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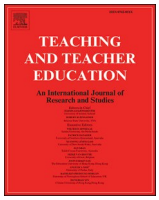

Research paper

Unpacking teachers' orientations toward a knowledge generation approach: Do we need to go beyond epistemology?

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ABSTRACT

This study aimed to assess the effectiveness of a professional development program rooted in knowledge generation theory. Specifically, it sought to examine the changes in teachers' three orientations following the completion of the first-year workshop, and how these changes impacted their classroom implementation. This investigation takes the form of a multiple-case study of twelve K-5 teachers. Data were collected through semi-structured interviews and classroom observations. The findings suggest that achieving changes toward generative learning in teachers is not just about altering their epistemological orientations and procedural pedagogical practices, but also involves a shift towards ontological and axiological perspectives.

1. Introduction

Creating knowledge generation environments is an important goal addressed in the new vision of recent science education reforms (NGSS Lead States, 2013). Unlike traditional replicative environments, knowledge generation environments require the development and use of epistemic tools (i.e., argument, dialogue, and language) to generate disciplinary knowledge and engage in scientific processes (Hand et al., 2021). However, teachers' development and use of epistemic tools in science classrooms is not straightforward and needs effective professional development (PD) for a successful shift towards use of knowledge generation environments (Bae et al., 2022).

To prepare teachers for utilizing epistemic tools in the classrooms, the science education field has placed much emphasis on epistemological shift and development of teachers. Several studies have argued that teachers' epistemological beliefs affect their implementation of pedagogical approaches (Brownlee & Berthelsen, 2006; Rott, 2020; Sengul et al., 2020). On the other hand, Packer and Goicoechea (2000) argue that learning needs to go beyond epistemological transformation. Olafson et al. (2010) further suggest that teachers' ontological view of learning is also a critical factor in helping the shift from traditional replicative environments to implementing knowledge generation environments. While epistemology focuses on people's beliefs "about the origin and acquisition of knowledge", ontology focuses on "the beliefs about the nature of reality and being" (Schraw, 2013, p. 1). These two philosophical orientations reflect how teachers conceptualize their teaching (Kelly, 2020). We argue that this perspective needs to address the epistemic practices that teachers implement. Such a fundamental shift would also need to address what teachers value as being important in implementing knowledge generation environments, which is axiology. Laudan (1984) defines axiology as aims underlying a specific approach to science and concepts that represent values. The importance of such an orientation is framed around the concept that when teachers value the nature of the particular approach, they begin to make substantial shifts in their orientation (Biesta, 2015).

Helping teachers shift these interconnected but distinctive orientations requires intentionally designed PDs. Studies over the past two decades have provided important information on the core features of effective PD (Darling-Hammond et al., 2017; Desimone, 2009). Although not every empirical study includes the same features, there is widespread use of common characteristics of PD models: content focus, active learning, coherence, duration, and collective participation (Desimone, 2009). In her proposed conceptual framework, Desimone (2009) argues that teachers who experience effective PD would likely increase their knowledge and skills and/or change their attitudes and beliefs, improve their approach to pedagogy, and these changes foster increased student learning.

When it comes to the factors that determine the succeed of a PD, successful PDs should aim to promote sustainable changes in teachers' epistemic orientations through immersive learning opportunities (Kelly,

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2011) while unsuccessful PDs typically focus on the replication of knowledge and tends to be isolated from classroom practices (Buczynski & Hansen, 2010). This requires a focus beyond beliefs related to teaching and needs to engage with teachers' ideas related to learning (Roehrig & Kruse, 2005). By necessity, the PD needs to be long-term and persistent (Boyle et al., 2004) given that there will be emerging pedagogical concerns as teachers adapt to implementing new learning environments within their classrooms (Zimmerman, 2006).

As an initial step to understand the impact of a long-term and immersive PD framed around knowledge generation theory, this study examines teachers' changes in epistemological, axiological, and ontological orientations after the first year PD workshops and how the development of each orientation plays a role in their later classroom implementation. The aim of this study was to explore the development of teachers' epistemological, axiological, and ontological views and how these changes are related to their transition to implementing generative learning environments. We asked: (1) How do teachers' epistemological, axiological, and ontological views change throughout the first year of a professional development? (2) How do these changes affect teachers' implementation in knowledge generation environments?

