a total of 1.66, the maximum value of the low implementation rates. Therefore, the first stratum, which represents respondents with low implementation scores, has 1.1 and 1.66, respectively, as the lower and upper boundaries. In the same vein, the medium implementation score category ranged from 1.7 to 2.26 with the high implementation score category ranging from 2.27 to 2.82. Respondents with low, medium, and high implementation scores were accordingly tabulated as 18, 49, and 28, respectively, as shown in Table 2.

TABLE 1 Summary of data sources, description, and frequency.

| Data sources | Brief descriptions | Frequency/duration |
|---|---|---|
| Participant observation fieldnotes (Papen, 2019) | • Field notes written by researchers, audio-visual recordings of respondents' interactions with learners, general instruction process and most importantly, the general instructional environment that document teacher respondents' actual climate for instructional practices.<br>• 8 criteria were set to determine the implementation level of teacher participants based on whether or not those activities are visible during instruction. The 8 criteria as found on the observation protocol (see Table 3) included: *student voice, teacher questioning, prior knowledge/ big ideas, language use, promoting writing, Argumentation structure, student argumentation, group structures.* | Though several participant observation notes were collected for the mother NSF project, the current secondary analysis purposefully selected one each for a participant for analysis |
| Individual semi-structured interviews (Olson, 2016; Edwards and Holland, 2013) | Interviews centered on areas that underpin epistemological development and understanding (West, 2004; Hofer and Pintrich, 1997; Hofer and Pintrich, 2002) and our RQs:<br>1. Belief systems and theoretical orientations held by teacher respondents about classroom learning environments--replicative or generative–for knowledge development<br>2. their comfort level in supporting student learning through (creating a classroom climate) that either supports (un)certainty of knowledge and knowing in written prompts dictates the enactment of classroom learning climate type. | Several semi-structured interviews were conducted for the mother NSF project with each spanning 1–2 h.<br>One interview was purposely selected for each case study teacher respondents for analysis |
| Vignettes/PD reflections (Erfanian et al., 2020; Hughes and Huby, 2002) | • Participants responded to four different vignettes prompts during a 3-day Professional development workshop<br>• All 4 question prompts sought to understand how respondents create epistemically rich learning environments for knowledge development–generative or replicative.<br>• They sought to unpack how respondents implement Science Writing Heuristic (SWH) approach in their actual class lessons<br>• Thus, question prompts elicited how each participating teacher utilizes epistemic tools such as language, dialogue, argumentation through negotiations, to guide their student learning<br>• Final day reflections also provided proxies for respondents to share how they generally create a classroom learning environment. | One time summer PD 2021 session for vignettes and reflections—one for each of the 6 case study teachers |
| Implementation scores (Phillips et al., 2012) | • We use the 8 criteria in Table 3 to score participants how they fared on each strand after each participant observation. Afterwards, we transformed these scoring into numbers. And aggregated these scores from different observers to scale the scores between 0–3. | Implementation scores were part of scoring metrics during every participant observation during which field notes taken |

In line with this, a cross-tabulation was used to create the categories as seen in Table 2.

## 5.6 Data analysis

Data were examined at four levels, viz.: (a) *Hypothesis coding, (b) open coding, (c) Thematic analysis,* and finally *(d) cross-case/stratum analysis.* Each level allowed for constant comparison in addition to continued data distillation until themes emerged. Included are the graphics and tables that were used to show the detailed codes and themes of all datasets. Transcripts of data from semi-structured interviews, vignettes/PD reflections and teacher observation notes were coded manually. There seems to be consensus amongst scholars who examine teacher beliefs that investigating teacher beliefs, as inferred by their actions, requires prolonged field documentation, observation, and reflections (Fraser, 1993; Fraser et al., 2012).

Accordingly, data collection that involved participant observation notes over four different timepoints of data collection, different semi-structured interviews using observational protocols spread over different timepoints, and teacher vignettes during PD sessions allowed the researcher to build dossiers of "cases" of the implementation and instructional practices of respondents (Fraser et al., 2012).

A codebook was developed by the researcher and used to pilot code each of the datasets.

To ensure detailed analysis, the interview transcripts, participant observation notes, and vignettes were examined for two cases each from the 3 different strata. This helped the research to see the parallels and nuances in the three different datasets for the three subgroups while also providing the affordance for later comparison of the results across different strata. Even though all different data from the three sources were manually coded using the codebook that was developed, some sections of manually coded transcripts were compared with the output from ATLAS.ti to ensure sameness and, most importantly, consistency of the two coding and data analysis processes–manual and AI coding using ATLAS.ti.

Given that the code book was birthed from the theoretical framework—epistemological development and understanding—and that the study was also exploratory, certain codes were of interest/ assigned either before or during the data collection process.

**Overview of Hypothesis coding**: Hypothesis coding encompasses researchers–created guesses of what might exist in the actual data either prior to or after initial data collection/analysis (Harding, 2018). In line with this, *the first level of data analysis was hypothesis coding of three different datasets*. The adoption of *hypothesis coding* is a best fit given that codes were "predetermined and researcher-generated" based on the prediction from the theoretical framework (Saldana, 2013, p. 147). These *theory-driven codes* foundationally allowed for the development of a codebook

TABLE 2 Cross tabulation of implementation scores.

| Stratum | Frequency of survey respondents | Frequency represented in case study sample | Number of selected case study teachers |
|---|---|---|---|
| High implementation score teachers (x > 2.27) | 28 | 28 | 2 |
| Medium implementation score teachers (1.66 < x < 2.27) | 49 | 49 | 2 |
| Low implementation score teachers (x < 1.66) | 18 | 18 | 2 |
| Total | 95 | 95 | 6 |

TABLE 3 Summary definitions of the criteria for measuring implementation scores and classroom learning environment for knowledge development.

| Teacher practices within learning environments type(s) | Explanations/definitions of the rubrics/criteria |
|---|---|
| a. Student voice | Creating an environment that lets students have voice and access to engaging in knowledge development. |
| b. Teacher questioning | Utilizing questioning to promote students' deeper cognition |
| c. Big idea/prior knowledge: | Determining/presenting big ideas diagnosing/unpacking prior knowledge via dialogical interactions |
| d. Language use | Promoting flexible use of language for knowledge generation. |
| e. Promoting writing/WTL: | Using writing as a learning tool through varied approaches (writing-to-learn). |
| f. Argument structures | Promoting use of Question-Design-Claim-Evidence (Q-D-C-E) cohesively as a structure of scientific argument |
| g. Student argumentation | Encouraging students to adopt, critique, and defend ideas for generating each component of a scientific argument |
| h. Group structure | Promoting students' engagement in dialogic interactions in small groups and whole class during work/talk/discussion |

(DeCuir-Gunby et al., 2011) that was used to parse out the data analytically.

**Overview of Open Coding/Eclectic coding**: Additionally, *open coding* allowed all the 40 codes from manual coding to refine the initial coding process. It involved line-by-line coding with few descriptive words (Birks and Mills, 2011, 2014; Urquhart, 2013, 2016). In the second analytic level of *open coding*, attributes, and descriptions were identified and categorized.

**Overview of Thematic Analysis**: In the next level of the coding process, *thematic analysis* was adopted at the 3rd level of data analysis. Thematic analysis, according to Saldaña (2021), fosters illumination of patterns and experiences in the data. Harding (2018) suggests identification of conceptual themes, creation of categories, collating codes from illustrative issues into categories, etc. for building a story.

**Cross-Case Analysis**: Finally, cases in each stratum were cross-analyzed in a cross-case analysis format— with cases in other two strata to enable the researchers to unpack the nuances within and between cases and strata for further discussions. This allowed for a comprehensive description of within and across cases, the themes and patterns. Both the *first and second round* of coding (hypothesis and eclectic/open) and data analysis utilized the adapted forms of the framework (Table 4)—levels of epistemological development and understanding (Hofer, 2004a; Hofer and Pintrich, 1997; Hofer and Pintrich, 2002; Kuhn, 2001; Moore, 2012; Pajares, 1992; Perry, 1970; West, 2004) to parse out the data. Epistemological development and understanding propose four levels of epistemological understanding which foundationally underpin the beliefs of the knowers, knowing, and knowledge development.

In this analysis however, the views, beliefs, and orientations of knowledge sources, ways of knowing, and certainty of knowledge, were explored in data by juxtaposing with how each of these levels in written prompts influence the type of classroom learning environment that gets created for knowledge development—replicative or generative—alignment. The definitions provided the needed proxies as analytical lenses for identifying teacher epistemic beliefs and for general parsing out of the data.

While the definitions in Table 4 allowed the researchers to dive deeper into the thought processes of the written prompts of respondents, the observation score protocol for implementation was used to gauge the actual classroom (implementation) environment. By placing side-by-side the implementation score metrics and written prompt responses from epistemic orientation surveys, we were able to unpack the influence of respondents' beliefs and theoretical orientations on teacher actual implementation in the classroom environment created based on teachers' beliefs.

Table 3 also provides brief explanations of the eight criteria that were adopted on the field observation notes protocol, interview transcripts, and vignettes/PD reflections for gauging teacher respondents' actual classroom implementation.

Table 5 shows a generalized data analytic process for all datasets.

## 5.7 Case study teacher profiles

For the two teachers in each stratum, the researchers developed and provided some descriptive profiles to signpost the reader about the teacher participants. This way, readers will not only acquaint themselves with information about respondents for the cases but also provide proxies for the teacher respondents in each stratum to be situated within the context of the entire larger study.

Drawing on the A-EOS survey data, interview data, and the vignettes, these descriptive case profiles were created from this data. All names of respondents have been pseudonymized to further de-identify respondents.

