



Research paper

Is epistemic orientation the chicken or the egg in professional development for knowledge generation approaches?

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HIGHLIGHTS

- Epistemic orientation influences teachers' willingness to consider utilizing knowledge generation approaches.
- Following professional development, teachers' epistemic orientations and their teaching practices showed alignment.
- Teachers oriented toward knowledge replication did not often create generative learning environments.
- Teachers oriented toward knowledge generation often created generative learning environments.
- An interrelated relationship exists between epistemic orientation, professional development, and classroom practice.

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ABSTRACT

Professional development has been marginally successful at encouraging the knowledge generation approaches promoted in international education policy. To explore whether increased attention to teachers' epistemic orientations might suggest necessary innovations to existing professional development routines, an explanatory sequential mixed-methods analysis was conducted inside a three-year professional development program for in-service elementary science teachers in two U.S. states. Findings suggest that teachers' epistemic orientations influenced their willingness to engage with knowledge generation approaches, challenge teacher educators' claims, and implement knowledge generation approaches in their classrooms, indicating an interrelated relationship between these factors. Implications for professional development design and recruitment are discussed.

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1. Introduction

The days where teaching through knowledge replication was untroubled practice in science education are long gone. Today, science education research and initiatives (NGSS Lead States, 2013; NRC, 2011) have eclipsed their prior focus on hands-on engagement and have begun more deeply defining the value of scientific practices as the pursuit of knowledge generation (Hand et al., 2021; Miller et al., 2018; Tolmie et al., 2016). Knowledge generation approaches are defined as those that enable students to actively construct new knowledge in the sciences (Hand et al., 2021; Yaman, 2021). This differs from replicative learning approaches where

knowledge is static and predetermined by experts, leaving activity to only serve as entertainment. In order to generate knowledge, students must design and implement their own investigations, compare their ideas with one another, and learn to support their claims with the best available evidence as they consider different possible explanations for natural phenomena (NGSS Lead States, 2013). To those familiar with constructivist views of learning, classrooms that function as generative learning environments are recognizable by enthusiastic student engagement in social epistemic practices such as dialogue, critique and argumentation (Fiorella & Mayer, 2016; Stroupe, 2014).

For teachers, learning to rely on knowledge generation approaches and epistemic practices is as much about reorienting oneself toward an evolving view of knowledge as it is about learning new practices aligned with this view, which is obviously a monumental feat (Martin & Hand, 2009; McNeill et al., 2016; Schwarz et al., 2020). By definition, as an innovative approach,

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teachers are unlikely to have experienced knowledge generation approaches as students, so they have less schema for how they might operate (Lortie, 1975). Furthermore, many teachers may have existing classroom routines that are markedly different from those consistent with this type of teaching (Osborne et al., 2019). Thus, learning to embrace a knowledge generation approach means challenging current norms and disrupting practices teachers may believe to be effective, which means teacher educators must go beyond tips, tricks, and pedagogical strategies when providing professional development.

One influence on teachers' willingness to transcend the status quo and construct knowledge generation environments is their Epistemic Orientation (EO), defined as a combination of their orientation toward knowledge, how knowledge is generated, and the extent to which knowledge is settled or fluid (Chen et al., 2016; Suh et al., 2022). The benefits of having an EO that is calibrated with knowledge generation approaches is theorized to be twofold. First, an EO toward knowledge as fluid and evolving can support teachers in engaging with knowledge generation approaches inside professional development settings. In this way, an EO toward knowledge construction can help teachers as learners be better able to take on new ideas about teaching and consider them alongside previously held beliefs and past practice (Brownlee et al., 2017; Buehl & Fives, 2016). Second, when teachers' EO is consistent with a knowledge generation approach, teachers are better positioned to use epistemic tools (i.e., dialogue) in alignment with their pedagogical goals (i.e., knowledge construction) so they can witness the value of this approach for themselves in their teaching (Bråten et al., 2017). This can lead to cyclical and ongoing growth as teachers' EO enables them to reflect on and reflexively shift their teaching to become more aligned with new approaches (Feucht et al., 2017; Hardy & Melville, 2018), such as knowledge generation.

While the proposed relationship between EO and knowledge generation approaches presents possibilities for teacher learning, it is yet unclear whether shifts in EO drive or follow teacher learning, particularly related to knowledge generation environments, creating a chicken-or-the-egg problem for teacher educators. What is established is that the relationship between EO—or any other self-reported belief or view teachers hold—and their actual teaching practices is a complex one (Gholami et al., 2021; Pajares, 1992; Windschitl, 2002). Accordingly, a comparative case study (Yin, 2014) was conducted in the context of a three-year professional development program for in-service elementary science teachers in two U.S. States. Our research questions are:

How do teachers' EOs relate to their experiences in professional development centered on their use of knowledge generation approaches?

How do teachers' EOs relate to their practices and perspectives following professional development centered on their use of knowledge generation approaches?

2. Background

This study is located at the nexus of three elements: *NGSS Lead States* (2013) and *NRC* (2011)-promoted knowledge generation approaches and the challenges these approaches pose for teachers, the ways professional development may support teachers in overcoming these challenges, and the role(s) EO plays in that development.

2.1. Knowledge generation approaches

Knowledge generation approaches emphasize students as active sense-makers (Hand et al., 2021; Yaman, 2021). Lee et al. (2008) explain, "Only through the learner's self-generation of

relationships and understanding can knowledge be generated meaningfully" (p. 113). Teachers can support knowledge generation through the use of epistemic tools, defined as implements that facilitate knowledge production by making thinking visible (Boon & Van Baalen, 2019; Tang, 2020). In knowledge generation environments, language, dialogue, and argument are not separate routines (i.e., "today we will have dialogue from 10:15–10:30"). Rather, teachers who construct knowledge generation environments engage in the purposeful use of epistemic tools to drive students to engage in critical examinations of their own thinking (McNeill et al., 2016).