1.1. Knowledge generation environments

The term generative learning was coined by Wittrock (1974). Osborne and Wittrock (1985) defined the generative learning model as central to the constructivist tradition and influenced by cognitive psychology. The generative learning model emphasizes that the learner is not a passive recipient of information. Indeed, generative learning highlights active participation in the learning process and considers generating a meaningful understanding of information found in the environment (Grabowski, 2004). As generative learning is fundamentally based on the connections between learners' prior knowledge and new knowledge (Wittrock, 1974), it frames teaching as guiding learners through their generative processes to critique and construct ideas. To this end, Osborne and Wittrock (1985) defined the purposes of this generative learning model as "focusing thinking and encouraging discussion" (p.64).

The translation of the generative learning theory into an instructional approach has been subject to misinterpretation in various studies, often resulting in the misconception that the theory prescribes a fixed set of instructional guidelines or models (Mayer, 2009). However, in order to fully comprehend the essence of the generative learning theory, an instructional approach should highlight the importance of teachers cultivating foundational orientations and resources that enable them to navigate the complexities inherent in generative learning environments. This means a knowledge generation instructional approach should diverge from a rigid adherence to prescribed instructional practices. Accordingly, this study aimed to investigate how teachers develop these fundamental orientations and explore the ways in which these orientations shape their instructional practices, rather than focusing on the acquisition of a predetermined set of pedagogical practices.

The generative learning model frames learning as knowledge construction (Mayer, 2010). Students are encouraged to negotiate prior knowledge and new ideas by using multiple modal representations, generating their test questions and creating suitable test designs to gather data, and justifying their claims based on evidence (Hand et al., 2019). Teachers can create generative learning environments by using epistemic tools (Tang, 2020) such as language, dialogue, and argument (Hand et al., 2021). It is worth noting that recent science reforms emphasize these tools for science learning, stating that students must participate in scientific communication practices that involve dialogue and negotiation (National Research Council [NRC], 2012). NRC framework states that "Every science or engineering lesson is in part a language lesson …" (NRC, 2012, p. 76).

The use of language as an epistemic tool provides opportunities for students to explain their views, challenge each other's ideas, and improve their scientific discourse (Schoerning et al., 2015). Cavagnetto (2010) argues that "language plays a central role in scientific practice (and therefore scientific literacy) because it requires and develops abilities such as metacognition and critical reasoning" (p.337). Norris and Phillips (2003) argue that language is fundamental to doing science, that is, you cannot do or learn without language. Science, much like any other field, is a product of human endeavor. Our means of interacting with it are limited to language-based tools such as text, diagrams, graphs, and equations (see Lemke, 1990). Without the use of language, we cannot fully comprehend and participate in the study of science. Second, creating productive dialogic interactions is a key pedagogical tool in generative science classrooms that improves students' cognitive skills (Kuhn & Crowell, 2011), and critical thinking (Schwarz & Baker, 2016), and promotes deeper learning (Nussbaum, 2011). Third, argument as an epistemic tool provides students with opportunities to convince themselves about the strength of a particular claim (Fiorella & Mayer, 2016), justify their claims based on evidence (Chen et al., 2016), and move between internal and external translation and representation of their ideas (Lammert et al., 2022).

1.2. Three orientations in pedagogical practices

The literature on epistemology in education has highlighted several constructs such as personal epistemology (Hofer, 2004), epistemological beliefs (Gill et al., 2004), and epistemic cognitions (Feucht et al., 2017). Hofer (2004) argues teachers' personal epistemology influences their classroom implementation and related pedagogical practices. Likewise, in an intervention study, Gill et al. (2004) found that teaching instructions improved preservice teachers' epistemological beliefs about teaching and learning in a short intervention time. Commenting on epistemic beliefs, Feucht (2010) argues "teachers with more advanced epistemic beliefs are more receptive to epistemic development and less resistant to educational reform" (p. 69). Moreover, teachers' epistemological move may affect students' practical epistemology in the classroom (Berland et al., 2016; Lidar et al., 2006). Collectively, the empirical and theoretical studies in the literature outline the critical role of teachers' epistemological orientations in their teaching and learning practices. However, Packer and Goicoechea (2000) argue that learning requires a change in both the person and the social world. In other words, learning is not only related to epistemological transformation.