TABLE 4 Definitions of the adapted four-level model of epistemological development and understanding for data analysis (West, 2004; Hofer and Pintrich, 1997; Hofer and Pintrich, 2002).

| Epistemological development and understanding levels | Definitions/explanations |
|---|---|
| Realists | Knowledge is *certain* and concrete and that there is one right or wrong answer to every question with no room for ambiguity. The teacher is seen as an infallible authority who gives knowledge to students Therefore, knowledge does not need to be justified. |
| Absolutists | Knowledge is *certain* and concrete and that there is one right or wrong answer to every question with no room for ambiguity. The teacher is seen as an infallible authority who gives knowledge to students. Therefore, knowledge does not need to be justified.<br>NB: Notion of emergence of uncertainty of knowledge, albeit uncertainty is qualified as being *transient*. |
| Multiplists | Beliefs in the uncertainty of knowledge become firmly established.<br>Belief in multiple sources of knowledge; subjective knowledge; knowledge not externally situated, knower is viewed as constructor of meaning; knowledge claims require justification in idiosyncratic or self-serving ways. |
| Evaluativists | Multiple sources of knowledge; uncertainty of knowledge; requires justification with evidence derived from contexts; knowledge not externally situated, knower is viewed as constructor of meaning; Subjective knowledge.<br>Procedural knowledge and knowing (connected and separated) |

## 5.8 Teachers with low implementation/EOS scores

### 5.8.1 Sandra and Steve

Sandra and Steve are both white who self-identify as a female (Sandra) and a male (Steve). To foster some level of balance in each stratum of the cases selected, one respondent was each selected from both sites of the study–Iowa and Alabama. Sandra and Steve were in their 4th and 2nd years of teaching. At the time of data collection, Sandra and Steve were 2nd and 4th grade teachers. Additionally, they both self-reported that they had each completed a 4-year college bachelor's degree.

## 5.9 Teachers with medium implementation/EOS scores

### 5.9.1 Kira and Freda

Kira and Freda are both white who also self-identify as females. To, again, ensure some level of balance in each stratum of the cases selected, one respondent was selected from either of both sites of the study–Iowa and Alabama. As Kira was selected from the Iowa site, Freda was drawn from the Alabama site of the larger NSF study. Kira and Freda had relatively more years teaching in the classroom. While Freda had 11 years of teaching, Kira had been teaching for the last 5 years. At the time of data collection, Kira and Freda were teachers of record in 5th and 4th grades, respectively. Also, they both self-reported that they had each completed a 4-year bachelor's degree/college, with Freda completing a master's program in addition to the bachelors.

## 5.10 Teachers with high implementation/EOS scores

### 5.10.1 Mirabel and Meridith

Similarly, Mirabel and Meridith both self-identify as white females. To, again, ensure some level of balance in each stratum of the cases selected, one respondent was selected from either of both sites of the study–Iowa and Alabama. As Mirabel was selected from the Iowa site, Meridith was also drawn from the Alabama site of the larger NSF study. Mirabel and Meridith had extensive teaching experience in the classroom. While Mirabel had 32 years of teaching, Meridith also had 26 years of teaching experience. At the time of data collection, Mirabel and Meridith were both teachers of record in 5th grade. Also, they both self-reported that they had each completed a 4-year bachelor's degree/college, with Meridith stating that she additionally started her master's degree but could not complete it due to family issues (Table 6).

## 5.11 Summary of case study teacher profiles

Demographically, all participating respondents, but one, were females. This is highly reflective of the larger NSF project. Out of 95 respondents, from which 6 respondents were purposefully sampled for this study, all, but three, were females. Consequently, the gender/sex demographics were reflective of the actual demographics of the larger study. The percentage ratio of male to female respondents for the study were 16.7 and 83.3%, respectively. The skewness in sex demographics was not done on purpose—purely a happenstance.

*It is important to also mention that participants in the larger NSF project were all white participants. So, the identification and selection of the 6 white participants as case study respondents was by default a happenstance.* Number of years of teaching or teaching experience is also important. Number of years of teaching was directly proportional to the strength of implementation as measured by the implementation scores. Low implementation score teacher respondents had relatively low number of years of teaching experience and vice versa. Number of years of teaching or teaching experience ranged from 2 to 32 years (Kini and Podolsky, 2016). Three (50.0%) of the total sample (6) were 5th grade teachers, with the remaining two (33.3%) and one (16.6%) teaching 2nd and 4th grades, respectively. 50% (3) were drawn from the two study sites–Alabama and Iowa, respectively.

TABLE 5 A generalized data analytic process/framework for respondents.

| Round 1: Initial coding (hypothesis and open coding) | Round 2: Sub-themes from hypothesis and open/eclectic codlings compared/ combined into categories. Subthemes of categories collated into themes during thematic analysis | Round 3: Categories of themes combined into RQ-Driven main themes after cross-case analysis |
|---|---|---|
| a) Combing through data for teacher beliefs about knowledge and knowing (using the four-level epistemological development and understanding model)<br>b) Seeking and identifying the epistemic beliefs/ orientation teachers hold about knowledge, knowing, and learning. | (i) Epistemic belief types–rigid/firm or fluid/flexible-beliefs about knowledge, knowing, and learning. | RQ1. What epistemic orientations (EO) and belief systems do science teachers hold about classroom environments for knowledge development—generation or replication? |
| a) Teacher instructional climate/authority figure role based on criteria in Table 3<br>b) Teacher Dominates classroom professing certainty of knowledge and knowing, decreased opportunities justification through negotiation–Teacher centered.<br>c) Teachers share authority with students. Teachers provide more epistemic authority and opportunity for students. Students are in charge of their learning and the learning environment in an epistemically rich way through negotiations–learner-centered | (i) Classroom Implementation approach and/or classroom learning environment type based implementation score, teacher instructional approach/activities, and 8 criteria in Table 3<br>(ii) Rigid/Firm classroom with routines and regurgitation/ replication of knowledge<br>(iii) Flexible/fluid/adaptive learning/instructional environment based that provides opportunities for negotiations a and contexts based on 8 criteria in Table 3 | 2. How are classroom learning environments of participating elementary school teachers characterized? |
| a) Seeking the relationships between teacher epistemic beliefs/orientations and actual classroom environment they develop for knowledge development<br>High EO teachers are generally high implementations with a created flexible/fluid/ adaptive classroom learning environment for knowledge development and vice versa. | (i) Teachers with low epistemic beliefs/epistemic orientation scores tend to be Low Implementation teacher, create a more rigid/firm learning environment with decreased opportunities for knowledge development and knowing with little or no negotiations.<br>(ii) Teachers with high epistemic beliefs and epistemic orientations scores tend to be High Implementation teacher, create a fluid learning environment with increased opportunities for knowledge development and knowing through negotiations | RQ3. How do teacher epistemic orientation (EO) and belief systems relate to and to what extent do teacher beliefs influence the type of classroom environment elementary school science teachers create for knowledge development--generative or replicative? |

# 6 Results

## 6.1 Results and discussions of low-stratum classroom implementers—Sandra and Steve's epistemic beliefs and their classroom implementation

### 6.1.1 Common grounds on (rigid) epistemic beliefs and theoretical orientations

The two teacher respondents within the low implementation stratum generally agree and share many commonalities about beliefs about knowledge, knowing, and knowledge development. It is against this backdrop that Sandra and Steve both minced no words in expressing their struggles from moving from *a teacher of the students* to being co-learner in the instructional (process) environment. They argued that it is hard for them to fathom how the class will go if learners are allowed to *control* their learning.

Steve's comments represented this when he opined that:

> "When we talked about how we don't really have any control over [student] learning in the class, that was kind of a big thing for me. I don't know, it kind of makes me want to just do more open-ended stuff in class. But I feel like if I do too much of that it won't get what I want or need them to take away at the end of the day. Right! because I don't want it to be so open ended that they don't know where to go, and then will not know if their response is yes or no or right or wrong" (Post PD Interview Transcript, 2021).

Steve further showed rigidity in his epistemic beliefs in several other ways when he suggested that there is every reason for a learner to know if [a] "response(s) [they provide is either right or wrong]" (PostPD Interview Transcript, 2021). This is consistent with the *realists/absolutists* standpoint which proposes that "knowledge is *certain* and *concrete* and that there is one right or wrong answer to every question with no room for ambiguity" (West, 2004; Hofer and Pintrich, 1997; Hofer and Pintrich, 2002).

Additionally, another medium which provides proxies to illustrate rigidity in Steve's epistemic beliefs concerns the way he wants his learners to stick to *classroom routines and cultures*. To this end, he wrote, "I would like them[students] to look at classroom culture and how the students interact with myself and the other students" (PD Reflections, 2021). Affirming his notion of rigidity in epistemic beliefs, Steve reinforced this by asserting again that "I know negotiation can be somehow challenging, but you should always remember that we negotiate ideas, not people"

TABLE 6 Case study teacher profiles.

| Levels of implementation | Name | Race | Years of teaching | Grade taught | Gender | Study site |
|---|---|---|---|---|---|---|
| Low | Sandra | White | 4 | 2nd | Female | Alabama |
| Low | Steve | White | 2 | 4th | Male | Iowa |
| Medium | Kira | White | 11 | 5th | Female | Iowa |
| Medium | Freda | White | 5 | 4th | Female | Alabama |
| High | Mirabel | White | 32 | 5th | Female | Iowa |
| High | Meredith | White | 26 | 5th | Female | Alabama |

(Teacher Observation notes, 2020). Explaining further, Steve elucidated that "just make sure you provide evidence to back the claim that you wrote in your group" (Teacher Observation notes, 2020).