Three epistemic tools which are particularly relevant in knowledge generation environments are language, dialogue, and argument (see Hand et al., 2021). Foundationally, language permits learners to construct scientific explanations (Norris & Phillips, 2003), and science education scholars have long recognized that writing can serve not just to make prior learning apparent, but can be a space of knowledge generation itself (Martin & Hand, 2009; Sampson et al., 2013; Toulmin, 1958). Second, dialogue, the volley of ideas necessary for student engagement in conceptual scientific thinking, holds particular utility (Schwarz et al., 2020). In traditional science classrooms that serve as knowledge replication environments, student-to-student talk is rare (Moje et al., 2001) since it serves little purpose when the students' role is the passive reception of knowledge. However, dialogue serves as a key epistemic tool to permit active learning in knowledge generation environments. Finally, teachers in knowledge generation environments rely on argument for the purpose of supporting students in constructing arguments that answer questions with claims supported by evidence (Del Longo & Cisotto, 2014; Hand, 2009). Importantly, argument serves as a space for students to move between internal and external translation and representation of their ideas.

While in general, teachers' beliefs influence their likelihood of using knowledge generation approaches, teachers who claim to value participatory, dialogic learning do not actually teach in participatory ways all the time (Windschitl, 2002), owing to a range of constraints from mandated curriculum and assessment pressures, to lack of time and resources, to their own fears of change or confusion with the process. In addition, studies of dialogic approaches tend to focus on discrete pedagogies employed by teachers rather than uncovering the underlying mechanisms for learning (Asterhan & Schwarz, 2016; Wilkinson et al., 2015) or the ways teachers' own orientations toward knowledge influence this process (Bråten et al., 2017), so the foundational relationship between EO and the use of these epistemic tools is not well understood. Furthermore, the ways in which EO influences teachers' active uptake of new ideas through professional development, and the ways this uptake is extended through practice, has yet to be explored.

2.2. Epistemic orientation (EO)

EO, an emerging construct, is an orientation toward learning and knowing that individuals draw on as they engage with knowledge and knowledge development (Suh et al., 2022). Although EO has not yet been well explored, three related constructs have: teachers' epistemological theories (e.g., Hofer & Pintrich, 1997) their epistemic understanding (e.g., Ryu & Sandoval, 2012) and their epistemic beliefs (e.g., Guilfoyle et al., 2020). As an orientation, rather than a theory, understanding, or belief, EO functions differently by acting as a filter to new ideas individuals have based on their orientation toward knowledge. EO constitutes a cognitive guidance system (Suh et al., 2022) over which the individual has ultimate control. Furthermore, EO is

focused on the epistemic rather than the epistemological, so it is based on individuals' orientation toward knowledge itself, rather than their theory of knowledge development (Hand et al., 2021).

In related literature, teachers' personal epistemologies have been shown to be closely linked to their teaching goals and teaching practices (Brownlee et al., 2011; Tsai, 2006). For example, Rott (2020) showed that teachers who held instrumentalist views seemed to care more about results while teachers who held problem-solving views focused more on strategy use. Literature in this area demonstrates that "individuals may hold a range of beliefs that may or may not be aligned ... for example, an individual may simultaneously hold beliefs in the certainty of knowledge and yet also believe that knowledge is personally constructed" (Brownlee et al., 2011, p. 6). Notably, individuals' epistemic and epistemological beliefs are not necessarily cohesive and singular (Gholami et al., 2021).

While EO likely influences the teachers' practices, other scholars have begun to pursue a second relationship, between EO and teachers' capacity to learn to develop new tools to shift and meet their teaching goals (Feucht et al., 2017). This research suggests that in order for teachers to construct their own arguments amongst different discourses about teachers' work and take up a stance of reflective practitioner (Gholami et al., 2021; Lammert et al., 2020), a key step toward developing an EO aligned with knowledge generation, they must develop knowledge-in-action through the experience of navigating unexpected teaching situations, and an EO toward knowledge as fluid and evolving is supportive of this growth (Feucht et al., 2017; Zeichner & Liston, 2013). Feucht et al.'s (2017) work suggests that teachers whose EO is not aligned with the view that individuals can construct new knowledge for themselves are unlikely to approach novel problems in their teaching as opportunities to develop new understandings, or spaces to reconsider their teaching identity (Gholami et al., 2021) in the first place. This has the potential to contribute toward what Dewey (1938/1997) termed *mis-educative* experiences that limit teachers' future interpretations of new possibilities in their teaching. Taken as a whole, emerging scholarship suggests that teachers' views and understandings of knowledge play an important role in their teaching practices, and also, in the ways they engage in professional learning environments. However, whether growth in one necessarily precedes the other is yet unclear.

2.3. EOs' role in science teacher education

A recent study identified four sub-dimensions of EO that are required for constructing a knowledge generation environment in science education (Suh et al., 2022): (1) epistemic alignment, the alignment between teachers' beliefs regarding knowing, learning, and teaching (2) authority relations in learning, including understandings of the learner's role and control over new learning (3) belief whether the nature of knowledge is changeable or not, and (4) beliefs about students' ability to learn. Defining these dimensions is an important step forward, however, little is understood about how these elements of EO influence teachers' willingness to learn new approaches in professional development settings or how they intersect with their ability to use these approaches in their classrooms. In general, professional development efforts in science have been marginally successful at their intended goal of improved student learning borne out of teachers' improved practice, (Borko, 2004; Fukkink & Lont, 2007; Klein & Gomby, 2008; Yoon et al., 2007), but teachers often report that traditional professional development fails to meet their needs (Rotherham et al., 2008; Zhang et al., 2015). Many professional development experiences in science are inconsistent with the constructivist, inquiry-based teaching practices the professional development is

intended to promote (Rinke et al., 2019; Zhang et al., 2015). When the emphasis is on lesson planning and logistics, rather than conceptual growth, teachers are prevented from experiencing the process of learning through language, dialogue, and argument for themselves (Penuel et al., 2020). Accordingly, we undertook this research with the perspective that EO may influence the ways professional development can support teachers' development of knowledge generation environments and their use of language, dialogue, and argument to drive student learning. This is not to ignore the powerful role contextual factors have on teachers' understandings and practices, but to understand the ways EO influences teacher learning as it occurs in relation to these dynamic classroom spaces.