Unlike epistemology, ontology has not been addressed in much detail in the educational fields (Schraw, 2013). Some researchers have attempted to evaluate the impact of teachers' epistemological and ontological beliefs simultaneously on teaching practices, goals, and actions (Avgitidou et al., 2013; Garner & Kaplan, 2019; Mansour, 2015). Importantly, Olafson et al. (2010) have argued that the role of teachers' ontological views is beyond their epistemological worldviews. In their empirical studies, they simultaneously investigated realistic and relativistic perspectives in the field of epistemology and ontology, through a quadrant scale that was used as a self-located scale in which the teacher participants were asked to self-locate themselves (Olafson et al., 2010; Schraw & Olafson, 2008). They argued that such an approach enabled them to not only examine teachers' epistemological worldviews but also their ontological worldviews regarding their use of instructional approaches and teaching practices. The outcomes suggest that epistemological and ontological beliefs appear to be closely linked and reflect teachers' knowledge and views of the world of teaching (Garner & Kaplan, 2019; Kang & Wallace, 2004).

In the field of education, axiology is another important domain (Biesta, 2015; Laudan, 1984). Biesta (2015) argues that in fact axiology is a critical determining factor of what education might work for through anticipating the goals and directions of education. Likewise, Laudan (1984) defines axiology as aims underlying a specific approach to science and concepts that represent values. While language, argument, and dialogue are three epistemic tools that are utilized in any learning environment, Hand et al. (2021) argue that it is when teachers

implement knowledge generation environments that they value and utilize in their classrooms. This study was theoretically framed un der Laudan's (1984) reticulated model of scientific rationality which compromised three philosophical orientations (epistemological, axiological, and ontological) in a practice of science teaching. She speculates the reticulated relationships between epistemology, axiology, and ontology overlap each other. In this study, we adapted an interrelated set of three orientations to frame generative science learning (Fig. 1). All these generative sets of traits in three orientations provide commitments to generative science learning. Each orientation in our knowledge generation framework comes with specific traits which were adapted from related literature on epistemology, axiology, and ontology in educational settings. We do not argue these traits are complete sets under an orientation. However, we assume these orientations should be utilized together for the effective practice of generative science learning.

1.3. PD framed around knowledge generation

Existing literature highlights there is an emerging perspective that teachers should understand and utilize language, dialogue, and argument as epistemic tools for creating effective knowledge generation environments. Valuing both students' everyday and academic language (Schoerning et al., 2015), creating non-threatening environments for peer-to-peer and student-to-teacher discussions (Cavagnetto, 2010), and encouraging students to support, defend, and challenge their claims by using evidence (Chen et al., 2016) are critical underpinning frameworks for implementing generative science learning environments. By using these tools, teachers shift their ideas regarding controlling students' learning and start perceiving students as subjects in the classroom.

This shift requires effective PDs for teachers (Bae et al., 2022). Specifically, we believe that a PD should frame around knowledge generation perspectives to improve teachers' knowledge and practice toward generative learning in science. We define such PD as immersive and long-term, where teachers are provided learning opportunities to "live" the experience of generating their own understandings of various learning tools and practices. These PDs are different from traditional, knowledge replicative PDs that focus on transmitting knowledge to participant teachers and are generally too isolated from classroom practices (Buczynski & Hansen, 2010).

1.4. A conceptual model of a generative PD

In shifting the focus from teaching to learning, the researchers focused the PD around an underlying framework related to learning where teaching is viewed as a function of understanding how people learn (Bransford et al., 2000). This requires that ideas related to learning move beyond declarative and procedural knowledge and emphasize the epistemological and ontological aspects of knowledge generation (Suh et al., 2023). Teachers' ideas are continually challenged and debated, with opportunities to negotiate their own understandings of learning as a function of being involved over a three-year cycle of engagement. This is done in order to provide teachers with an opportunity to "live" the experience of generating new knowledge related to their classrooms (Hand et al., 2019). The PD is framed around three different phases.