In parallel to this is Sandra who exhibits similar unyielding epistemic beliefs across different datasets. Sandra feels uncomfortable letting go of her "teacher authority figure" role of censoring what counts as knowledge (Biesta, 2017, p. 11) in her (science) classroom. She criticized attempts at relinquishing teacher authority or co-sharing authority with her students when she stated that "I have learned a lot and like it but how to let go of the kids with limited resources available, is something I still struggle with and am trying to figure out" (Vignette 1, 2021). Sandra further stated that "honestly I do not know, [and that she continues to find herself]… in the same boat going into year three" (PD Reflections, 2021) of her participation in the Science Writing Heuristic (SWH) approach project (Hand and Keys, 1999), a framework that guided the larger NSF project. She further explained that "how to really let my kids go" is one of my hardest (Post PD Interview Transcript., 2021).

Sandra further demonstrated her struggles with ceding her authority figure and dominance as a teacher in the classroom when she mentioned that:

> "I still struggle with how to let the kids go with their ideas with the limited time and resources available to us (Vignette 2, 2021). The real struggle on top of the resources, is how to integrate more but still follow our directives of following our maths and reading series with fidelity" (PD reflections/Vignette 3, 2021).

All these show the levels of rigidity in the epistemic beliefs of Sandra and Steve.

### 6.1.2 Common grounds for low teacher implementation strategies

To properly provide analogous perspectives for each of the two respondents in this (and other) strata, results of implementation for the two participating teachers will also be juxtaposed to help readers draw a line by placing side-by-side the previous belief systems and current implementation with ease. Common grounds regarding how the two study participants in this category undertake their classroom implementations will be parsed next. By implementation, respondents are being measured according to how they established an environment where *student voice* is dominant in the classroom, *learners' prior knowledge* are unpacked, *language use* and *writing-to-learn* activities are promoted, *student questions* and *questioning* guided and dominated instructional environment, *dialogic interactions* and *argumentation* through *negotiations* were fostered, etc.

Results show that Sandra and Steve implementations are underpinned by their rigid epistemic beliefs. Both respondents agree conceptually and in practice. They both admit that implementing the SWH approach using the 8 criteria (as described in Table 3) is hard. They contended that the inherent difficulties in using arguments and argumentation structures, not as heated emotional events, to support learning is a challenge for them. Along this line, Sandra averred that:

> "Negotiation! It's a tough one. Like I said, the hardest part for me about negotiations is getting my kids to participate in that. And I think that's just kind of what I need some help with. To get going with, yes, I teach fifth graders and sixth graders and sometimes they're kind of shy. They don't want to, you know, speak out amongst their peers that kind of, you know, tell their friends that they are wrong or not or what we believe and are used to is right or wrong. So that's kind of a tough one for me" (Interview Transcript, 2021).

During PD workshop sessions, Sandra again showed her displeasure and also registered her disquiet in implementing dialogue and argument structures in her classroom by describing it as "It's a tough one" (Interview Transcript, 2021). In a similar vein, Steve expressed frustrations in undertaking argumentation through negotiations in his science classroom. To this, Steve explained that he understands the concepts of dialogue and argumentation through negotiations in his head. He was, however, quick to point out that he gets confused implementing them in his science lessons. In line with this Steve posited that: I feel like on the scale, it's probably a six because the ideas and stuff make sense and I think I know where I want to go with that, but [actually] implementing it probably closer to like a three or four just because I do not know how I'm going to do it yet. Yeah. I have all these cool ideas in my head and I'm like, I do not know how that's going to work though. So, the information makes sense in my head to me as an adult but implementing it into fourth grade and how they do think and all those other needs. Using the argument, and I do not think I'd use language and negotiation" (Interview transcript, 2021).

Results further indicate that Sandra and Steve both described the role of unpacking *prior knowledge and big ideas* which generally serve to bridge what learners already know and what they want to know. Both Steve and Sandra, expressed fear about how *time* could be a limiting factor to reaching the standards.

### 6.1.3 Common grounds on learning environment for low implementers—replicative?

*Given Steve and Sandra's fears about time and other resources, they tended to follow sequenced classroom procedures amidst increased role*

*dominance as a teacher, kind of restraining what counts as knowledge in their classrooms.* Their firm beliefs have probably rendered them ensuring that routines and dictates of standards are reached in a regurgitative style of teaching/learning.

*It is worth pointing out at this time that the hypothesis codes developed/used are consistent with the initial themes that have emerged so far.* As propounded by the hypothesis codes and general coding process, emergent themes so far are a direct reflection of the codes were suggested prior to data analysis. It should be re-emphasized that all hypothesis codes that were utilized were drawn from the theoretical framework of epistemic understanding and development. For example, hypothesis codes advocated for a relationship between teacher beliefs and *(un)certainty* of knowledge. Thus, hypothesis codes were suggestive of a connection between rigid epistemic beliefs and replicative learning spaces and vice versa. Consistencies regarding the initial coding procedures—hypothesis coding—and the themes that have emerged so far increased rigor in the analytic process.

## 6.2 Results and discussions of medium classroom implementers

### 6.2.1 Kira and Freda's epistemic beliefs and their classroom implementation: common grounds regarding "malleable" epistemic beliefs and theoretical orientations

Kira and Freda expressed commonalities on features that bother on where they find themselves on the train of epistemic beliefs, on a continuum. They both self-located their epistemic beliefs about knowledge, knowing, and knowledge development somewhere in the middle of epistemic beliefs on a.

rigid—fluid continuum of implementation. Rating their implementation levels on a scale of 1–10 on rigid—flexible implementation continuum of establishing a more immersive learning environment, Freda equidistantly located her implementation asserting that:

> well, right now! I would say in the middle. I would say in the middle. I would say I am around five eish because I haven't tried it before. You know and I don't really know the questions to ask until I go through it. I'm sure we'll have a lot of questions as it goes along (Interview Transcript, 2020).

Similarly, Kira noted that:

> I'm confident, I would say, using this approach". Asked if she could rate her implementation on a 1–10 rigid/flexible scale on a continuum, Kira further explained that "I'm going to say a five or six or even seven. I don't want to be overconfident right now, but just because I haven't done it, but I'm confident. I'm excited about it (Interview Transcript, 2021).

### 6.2.2 Common grounds for medium level of classroom implementation–midpoint of replicative–generative?

Results show that both Kira and Freda, though appear to have mesial understanding of an immersive and epistemically rich learning environments, they both show their levels of discomfort in implementing some aspects of SWH approach, particularly argumentation through negotiation, and providing spaces for dialogic interactions to occur. They both expressed their readiness to try it out and work through to perfection (Vignette 2 for both respondents, 2021). They further explained their willingness to fall on university-based faculty, who doubled as Principal Investigators (PIs) for the large NSF study, onsite teacher educators (OSTEs), who served as a bridge between respondents and university-based faculty on the project, for support.

Both Kira and Freda expressed their readiness to shift from their current somehow *midpoint* location on the rigid—fluid epistemic belief continuum towards a more fluid extreme end. Explaining further how they can be better implementers with increased leverage in their levels of comfort with enacting an immersive, epistemically rich learning environment, Freda asserted that:

> Just knowing you guys are there. That helps me because I know when I do go to the classroom, even though we plan to teach, there's going to be things that we're going to have questions about. And just knowing that you guys are there if we have any questions, that helps me to feel more comfortable. And knowing that you're going to come out and visit. You're going to come out and watch us and you're going to, you know, see a lesson and I feel like… I'm one that if you see something I'm doing and it's not quite the way that it should be, tell me. You know, and I can fix it. I can work on it. But I just feel like having the support from you all, that helps knowing when I go into the classroom when I have those questions. All I have to do is email or pick up the phone. So, that's what we need" (Interview Transcript, 2021).

Freda further shed more light on how she held onto *control* as a teacher but was quick to also point out that she is ready to relinquish control for learners to own their learning. This is a clear show of oxymoron of Freda's chameleon-like rigid and fluid epistemic beliefs and implementations. She opined: I know I have to back away a little bit and I've tried that, you know, more in the past but I feel like the dialogue will be where I'm more comfortable. Because I feel like I can let them go and let them explore and let them come up and let them negotiate. But I do feel as controlling. I've got to let go of the control" (PD reflections, 2021). Similarly, Kira also delineated this by asserting that:

> I'm very comfortable with getting kids to think outside the box. I'm very comfortable teaching children to have respectful dialogue or negotiation with one another. I'm comfortable with writing, teaching them to write and express their thoughts and things like that. I haven't taught science because we've been departmentalized and so I have not taught science in a number of years. So, just getting back in the groove of teaching science to be honest. I have the lessons, I have the standards, I have the material, it's just putting it into practice (Vignette 3, 2021).

### 6.2.3 Common grounds on learning environment for medium implementers—midpoint of replicative—generative continuum?

That said, Kira noted her double-sided view of the implementation. She recounts how she continues to be held up in

certainty of knowledge and knowing. Superimposing the same with implementing an epistemically rich learning environment, Kira again posited that "I do want you[students] to have conversations with each other and learn from each other and then later go find the *correct answers*" (Teacher Observation notes, 2021). This is important because it helps us to characterize their epistemic beliefs about knowing and knowledge development and their classroom implementation.

## 6.3 Results and discussions of high classroom implementers

### 6.3.1 Shared fluidity in epistemic beliefs

Exhibiting unanimity in describing their epistemic beliefs, the two high implementation case study respondents recounted how they both allow multiple ways of knowing and being to direct their daily activities in their instructional space. Mirabel and Meredith both described how flexible they could go to allow students to own their learning. Mirabel supported this stance when she posited that "… whether it is bringing what they said down a level or raising it up, so all students feel valued. I try to make my lessons open [non-threatening], so no matter what a child brings to the classroom they still have an opportunity to learn within their level of knowledge." (Vignette 4, 2021). The fluidity in epistemic belief allowed Mirabel to promote *uncertainty of* knowledge and knowing and that the teacher's role rested on providing the required congenial environment that is [non-threatening] enough to encourage a(n) [equitable] level of understanding within the class" (Vignette 4, 2021).