3. Methods

This report focuses on the first year of a three-year long professional development program on knowledge generation approaches experienced by 122 elementary science teachers spread across two U.S. states. The goal of this study was to answer the research questions:

How do teachers' EOs relate to their experiences in professional development centered on their use of knowledge generation approaches?

How do teachers' EOs relate to their practices and perspectives following professional development centered on their use of knowledge generation approaches?

To understand how teachers' epistemic orientation influences their experiences learning to construct knowledge generation environments, an explanatory sequential mixed-methods approach (Creswell, 2013) was selected to provide insights into individual teachers' growth and change while allowing us to explore group-level trends in EO and practice.

3.1. Context

An important aspect of contextualizing the findings of this study is understanding the professional development program with which teachers engaged. Following the recommendations of Ball and Cohen (1999) this program was designed to be consistent with the learning theory and practices which it was intended to promote; language, dialogue, and argument were used by professional development leaders as tools for teacher learning just as teachers were encouraged to use these epistemic tools in their respective teaching. The program began with a six-day in-person intensive summer institute that had three parts.

Days 1–2: Learning Theory: The use of language, dialogue, and argument as epistemic tools for learning "big ideas." In small groups, teachers wrote definitions for the terms "language," "dialogue," and "argument."

Days 3–4: Pedagogy: Approaches to creating knowledge generation environments.

Days 5–6: Planning: Daily and unit-level instructional planning and standards alignment.

The six-day professional development program functioned as a knowledge generation environment that emphasized the links between theory, pedagogy, and practice, and encouraged teachers' reflection and reflexivity (Feucht et al., 2017) about the alignment between these three aspects of their work. After teachers returned to their classrooms in the fall, they were additionally supported by a planned visit from a teaching consultant in which their teaching was observed and they discussed their challenges and successes with the approach, and they participated in two half-day workshop sessions, one per semester, during the following school year.

3.2. Data sources

Data sources include an EO survey (Suh et al., 2022), field observations, and individual interviews. These data were collected following the schedule in Table 1.

EO survey. The survey (Suh et al., 2022) consists of 44 items on a five-point Likert scale, with half of the items negatively worded to minimize response bias. The survey was designed following a literature review, multiple iterations of video-stimulated recall interviews (Calderhead, 1981), and expert reviews. Four sub-constructs of EO were represented: (A) epistemic alignment, (B) authority relations in learning, (C) the nature of knowledge, and (D) student ability. Epistemic alignment items were those such as “Students learn more by memorizing facts. Authority relations items were those such as “Teachers should serve as the primary source of knowledge in the classroom.” Nature of knowledge items were those such as “I believe scientific knowledge can be changed with time.” Student ability items were those such as “Only the bright students learn a certain level of science.” The survey was piloted with 232 in-service teachers, and multi-dimensional Rasch Modeling were utilized to establish content and structural validity evidence. The instrument’s reliability estimated by the Expected A Posteriori (EAP) was 0.67 and Cronbach’s alpha of the entire survey was 0.85 in the pilot study. With the current data set, the instrument had a satisfactory EAP and weighted mean likelihood estimation (WLE) reliability, which were .91 and .90, respectively (DeVellis, 2016). The Cronbach’s α of the entire survey was 0.89, which is also acceptable.

Field observations. Following the professional development, field observations were conducted once per semester with each of the 30 teachers. Field observations lasted between 30 and 60 min in length, and were scheduled in advance. Interviews were conducted by graduate students and post-docs who positioned themselves as observers-as-participants (Merriam, 2014) as they worked to understand the student experience in the classroom, as well as document the teachers’ decisions and actions. Observers were instructed to record written notes of classroom conversations and activities, and to take photos of relevant learning artifacts, such as anchor charts and worksheets. In addition, observers were instructed to attend to eight practices determined through prior research (Hand, 2009) to be common practices in knowledge generation environments: (1.) attention to the big ideas of science, (2.) the use of academic and everyday language, (3.) writing to learn, (4.), the presence of student voice, (5.) the use of small group structures, (6.), teacher questioning, (7.) the use of argument structures such as Question- Claim- Evidence, and (8.) student-to-student argumentation. In addition to general, open-ended field notes, observers noted whether each of these practices was present, and if so, wrote a detailed example of how it was conducted.

Individual interviews. All case study participants ($n = 30$) were interviewed twice; once after the four-day summer professional development, before the school year began, and once at the midpoint of the 2019/2020 school year. All interviews were semi-structured and conducted via video conference. Each lasted

between 20 and 45 min. Interviews were conducted by graduate students and post-docs.

The first interview focused on four dimensions: 1) change in epistemic orientation and knowledge bases about the epistemic tools, 2) comfort level with the key ideas of the approach, 3) confidence in using the approach, and 4) cognitive flexibility (freedom). In addition, as a way to evaluate the ways teachers with different EOs might have engaged in the workshops differently, all of the teachers were presented with their groups’ definitions of “language,” “dialogue,” and “argument” and asked to comment on whether they agreed with these statements.