Phase 1. Negotiating foundational knowledge for generative learning.

1. Challenging teachers' views of learning – creating dissatisfaction with current ideas. Teachers are initially asked to define teaching and learning, with nearly all responses centered around the transfer and acquisition of knowledge. The central question (or big idea) for the professional development program is *who controls learning*? Teachers are challenged to articulate the degree to which they control learning, and what this means for learning within their classrooms. Importantly, the translation of this idea into practical implementation for teachers is negotiated by the teachers, that is, the teachers are encouraged to author their own understandings of how to apply these ideas into their particular classroom setting. There are no prescribed set of strategies for teachers to follow, that is, no authorized or prescribed strategies are provided to teachers to implement within their classrooms.
2. Challenge teachers to generate one-line statements related to their understanding of the epistemic nature of language, argument, and

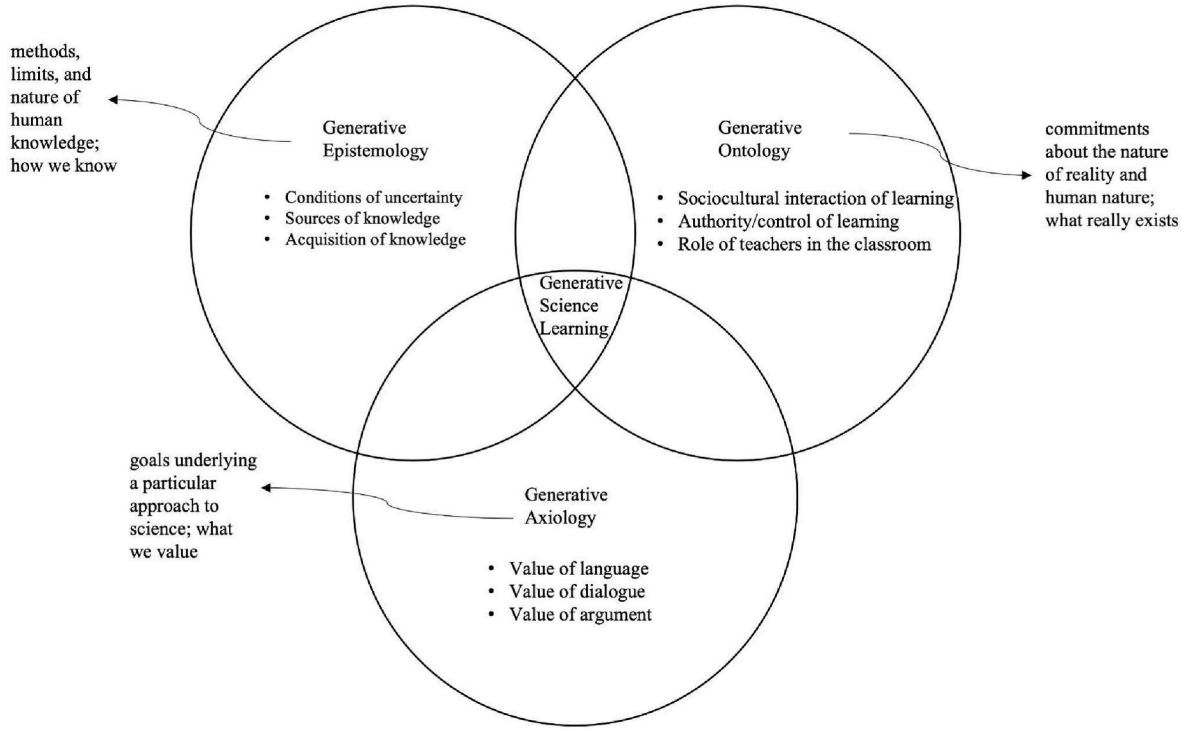


Fig. 1. Three orientations embedded in generative science learning.

dialogue. These three are viewed as epistemic tools that are critical components of the learning environment. Teachers are engaged with questions related to how these tools promote learning, rather than seeing them as a set of procedures that they need their students to complete. They are encouraged to develop pedagogical strategies that will work for them in their classroom environments and shift from a set of strategies to an overall approach that is framed around their conception of learning.