> Along the same line, Meredith also stressed the importance of offering multiple ways of knowing: "if we[teachers] offer choices, they[learners] can have more ownership of their learning and how they share their learning with others. We can highlight their individualities by offering different learning approaches and strategies that fit their prior experiences and values" (PD reflections, 2021). Explaining further, Mirabel opined during one of her cognitive semi-structured interviews that, "it's okay for a learner to be unsure of the responses they provide to your questions, and this lets the students' questions to lead the way" (Interview Transcript, 2021).

Another salient point regards how the two high implementation teachers exhibited flexibility in co-sharing their authority as a teacher. Concurring with multiplists/evaluativists' notion of the teacher as a student and absorbing themselves of their authority figure role of censoring what counts at knowledge, both Mirabel and Meredith elucidated how they provide comfort and freedom to their learners by taking a back bench stage for learners to negotiate their learning. To this Mirabel submitted that:

> Being flexible means putting more emphasis on how we teach as opposed to what we teach. I do this by providing more freedom for my students to lead their investigations. We start with what the students already know, the language they already have, and build from there, using the additive approach. We can be flexible by allowing students to be teachers to each other. We can be flexible by making the lessons and dialogue about them, about their interests, and about their questions. We can give them ownership of their learning (Interview Transcripts, 2020).

Meredith also supported this stance when she contended that:

I have always felt that empowering kids in the classroom is vital. I have always liked questioning the kids about their thinking. No matter a student's background it is my job to enrich their time in the classroom and take their thinking/learning to a higher level by allowing students more space to take ownership of their learning (PD Reflections, 2021).

### 6.3.2 Common grounds for high classroom implementation

Common ground regarding implementation is multifaceted. It allows us to visualize how the inherent bits of each of the 8 criteria in Table 3 are undertaken to create an immersive, epistemically rich learning environment that fosters *freedom* and *ownership* of learning to the students.

### 6.3.3 Common grounds on adaptive expertise/ adaptability/flexibility

Along the difference in how Mirabel and Meredith promoted the concept of *flexibility*, came parity in their opinion about *adaptive expertise*. For a teacher to be adaptive in instructional expertise, the teacher is expected to continually assess and gauge their instructional context which draws on the epistemic, social, semantic, and cultural tools to create a learning environment that fosters knowledge generation (Anthony et al., 2015; Mylopoulos et al., 2018).

The flexible belief systems held by Mirabel and Meredith fluidly provided proxies for them to exhibit adaptiveness and adaptability in their instruction. They both did not only show increased *student voice* but also demonstrated the fine use of epistemic tools—language, argument through negotiations, dialogue—for creating immersive learning environments.

Utilization of these epistemic tools were similar and pronounced. Mirabel's fluid epistemic beliefs regarding the use of language as an epistemic tool (Hand and Prain, 2012; Fulmer et al., 2021) anchored her choice of detailing the diverse use of language in its multimodality (Hand, 2017; Hand et al., 2018). In line with this, Mirabel asserted that:

> when I say make use of language, I mean to say that it could be oral language used for negotiating ideas or written language within an activity. If it is oral, then you need to ask more questions with your group. If written, then you need to decide on what is important, it could be drawing, making a sketch, writing in your notebook whatever your group wants to write on your investigations (Field Observation Notes, 2020).

Meredith also buttressed this by showing her flexibility in belief systems, comfort, and adaptive expertise in implementation of use of language as an epistemic tool by intimating that:

> I think about language as a tool for students to make knowledge and to clarify their thinking. I feel comfortable with the idea that different students will have different levels of background knowledge and language experiences. Language is students' way to show what they know. They may start with everyday language, and that is ok. They will develop more of an academic language as

> they move through their lessons and experiences, especially through dialogue with their peers and teacher. Students generate knowledge through language. She should think of language as speaking, writing, listening, reading, and viewing. These language-based acts exist in all curricular areas, including science. Therefore, if students develop their language abilities, they develop their knowledge of science. You can't learn science without language. The best way to learn [with] language is to be immersed in it. This can happen at home, in the world, and in the classroom. Students will observe the language, internalize it, and use it with meaningful immersion over time. Steps I take to utilize language in my classroom include having rich discussions, dialogue, and arguments amongst others (Vignette 2, 2021).

### 6.3.4 Common grounds on learning environment—generative?

Results further show that high implementers enact an epistemically rich and immersive learning environments that eliminate the authority figure role of the teacher—*students dominate the class discourse and student voice is pronounced*, *multiple ways of knowing are acknowledged* using epistemic tools like language, dialogue, and argumentation through negotiations to foster instruction, there's increased co-construction of knowledge, etc. In describing how she undertakes inquiry-based, argument-driven, immersive instruction Mirabel asserted that:

> I normally start by getting an idea of what students already know so that the learning can build from that knowledge (I use an additive approach). KWL charts are a possible starting point to determine what they already know. Even though [I may be] uncertain what ideas students will share or where the investigations may go, I create a general plan for organizing his lessons. I start by posing a problem or phenomenon to get students thinking and asking questions. When several questions have been generated by students, I follow their lead because students should guide the learning. I always choose one of their questions to explore deeper. Students can design an investigation to test their question and can make observations during that investigation. Students can use evidence from their investigation to make a claim. They can share their claims with each other and can revise if other students change their thinking through argumentation. They can seek evidence and information from other sources such as experts and books to support their claims. At the end, he can assess student learning through a variety *of formats such as writing, drawing, speaking,* etc. I also try to be flexible and give ownership and freedom to the students so they can determine the direction of the learning (Vignette 1, 2021).

## 6.4 Discussions of results across strata of implementers

Generally, low implementers appeared more established in the rigid epistemic beliefs with little to no room to want to shift. Both low implementers, Sandra and Steve, tended to enact some appreciable level of an epistemically rich classroom learning environment that provides freedom for learners to take *ownership* of their learning. However, both Steve and Sandra argued for and justified their low classroom implementation style citing "time" as justifications for their low implementation classroom learning climate (Interview Transcripts, 2021). Rationalizing this further, the duo again both pointed to *sequenced curricular expectations* as enough grounds to holding onto their firm beliefs about implementing an epistemically rich classroom learning environment with *reduced teacher visibility* and enhanced *student voice.* Again, the low implementers were more inclined to maintain epistemic beliefs with decreased opportunities for shifts or change.

Teacher respondents in the medium category continually voiced their notions of mesial comfort in enacting an epistemically rich learning environment, tended to be more open to trying out new stuff until they got better at it. High implementation score teachers tended to be more open to new ideas and ways to enact the SWH approach.

## 6.5 Main themes from cross-strata and cross-case analysis

Data were analyzed in multiple different ways using (manual) codes that were developed, written analytic memos, iterations across multiple sets of data (observation field notes and transcripts from semi-structured interviews, reflections from PD sessions and vignettes). As mentioned earlier, a qualitative data analysis package, ATLAS.ti, was utilized to compare portions of the codes created manually from interview transcripts and PD reflections for hypothesis and open/eclectic coding approaches used. Review of the codes led to their reorganization into initial 11 categories, strata, and themes through *thematic analytic* procedures.

Through cross-case and cross-strata analyses, and in alignment with the research questions that guided the study, the 11 categories and themes were reduced to few distinct, but interconnected connected, main themes. In the sections that follow, we elucidate the main themes citing examples of the cross-sectional and cross-strata responses from the semi-structured interviews, field observation notes, and PD reflections/vignettes that fit the themes, and wind up with a summary of findings for the study.

Second time consideration of the 11 themes led to merging some of the themes. Accordingly, 5 major themes were (re)created as: (1) Description of Teacher Epistemic beliefs and theoretical orientations, (2) Classroom Learning environment types for knowledge development—Replicative and generative learning environment, (3) Modeling classroom learning environments based on Teacher epistemic beliefs/Theoretical orientations, (4) Congruous Associations and impact of epistemic beliefs/orientations on Classroom learning environment type, and (5) Epistemic beliefs/orientation type fosters teacher adaptability, practice, and persistence. While the five themes above representatively fostered the visualizations of the study results and findings in appreciable detail, a need still existed to further coalesce them into two or three overarching themes.

In line with this, the 5 major themes were further coalesced by merging them into two broad and all-encompassing themes as seen in Table 7.

# 7 Findings

The primary goal of the study was to investigate the epistemic orientations held by elementary school (science) teachers, examine and

TABLE 7 Summary of major findings based on themes.

| Main themes | Categories and sub-themes |
|---|---|
| 1. Teacher epistemic beliefs orientation(s) type show classroom learning environment association | 1A. Rigid/firm epistemic beliefs replicative learning environment |
| | 1B. Fluid/Flexible Epistemic beliefs generative learning environment |
| 2. Struggles of teachers (resulting from rigid/fluid EO) mirror their sense of control/persistence/adaptability | 2A. Flexible EO teachers tend to exhibit increased teacher adaptability, persistence and co-shares control |
| | 2B Rigid EO teachers struggle to release control/less adaptive/less persistent |

characterize the relationships and influences of these epistemic (orientations) beliefs on classroom learning environments—replicative or generative—for knowledge development. In line with this, three main research questions were posed to guide the study. The main research questions have been listed below for iterative connections for readers.

**Research Questions 1 & 2:**

1. What epistemic Orientations (EO) and belief systems do participating elementary teachers hold about classroom learning environments for knowledge generation or replication?
2. How are classroom learning environments of participating elementary school teachers characterized?

**Research Question 3:** also sought to examine:

3. How and to what extent do teachers' epistemic orientation (EO) and belief systems relate to and influence the type of classroom environment elementary school science teachers create for knowledge development–-generative or replicative?

The two coalesced overarching themes are further unpacked to point out how each of the research questions is answered by the results from data analysis. Cross-case and cross-strata analyses of the data revealed two overarching patterns of how elementary school science teachers exhibit different epistemic beliefs and theoretical orientations regarding knowing, knowledge development, and how and to what extent such epistemic beliefs/orientations influence a knowledge development classroom learning environment type.