The second interview, conducted at the midpoint of the 2019/2020 school year, had four sections: (a) learning and knowledge generation, broadly defined, and their use of (b) language, (c) dialogue, and (d) argument. In addition, participants were asked questions about their implementation of knowledge generation approaches based on the field observations that had been conducted (e.g., “I noticed your students writing in science notebooks. Can you tell me more about that?”

3.3. Participant selection

We selected 30 case study teachers using purposive sampling on the basis of their EO survey responses. The EO survey was administered prior to the start of the workshops, in summer of 2019, and 122 responses were collected. An equal percentile based visual binning technique was utilized to classify the participants into a more knowledge generation-oriented group (EO3, upper 25%), a less knowledge generation-oriented group (EO1, lower 25%), and moderately oriented group (EO2, middle 50%). To create the three binned groups, we used three cut points (25% each) and collapsed the two-middle groups into one (Table 2).

Of the 122 teachers who completed the survey, 30 were recruited after the summer workshop. Since we were interested in how EO relates to teachers’ experiences and practices, we recruited approximately equal groups of EO bin 1s, 2s, and 3s (Table 3). Participants were never informed of their EO bin classification, nor were the professional development providers. All participants received the same professional development.

3.4. Analysis

Our explanatory sequential mixed-methods analysis (Creswell, 2013) focused on exploring the extent to which teachers’ EO, as reported on the surveys, could help us understand their

Table 1
Data collection schedule.

Data Type	Quantitative	Qualitative			
Data Source	EO Survey	Individual Interview	Field Observation	Individual Interview	Field Observation
Time	Summer 2019, Before Professional Development	Summer 2019, After Professional Development	2019/2020 School Year, Semester 1	2019/2020 School Year, Midpoint, (Dec./Jan.)	2019/2020 School Year, Semester 2
Purpose	Determine teachers’ EO prior to professional development	Elicit reactions to professional development and changes in EO	Gather evidence of implementation	Elicit reactions to implementation and changes in EO	Gather evidence of implementation

Table 2
Summary of the visual binning analysis.

Binned group	Mean	N	Std. Deviation
EO1	156.32	31	5.237
EO2	172.63	62	5.499
EO3	190.97	29	5.635
Total	172.84	122	13.344

Table 3
Summary of participants.

EO Binary	Number of Participants	Gender Identity ^a	Race/Ethnicity ^a	Language ^a	Location ^a
1: Least aligned with knowledge generation	9	1 man, 8 women	9 White/non-Hispanic	9 Monolingual (English)	6 Midwest, 3 Southeast
2: Moderate/inconsistently aligned with knowledge generation	11	11 women	10 White/non-Hispanic, 1 Declined to report	1 Bilingual (English/Spanish), 10 Monolingual (English)	9 Midwest, 2 Southeast
3: Most aligned with knowledge generation	10	10 women	1 Black/African American, 7 White/non-Hispanic, 2 Declined to report	1 Bilingual (English/Spanish), 7 Monolingual (English), 2 Declined to report	5 Midwest, 5 Southeast

^a All demographic information is self-reported.

engagement in the workshops, their observed classroom practices, and the perspectives they shared through interviews. First, quantitative analysis informed case selection and the grouping of teachers into EOS bins 1, 2 and 3. Then, qualitative analysis began by unitizing and coding interview transcripts into four a priori codes (Rubin & Rubin, 2011) aligned with the research focus: (A) learning, (B) language, (C) dialogue, and (D) argument. At this stage, data reduction focused on eliminating aspects of the interviews that were social (i.e., greetings between interviewer and interviewee) or focused on other aspects of teaching (i.e., discussion of changes to school schedules). Then, the data in each code were organized based on teachers' EO binary score from 1 to 3 so that teachers' views of (A) learning, (B) language, (C) dialogue, and (D) argument could be explored within each EO level. A second round of analysis focused on the way participants defined each construct, whether they viewed it as an epistemic tool, and whether they were able to provide examples of how it might work with specificity.

Finally, these data were triangulated with the observational field notes collected in these teachers' classrooms to explore the ways their practices were aligned and not aligned with their views. Data from both field observations conducted of each participant were coded using the same categories as the interviews: (A) learning, (B) language, (C) dialogue, and (D) argument. To do so, the eight practices of the classroom learning environment noted in observations were organized based on their corresponding a priori code. For example, "1. Big Ideas" as observed in the field notes was coded as part of "Learning," as seen in Table 4.

Since the purpose of this analysis was to explore trends between and across teachers of different EOs a final round of comparative case study analysis (Yin, 2014) focused on the identification of patterns within and between each group. Following Rubin and Rubin (2011), attention was given to common teaching experiences (i.e., difficulty giving up control of the learning environment) that were reported by multiple teachers or that teachers reported in a recurring manner across interviews; experiences that were

unique to individuals within each category were also noted. Findings are presented by code: (A) Learning, (B) Language, (C) Dialogue, and (D) Argument, with all data integrated within each section, and organized in increasing EO within each code to high-light trends.

4. Results

First, a summary of results is presented in Table 5. Then, these findings are expanded.

Results are organized around the codes (A) Learning, (B) Language, (C) Dialogue, and (D) Argument with the corresponding observed practices (Table 4) noted throughout. Within each category, results are presented separately for teachers at EO One, Two, and Three.

4.1. Learning

EO one. Following the workshops, all nine teachers at EO One explained that they were still working toward agreement with the view of learning presented. Many described that they were beginning to "allow" (LD; Teacher initials used throughout) students to control their own learning. One mentioned that she was learning to "help [students] use their own background to go forward" (KD).

Classroom observation emphasized: (1) Big ideas. Six of these nine teachers posted big ideas in their classrooms and referenced them in ways consistent with the approach proposed in the professional development, while one posted them in the form of a question, one posted all of the big ideas for the year on a chart that was never referenced, and one did not use big ideas at all.