3. Challenge teachers to generate one-line statements of the big ideas related to standards – asking teachers to reframe the standards into language for their students. One of the difficulties that elementary teachers have is framed around the lack of confidence that they have in relation to science conceptual understandings. Encouraging them to utilize their own language to frame the big ideas of the topics to be addressed in their curriculum promotes engagement in the science that is meaningful for the teachers. The intent of this component was to replicate the type of activities that they would encourage students to engage with – utilizing everyday language as a means to move towards academic language.

Phase 2. Authoring pedagogical approaches framed on foundational knowledge generated in Phase 1.

This component of the professional development program is centered on working with teachers as they adopted and adapted the theoretical underpinnings of generative learning into their classroom environments. The emphasis is on encouraging them to be authors of their environments and promoting opportunities for students to author their own knowledge. During the academic year, teachers within both regional clusters and their own school districts meet to share and develop their ideas on how their pedagogy and classroom environments are aligned to generative learning. The emphasis in these sessions is on teachers working with the professional development leaders as a means to develop and author their own implementation.

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

Importance is placed on providing teachers with the opportunities to cycle through phases 1 and 2. As teachers work through each phase, the opportunities to revisit aspects of the theory are critical for them to develop their own rich understanding of knowledge generation theory. Cycling through the phases also gives them opportunities to refine and develop their pedagogical understandings and practices for implementing knowledge generation environments.

2. Method

2.1. Context

This research is a part of a larger project that aims to help teachers implement the Science Writing Heuristic (SWH) approach (Keys et al., 1999). The SWH approach is a knowledge generation approach where teachers encourage students to use epistemic tools such as language, dialogic interaction, and argument (Hand et al., 2021). In the SWH approach, students are encouraged to negotiate their prior knowledge and new ideas by using multiple representations, to generate their own test questions, to create suitable test designs to collect data, and to justify their claims with evidence (Hand et al., 2021). This study focuses on the first year of a three-year long generative PD program on the SWH approach. In the summer, six-day PD workshops were held and after the workshops in the following semester, participant teachers were additionally supported by a planned visit from a PD consultant in which they discussed their challenges and successes with the approach. The main goals of the PD workshops were to emphasize epistemic tools (in-depth discussions related to language, argument, and dialogue), and help teachers to better understand the fundamentals of the knowledge generation environment.

The PD workshops were designed to provide knowledge generation environments in which the participant teachers were immersed in authoring their theoretical and practical understandings related to knowledge generation learning environments. In the first two days of the PD sessions, discussions were held around concepts related to who controls learning, and the use of language, dialogue, and argument as epistemic tools for learning *big ideas*. Teachers worked collaboratively to debate the concept of who controls learning and to define the terms language, dialogue, and argument in small groups. On days 3 and 4, discussions were centered around the approaches to creating knowledge generation environments. Finally, the PD workshops ended with teachers' planning of daily and unit-level instructions toward knowledge generation environments.

This study was designed as a multiple case study, following Yin's (2014) approach, and drawing on Merriam's (1998) insights regarding multiple case study methodology. The study involved a total of 12 teachers, aiming to develop a deeper understanding of how teachers' epistemological, axiological, and ontological orientations evolve after participating in the PD workshops. Furthermore, the study aimed to explore the relationship between these changes and their teaching practices in implementing knowledge generation environments in Table 1. According to Merriam (1998), a multiple case study allows for an in-depth analysis of each individual case as well as an exploration of patterns and commonalities across different cases. By employing this approach, we sought to uncover nuanced insights about the impact of PD on teacher orientations and teaching practices. The 12 participating teachers willingly engaged in an extensive and in-depth data collection process over the course of one year. They were purposefully selected from a larger group of participants in our PD program to ensure maximum diversity among the sample. This deliberate sampling technique aligns with Merriam's (1998) suggestion that multiple cases should be chosen to represent a variety of characteristics or perspectives, enhancing the depth and richness of the study.