(Main Theme 1) Teacher epistemic beliefs/orientation(s) type show classroom learning environment association.
(Main Theme 2) Struggles of teachers (resulting from rigid/fluid EO) mirror teachers' sense of control/persistence/adaptability.

In furtherance, the elemental components of each of the overarching themed findings are holistically described and, where necessary, specific examples of data, categories, sub-themes, etc. are used as exemplars for illustration and support.

*Consistent with and drawing on the theoretical framework that birthed the hypothesis codes— utilized for the initial manual coding process, teacher epistemic beliefs held by elementary school (science) teachers were identified and characterized on a rigid–fluid epistemic beliefs continuum.* Afterwards exemplars of their *positioning* and *dominance* of the teacher in the classroom—*teacher control*, sense of *(un)certainty* of knowledge and knowing, and *subjectivity* or *objectivity of knowledge* (which draws on knowledge requirements of justification or otherwise).

> Main Theme 1: Teacher epistemic beliefs/orientation(s) type show an association with classroom learning environment.

## 7.1 Descriptions of teacher epistemic beliefs and theoretical orientations

While teachers' beliefs and theoretical orientations regarding (un) certainty of knowledge and knowing were considerably essential in the identification of beliefs about knowledge development and knowing, *the posturing of the teacher as an authority figure* gauging what counts as knowledge—control— as well as classroom dominance were importantly explored. The two major sub-themes under this main theme—are explicated, comprehensively discussed, and contextually situated.

Across the data set from interview transcripts, field observation notes, PD reflections to vignettes described, implementers adopted a posturing that allowed the visualization of their views or epistemic beliefs about knowledge, knowing, learning, and knowledge development. Particularly, their views were not just expressive but impacted their implementation of a classroom learning environment type. In cross-case comparisons of their implementation and analysis, all case study teachers recounted, in different datasets, how they created a learning environment regarding their (un)yielding to certainty or uncertainty of knowledge, knowing, and knowledge development. Again, all 6 case study teachers described how they reckoned their role either as a *barrier* or *vehicle* to knowledge development, knowing, and knowledge.

Results further showed that, all 6 respondents' descriptions of their epistemic beliefs unequivocally support their wielding of some form of belief systems on a rigid–fluid epistemic beliefs continuum. *The salient distinctive factor of the epistemic beliefs and theoretical orientations of the teachers rested on which part of the extremes of location on the rigid—flexible epistemic beliefs in a continuum.*

## 7.2 Rigid and fluid epistemic beliefs

The difference in epistemic beliefs espoused by the 6 teacher case study teachers varied greatly from low implementation respondents to high implementation respondents. While all the case study teachers exhibited or disclosed—knowingly or unknowingly—some level of their espoused epistemic beliefs about knowing, knowledge, knowledge development, the degree to which case study teachers' implementational strategies or responses in data reflected their support for or against a belief system differed substantially, albeit on a continuum. Participants who reported *self-imposed constraints* recounted engaging routinized activities in their classroom that mirrored their firm/rigid epistemic beliefs and theoretical orientations. On the contrary, case study

teachers who appeared unworried about sequenced curricula and time as a constraint to achieving set expectations and standards tended to show a more fluid epistemic orientation.

Additionally, teachers who tended to dominate their classrooms, were more likely, steered towards *firm* beliefs at the end of the continuum, and respondents who allowed their learners to dominate their classrooms showed a high tendency of being located at the *flexible* end of the continuum.

While low implementation respondents could easily be located at the rigid extremes of epistemic beliefs about learning, instruction, knowing and knowledge development, high implementers tended to be found at the other extreme—flexible epistemic beliefs. Two of the six case study teachers—Steve and Sandra—described, and were also seen to have engaged in (pedagogical) practices that favorably aligned with the conception of a teacher who *controls* what counts as knowledge. Relatedly, engaging pedagogical practices of Meredith and Mirabel in a freed-up environment also showed more tilting towards the fluid end of the epistemic belief continuum.

On one hand, respondents expressed inferred knowledge of their belief systems and on another hand, they appeared to be unaware of their epistemic beliefs across different dataset. Sandra described her beliefs about knowing, teaching, and knowledge development in science by utilizing a pedagogical style that fostered "memorizing facts about science" (Interview Transcript, 2019). Explaining her epistemic (belief) stance on science learning, Sandra further submitted that "I have always taught science using an old-style textbook, and it was just a lot of memorizing facts about science" (Interview Transcript, 2019). This epitomizes Sandra's conception of learning, knowing, and knowledge development in science. Asked how she learns something; Sandra again maintained the concept of *memorizing* [facts]. She insisted that "but if it is something that I have to memorize [facts] and really learn, I do better on my own" (Interview transcript, 2019).

Along the same line, Steve also contended that something that frustrated him and that he continues to struggle to grapple with the most during SWH workshop concerns "having been left with the thought of no "right/wrong" confirmatory/denial to student responses in class (Workshop Reflections, 2019). He emphasized that he still struggles to fathom the statement creating spaces and "way[s] of letting students be their own teachers too" (Workshop Reflections, 2019). This is consistent with *Absolutists* and *Realists* [epistemic] beliefs of *certainty* of knowing and knowledge development.

Conversely, other case study respondents were fluidly flexible in the epistemic beliefs. It is interesting to point out that case study teachers who exhibited flexibilities in their epistemic beliefs sounded like they were aware of their fluid belief systems. Most importantly, case study teachers at the flexible epistemic belief end of the continuum cited both *multiple ways of knowing and learning* and argued for *uncertainty* of knowledge characterization. To this, Mirabel suggested that:

> "I think I would say knowledge is established by multiple ways of authority. Because I think you can gain knowledge from so many different aspects and different strategies as well. I don't think there is a single way for someone to gain knowledge, especially because knowledge is such an individual approach as well" (Interview Transcript, 2019).

Analogously, Meredith also shared similar flexible epistemic belief sentiments by suggesting that "I think it's multiple [ways of knowing]. I think plenty of people and events or books and things we see, guide what we believe and what we are learning about. Not just one person being the main source of our information" (Interview Transcript, 2019).

In furtherance, medium implementers also provided evidence of their mid-point location in their epistemic beliefs when Kira summarily suggested that:

> I am in a middle ground on that one. There are times when the quiet helps them and they can think of things in their head, but you also have to talk it through and bounce your ideas off of others. So, I am in a middle ground with that. I don't need to be quiet. I don't think it always needs to be talking. I think there is a combination of both" (Interview Transcript, 2019).

As these examples demonstrate, teachers' beliefs are exhibited in their classroom learning environments. This supports the ongoing attention to belief systems as part of research in teacher learning.

## 7.3 Characterizing classroom learning environments for knowledge development

The notion of classroom environment type for knowledge development was variedly enacted by all the six case study teachers. These notions of a classroom learning environment that got established for classroom engagements, knowing, and knowledge development were ubiquitously reported across datasets. While all 6 teachers set up different learning environments based on their epistemic beliefs about knowledge, knowing, knowledge development, results of data analysis provide us with enough information to unpack the nuances that characterized the subtleties in the learning environment each teacher created for knowing and knowledge development.

It is important to point out that, while two of the case study teachers—Steve and Sandra— were easily locatable at the replicative classroom learning environment end, Mirabel and Meredith could also be located at the generative learning environment extreme. Kira and Freda, on the other hand, maintained the mid-point location on the replicative. There was a strong association between epistemic beliefs and learning environment type for knowledge development.

## 7.4 Typology of classroom learning environments—replicative and generative

Learning environment types were described as experientially established by all participating case study respondents. Based on differing epistemic beliefs espoused by study respondents, different learning environments were created for knowing, learning, and knowledge development. From one extreme end of a more *sequenced* and *time-laden* knowledge transmission learning spaces to a more *open* learning environment that allows learners to undertake inquiry to validate knowledge co-construction—generative.

*At one end of the continuum sits replicative learning environments, generally characterized by knowledge transmission.* Such learning environments are dominated by the teacher as the *authority figure* and knowledge is transmitted like a commodity from the teacher, who acts as the fountain of knowledge dissipating knowledge in a take–and–reproduce manner, nothing short of the description of "banking models"

of education (Alam, 2013; Bybee, 2020; Kalsoom et al., 2020; Lammert et al., 2023a,b). Replicative learning environments *objectify* learners in the classroom learning process and environment. Such environments view the learner, learning, knowing, and knowledge development as the ability of the students to mechanically regurgitate what the teacher says/teaches as benchmarks for an effective instruction and learning. Replicative learning spaces provide, if any, reduced agentic opportunities for learners to co-create their learning. Sandra and Steve reported understanding of what it takes to create a teaching/learning space which supports learners to undertake inquiry. While the notion of co-creating knowledge was reasonably explained by Steve and Sandra, they both summarily touted *sequenced curricula expectations* and *routinized engagements* in the classroom as the reasoning behind creating more *restrictive* learning spaces. Sandra and Steve learning environments promoted the stultification of learners in the instructional and learning climates provided by their espoused epistemic beliefs.

Embroiled in the ongoing conversation regards the medium implementers who can be located somewhere in the midpoint of replicative—generative learning environments continuum. Kira and Freda are best exemplars of the case study respondents who arguably understand generative learning environments and their accompanying freedom and opportunities of knowing and knowledge development. However, their rigid epistemic beliefs would not let them release *total control* of learning to their students. It is common knowledge that students are the ones *doing* their learning, so they always have *control*. Nonetheless, the tendency for teachers to continue their *illusion of control of student learning is always eminent.* Accordingly, such teachers try to instantiate this illusion by exerting control over the physical and social interactions of the classroom (Hand and Prain, 2002).