EO two. Of the eleven teachers at EO Two, two specifically said the view of learning presented in the workshops was not new to them, and two others explained that they had always believed students needed to "try out and play" (JoM) with ideas to make

Table 4
Coding structure.

A Priori Codes	A Priori Observation Elements	Grounded Observation Sub-Elements	A Priori Interview Elements
Learning	(1.) Big Ideas	(A) Were Big Ideas posted on the wall? (B) Were Big Ideas written in student language? (C) Were Big Ideas used to anchor dialogue?	(A) Definition (B) Relationship between Learning and Teaching
Language	(2.) Academic and Everyday Language Use (3.) Writing to Learn	(A) Was everyday language permitted and/or encouraged? (B) Was writing to learn permitted and/or encouraged?	(A) Definition (B) Use as an Epistemic Tool
Dialogue	(4.) Student Voice (5.) Group Structures (6.) Teacher Questioning	(A) Was teacher-to-student dialogue permitted and/or encouraged? (B) Was student-to-student dialogue permitted and/or encouraged? (C) Who asked questions?	(A) Definition (B) Use as an Epistemic Tool
Argument	(7.) Argument Structures (8.) Student Argumentation	(A) Were students observed using questions, claims, and evidence as structures for dialogue (B) Were students observed using questions, claims, and evidence as structures for writing?	(A) Definition (B) Use as an Epistemic Tool

Table 5
Summary of findings: Patterns of teaching between EO levels.

Code	EO 1 Oriented toward Knowledge Replication	EO 2 Moderately/Inconsistently Oriented Knowledge Generation	EO 3 Oriented toward Knowledge Generation
Learning	Attempted to control student learning; Inconsistently used big ideas	Unclear views of learning; Consistently used big ideas, but not effectively	Understood that students controlled their own learning; Used big ideas effectively
Language	Used teacher- structured writing (e.g., templates); less negotiation of scientific vocabulary	Valued writing but struggled with district-provided curriculum; some negotiation of scientific vocabulary	Used student- structured writing (e.g., reflecting); more negotiation of scientific vocabulary
Dialogue	Teacher-centered dialogue; Teachers' questions drove conversation	Mixture of teacher-centered and student-centered dialogue	Student-centered dialogue; Students' questions drove conversation
Argument	Rarely used argument; Focused on students not offending peers	Rarely used argument; Focused on argument as a battle between ideas	Sometimes used argument; Focused on students' use of claim and evidence

sense of them, but they did not know whether this view was consistent with science education research. One emphasized that adults and children learn similarly (CC), while another explained that “learning is not the same for everyone” (GJ). One explained that her biggest take-away from the workshops was that she needed to allow her students to “fail” more, and “try and figure out what went wrong” (KL).

All eleven of the teachers at EO Two posted big ideas in their classrooms and referenced them at some point during their teaching, but some (e.g., AR) just read the big idea aloud and did not integrate it into the content of the lesson any further. One (GJ) referenced the big idea repeatedly throughout a lesson on genetics as her students viewed photos of different colored puppies and were asked what questions they wanted to investigate about the dogs' parentage.

EO three. The ten teachers at EO Three did not express any disagreement with the view of learning proposed in the workshops, and two responses explained that the workshops were “confirmation” (KaB) of their views that gave them permission to teach in ways consistent with knowledge generation approaches. “In some ways I always knew I learned better by doing and participating, but yet that's not really how I was taught and it's not necessarily how I've always been teaching in the past” (DK) one explained.

Observations revealed that these teachers all posted big ideas in their classrooms and used them in various ways throughout their teaching. One referenced the big idea only once (TrL) while most reminded students to “dive into it” (JoB) repeatedly.

Summary. Overall, none of the thirty teachers expressed outright disagreement with the view of learning presented in the workshops, but teachers at EO One tended to suggest they were still hesitant to allow their students to have control over their learning, while those at EO Two and Three tended to recognize that students already have control over their ideas regardless of what a teacher might allow or disallow. Instead, teachers at EO Two and Three were focused on building curricular structures and routines, such as the use of big ideas, that would allow them to maximize the utility of the approach.

4.2. Language

EO one. When asked about their use of language in teaching science, six of the nine teachers at EO One were able to explain the value of their students writing regularly in the science classroom. Three struggled to provide a definition of language and explained that this topic was confusing for them. Of the six who talked about writing, just two teachers described language as an idea generation tool, while four described writing to communicate what one already knows.

Classroom observations focused on: (2) academic and everyday language, and (3) writing-to-learn. Six of the nine teachers at EO

One were observed using writing in their teaching, although four relied on pre-made templates/graphic organizers, and one's use of writing was limited to copying definitions off the board. Just three teachers at EO One encouraged their students to relate everyday and academic language. One explained that appropriate terminology is context-dependent and argued that it all depends on “What you want them to use the language for” (SD).

EO two. When asked about their use of language in science teaching, nine of eleven teachers at EO Two mentioned writing, and six of these nine teachers also explained that language use could include multimodal representations. Four of the nine teachers who talked about writing described it as a tool for learning through “interpretation and comparing ideas” (Lis), while just one defined it as a space for “describing” (JeS). When asked whether they agreed with their group's definition of language, three confessed they were still confused, three simply said they agreed with their group's definition, and five elaborated the position that language was foundational to learning science.

In observations, five of these eleven teachers talked about the movement from everyday to academic language. One described frustration with the curriculum adopted by her district, which encouraged teachers to pre-teach scientific vocabulary before investigations began, saying, “sometimes we have no choice but to use certain vocabulary or language with the students, and it just doesn't make sense” (AR). This teacher was observed prioritizing vocabulary memorization.