The study included teachers from two different states in the United States, specifically a Midwest state and a Southeast state. We deliberately sought teachers from diverse living areas, encompassing rural, suburban, and urban settings. The student enrollment numbers by grade and free/reduced lunch rates vary widely across each school district. Drawing from previous studies highlighted the need for professional support in enhancing their understanding of epistemic tools (e.g., Gonzalez-Howard & McNeill, 2020), our participant selection aimed to include teachers with diverse levels of experience, ranging from 1 to 30 years. This approach ensured that we captured insights from both novice and experienced teachers, providing a comprehensive understanding of the impact of professional development. Regarding the curriculum, half of the teachers had curriculums endorsed by the district. However, the majority of them indicated that they used the curriculums as a reference rather than strictly adhering to them in a sequential manner. They expressed that they did not experience any pressure to strictly follow the curriculums. Based on the information provided in Table 1, it can be observed that two-thirds of the teachers stated that their reason for attending the PD program was to enhance their teaching skills and acquire more experience. They viewed PD as a valuable personal investment. Conversely, the remaining four teachers participated in the program at the request of their schools. This difference in motivation provides insights into variations in their commitment levels and engagement with the professional development initiative.

2.2. Data sources

The present study includes a data set of the project's first-year data collected during the first three time points: time point 1 (TP1) before the PD, time point 2 (TP2) after the PD, and time point 3 (TP3) end of the first year (Table 2). Data sources include teachers' semi-structured interviews, classroom observation field notes, and implementation scores.

Table 1
Participant information.

Teacher	Region	Community	Years of teaching experience	Grade level	District enrollment by grade	Economically disadvantaged rate (all grades)	Curriculum		Commitment to PD participation	
							District-prompted	No curricular restrictions	School-driven investment	Personal investment
T1	Midwest	Rural	1	4	37	47%	X			X
T2	Midwest	Rural	17	4	37	47%	X		X	
T3	Midwest	Rural	26	3	25	47%	X		X	
T4	Midwest	Suburban	19	3	214	38%		X		X
T5	Midwest	Suburban	17	5	254	38%		X		X
T6	Midwest	Rural	30	5	36	47%	X		X	
T7	Midwest	Suburban	12	4	219	38%	X			X
T8	Midwest	Suburban	13	3	214	38%		X		X
T9	Midwest	Rural	17	3	25	47%	X		X	
T10	Midwest	Rural	4	5	36	47%		X		X
T11	Southeast	Rural	12	5	186	80%		X		X
T12	Southeast	Urban	2	5	835	45%		X		X

Note. The data on 'district enrollment by grade' and 'economically disadvantaged rate (all grades)' was accessed online via the public data set of each school district, representing the 2019–2020 academic year.

Table 2
Data sources.

Timepoint	Time	Data sources
TP1 (before PD)	Spring 2019	Semi-structured interview, field observation
TP2 (after PD)	Summer 2019 - Fall 2019	Semi-structured interview, field observation
TP3 (after PD)	Winter 2019 - Spring 2020	Field observation

Interviews: Before the PD workshops, one semi-structured interview was conducted with each teacher in Spring 2019. Each interview lasted between 20 and 45 min. The interview protocol has four sections: (a) ideas about learning and knowledge generation in a broad sense, (b) language, (c) argument, and (d) dialogue. Sample interview questions included the following.

- Thinking back to your learning experience, do you believe knowledge is established by a single authority or multiple authorities? Why? How do you know when you know something?
- How do you believe students learn best? What does your view of learning mean in your teaching? What are the things that you can control, and cannot control in student learning?
- Do you think engaging with visual representations is helpful to students? Please explain.
- Do you believe having conversations with other students is helpful to the students' learning?
- The NGSS emphasizes engaging in argumentation from practice. Could you share your interpretation of that? What role do you think argumentation plays in learning science?