*At the other end of the continuum also sits a learning environment type that provides learners with agentic opportunities to undertake knowledge co-creation and validation—generative learning.* Generative learning environments create spaces for learners by centering the ideas and the knowledge each learner brings to the classroom for all to bounce off ideas with each other. In generative learning environments, there is much freedom which shifts the role of the teacher as the authority figure to co-constructor of knowledge with the learners. In what other scholars have termed *emancipation* (Biesta, 2012; Rancière, 2021; Worthman, 2008), providing more freedom and opportunities in generative learning environments *emancipates* the learner from the *authority figure's oppression* into freedom for co-creation of knowledge and knowledge development. Providing credence to "whoever teaches without emancipation stultifies" mantra, generative learning environments provide epistemically rich learning spaces for knowledge co-creation and development (Crockett, 2012, p. 8; Porres et al., 2020; Biesta, 2010).

*Results from data analysis explicitly allow both researchers and readers to visualize how Meredith and Mirabel draw on many different epistemic tools—language, dialogue, arguments/arguments—to create a learning environment where freedom and opportunities are provided for learners to wrestle through and bounce off their ideas with colleagues.* The ideas of knowing and knowledge development are properly given meaning in generative learning spaces when Mirabel and Meredith described their degrees of comfort with allowing learners more space to ask questions, make claims, and provide justification or evidence to support their claims. Most importantly when the authority figure role of the teacher becomes conspicuously missing.

## 7.5 Teacher epistemic beliefs are associated with classroom environment type

Results from data analysis further revealed that each of the six case study teachers modeled a classroom environment type that was in tandem with their espoused epistemic beliefs and theoretical orientations. All 6 participants generally described their ideal learning environment for knowledge development and knowing. Results across cases show that there was a strong relationship between the belief systems wielded by a case study teacher respondent and the environment type that was created for knowledge development and knowing.

Even though, a strong association between epistemic beliefs and classroom learning environment type for all case study respondents are shown in data and results, discussing the nuances of the 3 different strata—low, medium, high implementers—regarding their implementations will help to unpack the fine distinctions between and amongst them. In line with this, data analysis and results showed that teachers with low epistemic orientation generally demonstrated firm/rigid classroom learning environments with routines from the authority figure of the classroom for knowledge replication. At the other end of the extreme, lie teachers with high epistemic orientation or epistemic beliefs tended to be largely flexible in their constructions of a classroom learning environment type for knowledge co-construction. Middle implementers had a mix of epistemic beliefs from rigid to flexible. While Kira and Freda demonstrated understanding of SWH approach to enacting an epistemically rich learning environment about knowledge development, the duo countlessly got held up in continuing to oppress learning and learners, more than to support learning.

Therefore, findings from this study are consistent with the growing body of science education literature on teacher beliefs and knowledge development—*congruous thesis*. These science education literature(s) have supported the notion that teacher beliefs and theoretical values generally influence the learning environment type for knowledge development (Akuoko, 2024; Gabel et al., 1998; Wahyudi and Treagust, 2004). Proponents of *congruous thesis* posit that classroom learning environment types that get modeled are generally underpinned by epistemic beliefs held by the teacher. They explained that a teacher who espouses *firm* and *certain* epistemic beliefs about knowledge, knowing, and knowledge development tend to create learning environments that support knowledge regurgitation, an enduring characteristic of replicative learning environments. Similarly, they support the conception that teachers who wield *fluid* epistemic beliefs generally model a classroom learning environment type that frees up space and provide opportunities for learners to negotiate their versions of knowledge through enquiry and validations.

Such learning environments support equity of knowledge and provide all the support, scaffolds, and the epistemic tools needed for generating their own learning.

## 7.6 Struggles of teachers mirror their sense of persistence/control/adaptability

Another major finding from data analysis was that struggles of case study teachers mirrored their sense of persistence, control, and/or teacher adaptability in the classroom learning environment for

knowledge development. Data showed how each of the six case study teachers described how they either persisted or adapted their teaching when designing a learning environment type that fostered SWH approach (a framework that guided the design of epistemically rich learning environments in the mother NSF study) to guide teacher implementation. Findings generally showed various degrees of teacher persistence and adaptability in the elementary school science classrooms.

## 7.7 Struggles of teachers and teacher persistence

Teacher's descriptions of classroom learning environments and activities that happen in such classrooms for knowledge development could better be explained as nothing short of display of *persistence* in the classroom. It is noteworthy to stress that *teacher persistence* has largely been explored in literature along with the notion of teacher attrition or retention (Saatcioglu, 2020; Scott et al., 2022) far different from how this study conceptualized it.

Findings further show that, while low stratum implementers, Sandra, and Steve, exhibited decreased levels of tenacity, perseverance, and persistence, high implementers—Mirabel and Meredith—flexibly endured and persevered to ensure their classroom learning environments still provided opportunities and support for inquiry.

In this study, teacher persistence encapsulates the actual act of teaching and the daily pedagogical decisions, activities, and actions that mediate instruction/learning in the classroom. Continuing to work hard at teaching is part of what constitutes teacher persistence, but working hard by itself cannot be equated to teacher persistence. Thus, the tendency for a teacher to persist steadfastly, until successful, in the many specific courses of action that constitute teaching (Wheatley, 2002). Regarding this finding, the researcher explains teacher persistence as the attributes of or within teachers that ginger teachers to engage reflectively on their practices until their students achieve success.

## 7.8 Struggles of teachers and teacher adaptiveness/control

Along the difference in teachers' epistemic beliefs, came shared commonalities in their opinion about adaptability and adaptive expertise. For a teacher to be adaptive in instructional expertise, the teacher is expected to continually assess and gauge their instructional contexts which draw on the epistemic, social, semantic, and cultural tools to create a learning environment that fosters knowledge generation (Anthony et al., 2015; Mylopoulos et al., 2018). The belief systems held by teachers reflected their levels of adaptive expertise in the instructional climates.

Study results and findings show that teachers who exhibited *firm epistemic beliefs* and theoretical orientations about knowing, and knowledge development were less adaptive in their instructional climate. In sharp contrast, teachers who exhibited *flexible epistemic beliefs* and theoretical orientations showed increased levels of adaptive expertise in their classrooms. It can, therefore, be argued that teachers' epistemic beliefs provided proxies for them to exhibit adaptive expertise/adaptability or otherwise in their instruction.

Fluid epistemic beliefs holders and high implementers did not only show increased *student voice* but also allowed the fine use of epistemic tools—language, argument through negotiations, dialogue—for creating immersive learning environments. Utilization of these epistemic tools were similar and pronounced in medium and high implementation teachers. For example, Mirabel's fluid epistemic beliefs regarding the use of language as an epistemic tool (Hand and Prain, 2012; Fulmer et al., 2021) anchored her choice of detailing the diverse use of language in its multimodality (Hand, 2017; Hand et al., 2018).

Some studies have explored the interconnectedness of teacher flexibility, teacher identity, teacher personal orientation, and teacher personal practice theories—to which teacher beliefs could be inherently situated (Bowers et al., 2020; Männikkö and Husu, 2019). Activating prior knowledge and experiences during instruction draws on flexibility in orientations and the level of adaptive expertise of the teacher (Crawford et al., 2005; De Arment et al., 2013; Kua et al., 2021). Thus, flexibility in epistemic beliefs and theoretical orientations is a precursor to the extent to which prior knowledge and experiences are utilized (Barnett and Koslowski, 2002; Levin et al., 2013). For example, Levin and He (2008) note that teacher personal orientations–including (epistemic) beliefs impact their adaptive expertise.

# 8 Discussion

The primary purpose of this multi-case study design was to examine the relationship between elementary school science teachers' epistemic orientation (EO) and its influence on the type of classroom environment for knowledge generation or replication characterization. The study viewed epistemic orientation as teacher beliefs systems that impact knowledge development through implementation practices in the classroom. Recognizing the role of epistemic beliefs of knowledge, knowing, and knowledge development, the study aimed to explore the influence of different ranges of epistemic beliefs, albeit on a rigid–flexible continuum, on the type of classroom learning environment that gets set up for instruction and learning. Based on this, the study utilized epistemic orientation score metrics data and implementation score data for each of the case study teachers. Drawing on existing data from a 3-year NSF study that summarily sought to examine teacher adaptive expertise in the epistemic complexities of science, EO score and implementation scores, used to operationalize a learning environment type, allowed for visualizing the relationship between teacher epistemic orientations and classroom learning environment.

Case studies of 6 elementary school science teachers allowed for comprehensive and exhaustive deepening of our understanding of each case selected from the three categories--teachers with low, medium, or high EO or implementation scores. Data from semi-structured interviews, PD reflections/vignettes, and observation field notes were analyzed to deepen the understanding and also identify the specifics of teacher epistemic beliefs that impact teacher classroom implementation for knowledge development. It is important to emphasize at this point that the implementation score data is based on 3rd-party raters, not self-reported report. While previous studies on beliefs and theoretical orientations gathered data through surveys only, this study utilized a combination of both surveys as in epistemic orientation scores and implementation from 3rd party raters.

Even as results and findings from this study point to strong associations between epistemic beliefs and (classroom) learning

environment type and thus fall within the *congruous thesis* standpoint of prior (science education) research, delineating the unique circumstances that characterized the current study for juxtaposition is worth a discussion time and space. Several reasons, inter alia, could account for the uniqueness of the findings which contrast similar studies that conform to the incongruous thesis—belief and practice disconnect—relative to this study.

First, the larger NSF project, from which the current study is birthed, offered *longer experiences of learning* the SWH approach (Keys et al., 1999; Nam et al., 2011). This could have accounted for witnessed consistencies in the Teacher implementation score data. Another reasoning, for congruous beliefs–practice learning environment association was that the framework—SWH approach—that guided the study utilized a different approach of fostering *conceptual change,* in participating teachers, by creating disequilibrium and/or dissatisfaction with their current state of practice (Posner et al., 1982; Strike and Posner, 1982; Chen and Wang, 2016). This is at variance with the conventional PD approaches which generally focus on what gets learned at PD sessions instead of seeking to shift belief systems through cognitive *disequilibration and dissatisfaction* (Posner et al., 1982).