EO three. All ten teachers at EO Three talked about language use as involving writing, and six also described additional modes of language. One teacher (DV) said she disagreed with her group's definition of language, but was not clear how; the remaining nine said they agreed. These ten teachers explained that language had many purposes, including allowing opinions to be shared, to document thinking and explain ideas, and as a tool to learn new ideas. Only one of these ten teachers mentioned students' movement from everyday to academic language (TL).

When observed, these teachers tended to permit and even encourage students to use everyday language to describe scientific phenomenon. For example, as her students conducted an investigation on water vapor, one teacher (DK) praised her students for making the observation that “The drops are hard to see ... its moisty.” without taking the opportunity to suggest more precise terminology (i.e., droplets, condensation). One explained that using language is simply “How I teach ... I mean, we talk, and we write, and they have ownership with their science journals” (SC).

Summary. In general, following the workshops, the majority of teachers expressed the view that student language, and writing in particular, is worth inviting into their classrooms. However, teachers at EO Two and Three tended to describe a broader range of modalities of language, and they were more likely to view writing as a tool for new learning than a way to report what has already been learned. The teachers at EO Two were the most concerned

with relating everyday and academic language, and they expressed various challenges with this process, whereas teachers at EO One rarely provided specific ideas about this topic at all, and teachers at EO Three were more confident in supporting their students' everyday language use. Teachers at higher EO levels tended to add more to their groups' definitions of language, even going so far as to argue against them in one case.

4.3. Dialogue

EO one. When asked about their use of dialogue in science teaching, all nine teachers at EO One were able to define dialogue as a conversational space in which to explore ideas, and six of these teachers added several ideas to their group's definitions. Five teachers described dialogue tentatively, as something new that they were attempting more often, while two teachers expressed discomfort with using dialogue, and two others reported they were very confident in dialogic teaching.

Observations focused on: (4) Student voice, (5) Group structures, and (6) Teacher questioning. These nine teachers were observed often asking questions that reviewed previous lessons (i.e., "Who remembers what we did last time?" (AT) or required factual recall (i.e., "What are the five senses?" (KB). Seven of these teachers were observed engaging their students in some type of partner or small group learning, and in doing so, two teachers emphasized the importance of listening in dialogue.

EO two. The eleven teachers at EO Two defined dialogue in a broader range of ways than those at EO One. Dialogue was described as a "dynamic" (BW) process of comparing ideas and "exploring" (Lis) alternatives. Rather than describing dialogue as something they were generally trying to do more often, these eleven teachers described being more selective about when to engage students in conversation.

In observations, these teachers shifted often between whole group, small group, partner, and individual work. Just one explained that dialogue was "always" happening (TB) while five explained that self-talk and personal moments to think independently are important. These teachers asked some review and factual recall questions, but they were also observed attempting abstract, open-ended questions (i.e., "Can you think of a time that you have ever seen sound?" (AR) and promoting student-to-student dialogue through the use of small group and partner structures. Just one teacher emphasized the importance of listening to her students.

EO three. All ten teachers at EO Three were able to define dialogue and describe how they use it in their teaching and agreed with their groups' definitions. These teachers provided extended responses about shifts in their confidence to use dialogue. One explained that following the workshops, she "started not so confident, and then I have worked my way up to, 'it's okay to sit here and not know necessarily what it is we're talking about' (TaL). Two teachers talked strategically about waiting for discussion to evolve. Three explained that they did not feel their students were developmentally capable of engaging in dialogue, while one emphasized that dialogue was important since students have different background knowledge and experiences.

These teachers were observed using a wide range of question types, as well as prompting students to share their thinking with one another, (i.e., "What do you guys think?" (JB), soliciting and recording students' questions, and moving between small and whole group structures several times within lessons. No teachers at EO Three mentioned listening, but three mentioned that dialogue reveals to them the lack of control they have over students' ideas.

Summary. Generally, teachers left the workshops with an understanding that classroom conversations matter, but they varied

in their understandings of their role in shaping them. Teachers at EO Three tended to report more specific challenges with dialogue, whereas teachers at EO Two and One were less specific about the process. While teachers at lower EO levels tended to emphasize that students need to listen during dialogue, suggesting more of an orientation toward passive knowledge reception, those at higher EO levels noted that dialogue reveals that students can always decide for themselves which ideas they find most convincing.

4.4. Argument

EO one. Of the nine teachers at EO One, six explained that argument is a process of sharing opinions, going back and forth, translating ideas, and explaining ones' beliefs, while three were unable to provide a definition on their own. When asked if they agreed with the definitions their groups constructed, all responses were affirmative. Two teachers specifically explained that argument was new to them and difficult for them as teachers, but one explained she thought it was important for students to have a voice (EW), while the other stated "I always try to get different points in our ideas from kids before we move on just to kind of get them thinking a little bit. But right now, that's kind of a struggle for me" (KB).

Observations emphasized: (7) Argument structures, and (8) Student argumentation. Seven of the nine teachers did not use argument in any form. These teachers explained that the difficulty with argument was that students were not able to engage in it effectively or respectfully. They talked about making sure debates were done "in a friendly way" (SHS) and "civil" (SJ). Teachers at EO One were observed asking students "Why?" (AnT) and pushing them to explain their reasoning, but only one (KD) used the specific framework of questions, claims, and evidence.

EO two. The eleven teachers at EO Two tended to describe argument as a process of agreeing and disagreeing with others, and all eleven agreed with the definition their groups constructed during the workshops. Six also elaborated and specifically explained that the purpose of argument was for students' ideas to be contrasted, and/or they stated it is possible for ideas to shift during argumentation. Although two teachers mentioned the importance of removing emotion from argument and being respectful, other teachers at EO Two described argument using war metaphors like, "battling it out" (JeL).

In observations, one teacher used the motto, "Strengthen your argument, strengthen your partner" (Lis) as she encouraged student argumentation. Four teachers mentioned the question, claim, and evidence structure. Four of these teachers were observed using the language of questions, claims, and evidence. Three of these teachers found it helpful, while one (JeL) critiqued the language as confusing for students. For example, while students collected data, one teacher reminded them to "anticipate needing to make a claim" (BW) as they decided what to attend to.

EO three. While seven teachers agreed, three of the ten teachers at EO Three challenged the way argument was presented in the workshops. One explained, "With those guidelines about being respectful, and nothing's personal ... that's just not how they are, not how society is. We take everything so personally" (DK). Another stated that she disagreed that argument must be done respectfully, since to her, whether or not an argument included an emotional appeal would not change its quality, but she agreed that "if you don't change your thinking, you're probably not learning" (LaS).

In practice, six of these ten teachers very directly connected argument and learning, and they saw argument as "The way" (JH) learning works. Three of these teachers were observed using the structure of questions, claims, and evidence, and two additional teachers used small group work situations in which they

encouraged students to compare their ideas and reasoning with one another.

Summary. Overall, argumentation was a challenge for most teachers. Interestingly, the teachers at EO Three resisted the definition provided in the workshops more than those at EO Two or One. Teachers at EO One tended to be more concerned with creating an atmosphere in which argument could be used respectfully, whereas teachers at EO Two and Three were more concerned with the utility of argument for learning.

5. Discussion

When we began this research by asking how teachers' EOs relate to their practices, perspectives, and experiences in professional development for knowledge generation approaches, we wondered whether EO was the input or output that makes professional learning happen. Our analysis revealed that EO is likely *both* the chicken and the egg in professional development; initial EO influences what teachers choose to learn, but EO also influences what teachers choose to enact in practice, which shapes their potential for the reflexivity (Feucht et al., 2017) needed to construct new understandings.

5.1. Implications for professional development design

Throughout this analysis, we noted that the professional development leaders were unaware of the individual teachers' EO scores. We certainly did not design three different sets of workshops to meet the distinct needs of teachers at EOs 1, 2, and 3, nor would we recommend this type of differentiation to others. Instead, we found it was essential that teachers engaged in a collective inquiry with peers who were oriented differently than they were, which allowed different perspectives to be shared through dialogue. In this study, whether a teacher had an EO that was minimally or tightly calibrated toward a knowledge generation approach, they received the same supports, participated in the same discussions, and completed the same curricular planning, but they did so amongst a community of colleagues who were invited to see the value of epistemic tools as they used language, engaged in dialogue, and argued with one another. This suggests that when moving toward the knowledge generation approaches promoted in science education policy (NGSS Lead States, 2013) teacher educators' challenge is not one of how best to differentiate based on EO, but how best to create a dialogic environment in which teachers who hold different EOs are made comfortable sharing, comparing, and challenging them with others. One unanswered question to be addressed by future research is whether continued engagement in these dialogues would shift all teachers' EO over time.

Notably, this type of dialogic learning environment is very different from what is typically found in the professional development teachers are provided, which is typically devoid of theory and focused on tips and tricks (Rinke et al., 2019; Rotherham et al., 2008; Zhang et al., 2015). Furthermore, the pedagogically productive conversations this approach requires of teachers are drastically different from what typically occurs between educators (Lefstein et al., 2020) who regularly use talk for social purposes or to express frustration with challenges rather than to be vulnerable and engaged in shared reflection with others. However, we note that this rarely used approach was highly effective; virtually all of the teachers, regardless of EO, reported that the workshops led to shifts in their understandings about teaching and learning and growth in their instructional practices. While much of the learning was universal, what varied was the ways teachers' EOs intersected with and disconnected from the content and approach promoted during the workshops.

5.2. Implications for professional development experiences

Prior research indicates that EO can change in relation to new experiences, although the individual retains ultimate control over their own EO (Hand et al., 2018). Based on the current study, it is readily apparent that alignment between EO and knowledge generation approaches is supportive of teacher learning toward implementing knowledge generation approaches in classrooms. We found it somewhat unremarkable that teachers whose EO was most aligned with knowledge generation made statements in favor of knowledge generation when asked to define learning approaches in the workshops. What surprised us was that teachers aligned with knowledge generation views were also more likely to argue back against the definitions of epistemic tools that their groups constructed even though these epistemic tools are particularly useful in the learning environments they intended to create. This suggests that teachers with an EO toward knowledge generation approached the workshops with an openness to knowledge as unfolding, a healthy skepticism, and a willingness to construct new ideas (even if they were not always the ideas professional development leaders hoped they would take on). Again, professional development leaders relied on dialogue as epistemic tool to support teacher learning and created contexts in which participants could envision the utility of their definitions in practice. This suggests an opening for further research on teachers' epistemic agency. More fully understanding the experiences with the greatest likelihood to shift teachers toward an EO aligned with a knowledge generation approach is crucial in supporting future efforts toward teacher learning.

5.3. Implications for professional development recruitment

In addition, this study has direct implications for professional development recruitment efforts. As the field moves toward generative learning (NRC, 2011), particularly in science education (NGSS Lead States, 2013) there is a need for professional development intended to make a substantive shift in teachers' thinking rather than simply provide resources and strategies aligned with teachers' existing views. However, if EO is the "egg," this raises questions about the likelihood of teachers with an EO toward knowledge replication seeking out, actively engaging in, and growing through professional development focused on knowledge generation. Particularly as schools are governed by building-level, district, state, and national policies that mandate teachers' adherence to curricular standards and use of particular products, textbooks, and assessments, teachers may seek out professional development experiences that are aligned with current school norms, rather than those requiring innovation. Here, we note that encouraging teachers' deep engagement with learning theory, and supporting their epistemic metacognition (Tang, 2020) may be of value for teachers who are willing to shift their own thinking. Dialogue on epistemic beliefs of this type can invite cognitive conflict, but when not examined more closely, it can also confirm existing beliefs, which suggests it must be carefully structured by professional development providers.