*Results helped to deepen our understanding of the selected cases in their unitary and cross-case forms.* In particular, it allowed an in-depth dive to examine the nuances within and between the different dataset from the semi-structured interviews, vignettes/PD reflections, field observation notes, and most importantly, classroom implementation scores. Again, the study aimed to answer the following research questions:

1. What epistemic Orientations (EO) and belief systems do the participating elementary teachers hold about classroom learning environments for knowledge generation or replication?
2. How are classroom learning environments of participating elementary school teachers characterized?
3. How do teacher epistemic orientation (EO) and belief systems relate to and to what extent do teacher beliefs influence the type of classroom environment elementary school science teachers create for knowledge development–-generative or replicative?

Data analysis and results helped to fill some of the gaps relating to qualitative nuances between and amongst selected cases in their unitary and cross-case/cross-strata forms. Two salient overarching themes germane to teacher epistemic orientation and its relationship with the classroom learning environment for knowledge development, emerged from data analysis. These main themes are summarized in Table 8.

As detailed above, the data analysis and results revealed two thematic findings regarding the relationship between teacher epistemic beliefs and classroom learning environment types for knowledge development. Findings are discussed and presented in accordance with the two thematic areas of teacher beliefs, classroom learning environments and teacher struggles–-teacher adaptiveness and persistence and/or control and situated within current (science) education literature.

## 8.1 Teacher epistemic beliefs and classroom environment type association

The study sought to understand the epistemic beliefs and theoretical orientations held by elementary school science teachers, and how, and the extent to which teachers' epistemic beliefs influenced the classroom learning environment type created—replicative or generative—for knowledge development. It helps to unpack teachers' beliefs about knowing and knowledge and their influence on the eventual classroom instructional climate they establish for knowledge development.

The present findings are consistent with prior work that studied how teacher epistemic beliefs influenced the classroom learning environment type (Bae et al., 2021; Bae et al., 2022; Bernholt et al., 2021; Lazarides and Watt, 2015; Uysal, 2010; Wang et al., 2022). These findings are consistent with previous research indicating the notable role of espoused beliefs or theoretical orientations with classroom learning environment type (Abell, 2013; Buehl and Beck, 2014; Fraser, 1998; Fraser et al., 2012; Hoy et al., 2006; Lederman and Abell, 2014; Richardson, 1996). In what some scholars have referred to as "congruous thesis," [where] "findings depict congruity between a teacher's espoused beliefs and classroom practices and/or instructional climate" (Fraser et al., 2012, p. 481), a relationship has been found between espoused beliefs and practice.

Consistent with *congruous thesis* and with the findings of this study, Laplante (1997) reported the influence of teachers' epistemic beliefs of two elementary school teachers on their practice and epistemic climate in Canada. The study also found a relationship between teacher beliefs and the knowledge "transmitted or generated"—learning environment type—by the teacher and the learning environment (Laplante, 1997, p. 14). Brickhouse also notes a similar pattern of influence of teacher beliefs on explicit lessons and implicit curriculum (Brickhouse, 1990). Bencze et al. (2006) also reported a direct relationship between teachers' espoused beliefs and their tendencies to control student knowledge building. They further intimated that teachers' espoused beliefs—positivist or constructivist—largely impacted the ways they promoted student–centered or teacher—centered approaches. A similar congruous association between teacher epistemic beliefs and classroom climate was reported when teacher beliefs were examined in relation to teacher efficacy and their influence on varying perspectives of classroom climate for knowledge development (Rubie-Davies, 2014).

In furtherance, a similar exploration investigated the relationship between school climate and teacher beliefs about self-efficacy. Pearson Product–Moment Correlation Coefficient was used to analyze the data. While a non-significant linear relationship was found between teacher beliefs and school climate, a positive correlation was nonetheless reported between teacher beliefs and classroom community engagements (Lacks, 2016). Another study also examined the relationship between teacher beliefs and their associated teacher practices and instructional climate at two public elementary schools in the U.S. They concluded that teachers held heterogeneous beliefs that were unaligned with their practices. They further suggested that their findings were in support of the *congruous thesis*, alignment of a relationship between the two constructs—teacher beliefs and instructional climate (Guerra and Wubbena, 2017).

Epistemic beliefs have also been found to influence classroom environment type (Fives and Buehl, 2012; Pajares, 1992). Some scholars have argued that teachers' instructional strategies are generally dependent on varied beliefs regarding how instructions should go. Successively, the ways teachers interact with their students and deliver their instruction strongly contribute to the relationships that are created in the classroom, and by extrapolation, the epistemic climate of the

TABLE 8 Summary of beliefs—environment type associations.

| Main themes (findings) |
|---|
| 1. Teacher epistemic beliefs/orientation(s) type show classroom learning environment association |
| Subthemes: |
| (a) Descriptions of teacher epistemic beliefs and theoretical orientations. |
| (i) Rigid/firm epistemic beliefs |
| (ii) Fluid/flexible epistemic beliefs |
| 2. Typology of (classroom) learning environments. |
| (i) Replicative learning environment |
| (ii) Generative learning environment |
| Summary: teacher epistemic beliefs and classroom environment type association summary |
| (i) Rigid/firm epistemic beliefs replicative environment |
| (ii) Fluid/flexible epistemic beliefs generative environment |
| 3. Struggles of teachers mirror their sense of persistence/control/adaptability. |
| • Struggles of teachers as a reflection of their persistence |
| • Struggles of teachers as a reflection of their adaptability and control. |

classroom (Peterson et al., 2011). Part of the reason is that teachers' beliefs about student learning and about how to teach can be a guidepost to instructing and interacting with students in particular ways. Thus, teachers' beliefs, according to Peterson et al. (2011) are powerful contributors to the classroom climate for knowledge development.

While the analysis further supported the congruous thesis, there were gradations of epistemic beliefs and classroom learning environment association. Both low and high implementation score teachers showed relatively stable epistemic beliefs and learning environment type association but medium implementation score teachers showed pendulum-like swings in their epistemic beliefs and learning environment associations. The study also found that belief type was correlational to teachers' level of implementation.

The low implementation score teachers showed difficult-to-adjust, firm, and stable epistemic orientation/beliefs towards knowing and knowledge development. For fear of not completing the standards in the NGSS document and unexplainable tilting towards *time as a constraint,* low implementation stratum (LIS) teachers would do anything at the altar of time to stop creating spaces for students to wrestle through their ideas via negotiations. Consistent with previous research, low implementation score teachers espoused "strongly held and relatively static epistemic beliefs in nature" (Rokeach, 1972). Cobb and Bowers (1999), in like manner, analyzed the association between teacher beliefs and their participation in unfolding classroom events. The study findings, similarly, reported a congruous relationship between teacher's beliefs and their participation in classroom events.

High implementation score (HIS) teachers, on the other hand, showed fluidity in their epistemic beliefs. They were able to re-invent their instructional activities and instructional climate by readjusting their beliefs to maximize opportunities for learning. For one example, Sing Chai et al. (2009) examined changes in Singaporean pre-service teachers' epistemological beliefs and beliefs about learning and teaching during a teacher preparation program. Findings showed that participants exhibited significant changes in epistemological beliefs and beliefs about learning and teaching.

Some studies have also specifically examined beliefs in relations to knowledge transmissive or generation. Norton et al. (2005) investigated teachers' intentions and beliefs and knowledge transmission or knowledge generation in the UK. Despite their report that teachers' intentions, more than beliefs, were more oriented towards knowledge transmission [or knowledge generations], they also found an association between teachers' orientation/beliefs and learning environment type. While environment type topologies—transmission and generation—were both found to share beliefs–environment topology relation (Blömeke, 2012; Norton et al., 2005), beliefs—transmissive typology was more common and consistent with previous scholarship. As a case in point, Blömeke (2012) investigated the relationship amongst teacher knowledge, instructional climate, and teacher beliefs across countries. They found, inter alia, the "influence of teacher beliefs on a teacher's teaching and learning, either from a more constructivist or from a transmission point of view" (p. 1).

Finally, important consequential links between teacher's beliefs and student-centered instruction and instructional climate have also been found (Solomon et al., 1996; Rubie-Davies, 2014). Rubie-Davies (2014) investigated the connections and conundrums between beliefs formed by teachers and their influence on design decisions and general instruction. The study found an ultimate impact of teachers' belief systems and instructional decisions.

## 8.2 Struggles of teachers mirror their sense of persistence/control/adaptability

### 8.2.1 Struggles of teachers as a reflection of their persistence

The study also found a relation between teacher struggles and their sense of persistence, control, and adaptiveness or adaptive expertise. Struggles of teachers reflected their levels of adaptiveness, control, or persistence in designing a classroom learning environment type. Low implementation score (LIS) teacher respondents exhibited low tenacity in creating a more fluid learning environment. Even as they (Sandra and Steve) tried as they could to tilt their learning and instructional environment towards generative end of the continuum, their rigidly–postured epistemic beliefs about wanting to complete *sequenced curriculum, state & federal standards and expectations,* and most importantly, the fear of self-created shadows—*time, labeled as a constraint*—stunted their self-drives to open up more spaces and multiple ways of being in their classroom. This created a chain that reined and controlled their instructional and learning environment. Thus, LIS respondents showed less tenacity and perseverance towards establishing a classroom learning environment type that promoted/supported replicative learning.

The opposite was showcased by high implementation score respondents (HIS). The fluidity in their epistemic beliefs challenged their practice and environment type that were created for knowledge development. In fact, Meredith and Mirabel showed increased persistence even when some aspects of the framework that guided the study (SWH) posed a conceptual challenge. Asserting and accepting uncertainties in what next to do as a teacher to create an open instructional environment, Mirabel explained her level of perseverance even when faced with challenges to creating a fluid environment. Bold, resolute, and a tenacious show of pushing further for the

purposes of persistence, Mirabel exhibited increased levels of persistence when she averred that "even though, [I may be] uncertain what ideas students will share or where the investigations may go, I [still] create a general plan for organizing the lessons" (Interview Transcript, 2020).

Consistent with previous research, Wong and Luft (2015) explored teacher beliefs and its impact on persistence in the classroom. Adopting a mixed methods methodological procedure, the relation between teacher's beliefs and their persistence in the classroom was investigated. The study found that "teachers with more student-centered beliefs were more likely to persist to the end of the third year of [their] teaching" and vice versa. (p. 1). Another study explored the impact of teacher (efficacy) beliefs on teachers' persistence. They concluded that "[epistemic] beliefs influence teachers' persistence when things do not go on smoothly in the classroom and their resilience in the face of setbacks" (Tschannen-Moran and Hoy, 2001, p. 4).

### 8.2.2 Struggles of teachers as a reflection of their adaptive expertise

Results and findings point to differentials in teacher adaptabilities, adaptive expertise, and adaptive practices in varied learning environments. Teacher adaptability embodies teachers' response to uncertainties, unplanned changes, and/or unpredictable novelties that confront the teacher on a daily basis (Collie and Martin, 2016). Teacher adaptability fosters adaptive practice either in favor of knowledge transmission or generation. In all this, the teacher is expected to continually assess and gauge their instructional context by utilizing epistemic, social, semantic, and cultural tools to create a learning environment that fosters knowledge generation (Anthony et al., 2015; Mylopoulos et al., 2018). Therefore, adaptive expertise becomes the salient construct mediating both adaptability and adaptive practices.

The current study framed adaptive expertise of the case study teacher as one who was able to gauge and assess happenings in the classroom, unexpected changes that may crop up during instruction, and draw on epistemic, social, semantic, and cultural tools to leverage a learning environment type that fostered knowledge generation (Loughland, 2019; Parsons and Vaughn, 2016). While medium implementation score (MIS) and High implementation score (HIS) teachers exhibited mesial and high levels of adaptive expertise during implementation, LIS case study teachers continued to stick to "*routines*" and fixed curricula expectations of authorized (fixed curricula) knowledge written by experts. Belief systems held by case study teachers also impacted their abilities to be adaptive in their expertise. Case study teachers with rigid beliefs were less adaptive whereas case study teachers with flexible beliefs quite often showed strong adaptive expertise. Gosselin and Winstead (2012) reported the influence of teacher beliefs not only on the environment but also the teacher's cognitive, emotional…" and all the teacher decisions and activities that occur in the classroom that shape the climate for knowledge development (p. 199).

The belief systems held by teachers reflected their levels of adaptiveness and adaptability in the instructional climates. Study results and findings show that teachers who exhibited *firm epistemic beliefs* and theoretical orientations about knowing, and knowledge development were less adaptive in their instructional climate. In sharp contrast, teachers who exhibited *flexible epistemic beliefs* and theoretical orientations showed increased levels of adaptive expertise in their classrooms. It can therefore be argued that teachers' epistemic beliefs provided proxies for them to exhibit adaptiveness and adaptability or otherwise in their instruction.

Fluid epistemic beliefs holders and high implementers did not only show increased *student voice* but also allowed the fine use of epistemic tools—language, argument through negotiations, dialogue—for creating immersive learning environments. Utilization of these epistemic tools were similar and pronounced in medium and high implementation teachers. As a case in point, Mirabel's fluid epistemic beliefs regarding use of language as an epistemic tool (Hand and Prain, 2012; Fulmer et al., 2021) anchored her choice of detailing the diverse use of language in its multimodality (Hand, 2017; Hand et al., 2018).

Some studies have explored the interconnectedness of teacher flexibility, teacher identity, teacher personal orientation, and teacher personal practice theories—to which teacher beliefs could be inherently situated (Bowers et al., 2020; Männikkö and Husu, 2019). Activating prior knowledge and experiences during instruction draws on flexibility in orientations and the level of adaptive expertise of the teacher (Crawford et al., 2005; De Arment et al., 2013; Kua et al., 2021). Thus, flexibility in epistemic beliefs and theoretical orientations is a precursor to the extent to which prior knowledge and experiences are utilized (Barnett and Koslowski, 2002; Levin et al., 2013). For example, Levin and He (2008) note that teacher personal orientations–including (epistemic) beliefs impact their adaptiveness and expertise.

## 9 Conclusion

Consistent with one school of thought on teacher beliefs and classroom learning climates, all case study teachers exhibited some levels of association between epistemic beliefs and the learning environments. This school of thought—congruous thesis—posits that teachers' beliefs resultantly foster the establishment of a classroom learning environment type for knowledge development. Proponents of this argue that the epistemic beliefs held by a teacher congruently dictate the classroom learning environment type that gets established for knowledge development (Peterson et al., 2011; Rubie-Davies, 2014). The results of the current study help us to explain the variations and/or gradations of epistemic belief types held by case study teachers–rigid or fluid—which in turn, afford us the lens to characterize different learning environments, either replicative or generative, based on teachers' epistemic beliefs and theoretical orientations.

Findings from this qualitative multi-case design support previous research regarding how various identified epistemic beliefs and their contexts interact to shape a learning environment type (Pajares, 1992; Peterson et al., 2011; Leary and Tangney, 2011; Guerra and Wubbena, 2017). It also adds substantially to the research base by tracing the trajectory of the beliefs systems and theoretical orientations of elementary science teachers and the resulting impact of their established classroom practices and learning environment. Particularly, results provide us with the nuances of the specificities and peculiarities of belief types and their corresponding learning environment type(s).

That said, results also provide us with a broad understanding of the relationships between epistemic beliefs and implementation as well as the individual roles of different subscales of EOS and how each relates to teacher implementation. The secondary case study analysis provides deeper insight to better understand the nuances of the epistemic orientation for these 6 teachers across multiple contexts as a part of their overall beliefs–implementation.

*The study has several pertinent implications for educational policy, practice, and research*. Findings from this study suggest that policy makers and stakeholders both in teacher preparation and curriculum development could begin to consider teacher beliefs and attitudes as foundational underpinnings for framing future science standards. Given that, the foundational document that birthed the current NGSS standards proposes that, "in order to support implementation of the new standards and the curricula designed to achieve them, the initial preparation and professional development of teachers of science will need to change" (National Research Council, 2012, p. 255). This is consistent with Jones and Leagon (2014) when they suggested that "one of the powerful drawbacks that challenges the effectiveness of professional development is the failure to address teachers' attitudes and beliefs about their instructional practices" (p. 830).

Findings from this study show that teachers with low epistemic beliefs tend to be more restricted and/or are prescriptive about the environment, thus inhibiting the students' freedom of expression in the learning environments and vice-versa. These findings suggest that school administrators and teacher mentors need to heed to the beliefs systems and theoretical orientations of teachers that undergird the creation of a classroom climate type. Accordingly, teacher belief systems have an important role to play in teachers attempts at creating a needed instructional climate for knowledge development. In the context of teacher professional development and general practice, organizers of PDs should consider the epistemic beliefs and theoretical orientations of teachers when planning and/organizing teacher PDs.

Potential exists for future studies to adopt multi-perspective approaches to studying teacher implementation and its links to (teacher) beliefs and understanding. For example, previous research utilized student questionnaire data about the learning environment. The study conceptualized students as 3rd party participants for their study (Bae et al., 2021). The current study which also draws on teacher implementation scores to understanding epistemic beliefs and learning environments—also utilized data collected by a 3rd party observer, on-site teacher educators (Lammert et al., 2023a,b). Future research could adopt a multi-perspective approach to examine these variables and different datasets in synergy to unpack how their integration could play out in their findings.

Finally, future studies could explore teacher epistemic orientation using mixed method methodological procedures. It is suggested that future research could first explore, if indeed teacher belief systems and instructional practice belong to the "congruous thesis" scholarship (Fraser, 2012, p. 487) in a quantitative-qualitative explanatory sequential design fashion before selecting cases for deeper understanding. Along this line, future studies could test if EOS is indeed a predictor of the implementation of instructional practice in the classroom in a simple linear regression. Afterwards, future investigators could refine and deepen their understanding in similar case study designs.

### 9.1 Limitations of the study

Despite the study's strengths in methodological design, rigor in data collection methods and analytic procedures, and data triangulation, few issues could compromise the overall results and findings. One, a sample size of 6 participants, while sufficing fittingly for a multi-case study design, limits the results/findings, particularly from the standpoint of generalization, rendering the study results/findings to be more context bound—consistent with the one of the main rationales for qualitative research.

Two, the lack of diversity in our sample could impact the applicability of the results to different educational contexts or diverse populations. it must, however, be emphasized that, all participants in the larger NSF study were white, So, the identification and selection of the 6 white participants as case study respondents, was by default, a happenstance. Additionally, the midwestern state, from where majority of the participants for the original NSF study were drawn, is predominantly a white community, with about 84% of the total population identifying as white (U.S. Census Bureau, n.d), so the study's sample is consistent with the location itself.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

## Ethics statement

The studies involving humans were approved by Institutional Review Board (IRB), University of Iowa. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

EA: Data curation, Writing – review & editing, Writing – original draft. GF: Supervision, Validation, Writing – review & editing, Data curation, Funding acquisition. BH: Writing – review & editing, Data curation, Funding acquisition, Supervision. JS: Writing – review & editing, Data curation, Funding acquisition. GG: Writing – review & editing, Supervision.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

## Publisher's note



## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2025.1508207/full#supplementary-material

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