We also recognize the valuable role administrators play in determining the types of professional development offerings teachers can access. While it is unlikely that teachers oriented toward knowledge replication would seek out professional development on knowledge generation if they were not encouraged to do so by those in positions of power, experiences that challenge their thinking are precisely those that could benefit their approach to teaching. One contextual constraint that was well-observed in this study was the preponderance of scripted curricular materials provided to teachers who had little prior experience teaching science;

although many had asked administrators for resources, the structured nature of these products clashed with approaches that center knowledge generation, causing further tension. When teachers seek out professional learning experiences aligned with knowledge generation approaches, it is imperative that they share these ideas with administrators about what resources support this teaching. Together, teachers and administrators must find agreement on what an ideal classroom should look and sound like, particularly given the evaluative role administrators hold. Our upcoming work will explore the ways coaches, principals, and other administrators can be brought into the fold of professional development for knowledge generation approaches for the purpose of creating even further alignment between their goals and teachers' goals.

5.4. Implications furthering theories of EO

It is evident that as the “egg,” teachers' EO plays an important role in their willingness to reconsider their teaching practices inside a knowledge generation view, and as the “chicken,” teachers' practice is shaped by the EOs they hold. Since we conducted this study with in-service teachers, we cannot say how EO may have been shaped by preservice experiences that occurred even before this professional development took place. Still, we note that individual differences suggest that factors in addition to EO were still at play. Consistent with prior studies (Hand et al., 2018), within groups of teachers at every EO level, teachers' trajectories differed; some quickly saw the workshops as confirming what they already knew to be true, while others maintained a slow, hesitant pace throughout the workshop days and subsequent months. We believe both experiences are equally valid.

Teachers need experiences trying out knowledge generation approaches as much as they need experiences that challenge them to consider new possibilities; however, some of the teachers in this study were restricted in the extent to which they were able to implement the approach promoted by the workshops due to school policy, curriculum, and assessment. Many of these teachers taught in settings where a particular number of instructional minutes were dedicated to the daily literacy block, but no minutes were prescribed for science, enabling it to fall between the cracks of the calendar. In these cases, there seemed to be a compounding of contextual and conceptual challenges that slowed the learning process. Encouraging the prescription of minutes for science would be a reactionary approach; instead, more needs to be done to educate those with policy-making authority about the purposeful literacy learning that can be embedded in science teaching and the limitations of siloed curriculum. In other settings, teachers had the freedom to fully enact new approaches, and as they used professional development spaces to reflect on this learning, their growth seemed to accelerate. Thus, this work has also revealed yet again that one's view of learning is foundational to one's view of teaching, but, owing to a range of contextual constraints (Windschitl, 2002), individuals are not always consistent in the way we align the two. Additional study can more closely reveal the particular curricular and policy-related challenges that teachers face and the ways EO can serve to help them overcome those challenges.

5.5. Disciplinary implications and necessary future research

Lastly, important conclusions can be drawn from this work specific to the discipline of science and in relation to professional development intended to emphasize the use of epistemic tools such as language, dialogue, and argument for teaching. It is

important to make sense of these findings within the disciplinary context, since the use of epistemic tools and EO are both connected to ones' view of learning, and ones' view of learning is related to ones' willingness to use knowledge generation approaches for teaching science. However, the work of other disciplines, such as social studies, math, and the English Language Arts, can equally be informed by notions of knowledge generation (NRC, 2011). Ongoing longitudinal study across disciplines is required to understand the specific features of professional learning that need to be adapted to engage teachers' shifting EOs in these areas. Still, this study represents a valuable first step in exploring the ways teachers' varying incoming EOs leads to different outcomes as they engage in professional development experiences. The twofold role EO plays in both the ways teachers engage in learning, and the ways teachers create learning experiences for their students, suggest the construct of EO is far more important than one would assume based on how little research about it exists, particularly across disciplines outside of science. In this study, which represents an important step forward toward defining the professional learning needed for knowledge generation, EO served as a foundational construct to understand teachers' knowledge and practices for teaching science.

5.6. Limitations

As a qualitative comparative case study, the findings of this research are bounded to its participants, who largely match the predominantly white, monolingual, and female elementary teacher workforce in the US (National Center for Education Statistics, 2018). This is particularly relevant to the constructs under study in this research since the approach promoted through the professional development series was rooted in language-based science teaching, and factors such as socioeconomic status, race and gender are closely related to the varieties of English used by teachers (Lippi-Green, 2012). In addition, these findings are based on data collected from just two scheduled observations of teaching per participant, which may have been influenced by the presence of an observer (Berger et al., 2018). However, one strength of this study design is its use of multiple sites across two US regions, its relatively large sample size ($n = 30$) for a case study design (Yin, 2014), and its use of multiple data sources (e.g., surveys, observations, and interviews) to triangulate findings. Further research that explores the relationship between EO and professional learning in new locations and contexts, with a more diverse group of teachers, and involving more extensive classroom observation would likely reveal new insights.

6. Conclusions

This research asked how teachers' EOs relate to their experiences in professional development centered on the use of knowledge generation approaches. In examining the experiences of thirty educators in a professional development series focused on science teaching, this study revealed a twofold role EO can play: first, in shaping teachers' interest and willingness to learn new approaches, and second, in shaping the ways these approaches are manifested and refined through teachers' practice. The findings from this study suggest that teachers who entered professional development with different EOs engaged with the content of the workshops differently, and their learning unfolded in distinct ways in their classroom practices as they reflexively reconsidered their views of teaching and learning.

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