Teachers participated in the PD workshops in Summer 2019. After the PD workshops, one semi-structured interview was conducted with each teacher again in the subsequent semester. The interview protocol included similar questions to the first interview to assess teacher change in epistemological and ontological orientations and knowledge bases about the epistemic tools, comfort level with the key ideas of the approach, and confidence with the use of epistemic tools (language, dialogue, and argument). In addition, all the teachers were presented with their workshop groups' one-sentence definitions of language, dialogue, and argument and asked to comment on whether they agreed with these statements.

Field observations: Field observations were conducted during science instructional time with each teacher at each timepoint of the study. Field observations lasted between 30 and 60 min in length, and were scheduled in advance. An observation protocol was designed before the field observations and used to assess teacher performance toward knowledge generation during classroom observations (see supplementary material). The protocol included eight practices (the presence of student voice, teacher questioning, attention to the big ideas of science, the use of academic and everyday language, writing to learn, the use of argument structures, peer-to-peer argumentation, and the use of small group and whole class structures) that require the use of three epistemic tools (language, dialogue, and argument) which are consistent with knowledge generation approaches (Hand et al., 2021). Graduate students and post-docs were trained to use the observation protocol by viewing example classroom videos. Observers were instructed to record written notes of classroom conversations and activities and to take photos of relevant learning artifacts.

2.3. Data analysis

This research aimed to locate teachers on a generative/replicative scale with respect to their epistemological, axiological, and ontological views. To do this, there was a need for a detailed scale. Therefore, a codebook was designed based on the literature to assess teachers' alignment to generative and replicative epistemological, axiological, and ontological views (Table 3). This instrument included six distinct categories: replicative epistemology, generative epistemology, replicative axiology, generative axiology, replicative ontology, and generative ontology. Each category includes three traits to explore teachers' views and beliefs regarding each orientation.

First, epistemological orientations are related to teachers' views and beliefs about the nature of human knowledge embodying conditions of uncertainty, sources of knowledge, and acquisition of knowledge. Each trait spans the replicative and generative sides of epistemology. For example, if a teacher believes that knowledge is tentative and constructed by multiple authorities, we assume that teacher has generative ideas regarding conditions of uncertainty. On the other hand, if a teacher mentions a fixed set of knowledge, she is categorized under replicative epistemology regarding conditions of uncertainty.

Second, axiological orientations are centered on the value that teachers place on the use of language, argument, and dialogue as critical elements within their generative science classrooms (Hand et al., 2021). In generative science classrooms, all negotiation processes occur in a frame of dialogic interactions that takes place through language. For example, students' use of oral and written language can help them build conceptual understanding in generative science classrooms. Therefore, if a teacher values language, argument, and dialogue throughout their classrooms, her axiological orientations are assumed to be toward generative learning.

Table 3
Codebook for teachers' epistemological, axiological, and ontological views.

Replicative Epistemology	Generative Epistemology
A teacher would believe a fixed set of knowledge (an objective body of knowledge) (Olafson et al., 2010) **[Conditions of uncertainty]**	A teacher would believe a rapidly changing system of knowledge. (Knowledge is tentative and constructed by multiple authorities) **[Conditions of uncertainty]**
A teacher would assume that "curriculum is fixed and permanent and focuses on fact-based subject matter" (Olafson et al., 2010, p. 249) **[Sources of knowledge]**	A teacher would emphasize a dynamic (student-centered) curriculum. She would highlight active participation of the learners. **[Sources of knowledge]**
A teacher believes that "the learner only copies mental matrixes and cognitive experiences of the others" (Karpov, 2016, p. 1628) (memorization and mastery of new knowledge) **[Acquisition of knowledge]**	A teacher believes that the learner acquires subjective knowledge from direct experience (ability to creating the learner's own mental schemes by connecting existing and new knowledge) (Karpov, 2016) **[Acquisition of knowledge]**
Replicative Axiology	**Generative Axiology**
A teacher believes that multiple forms of language can be merely utilized as a representation tool **[Value of language]**	A teacher believes that the learner can construct knowledge and relate their learning with other concepts by using multiple forms of language (Hand et al., 2019) **[Value of language]**
A teacher believes that teacher-centered dialogue is an effective tool in transmitting knowledge to students **[Value of dialogue]**	A teacher believes that student-centered dialogue is a valuable knowledge generation tool that helps students to make meaning of concepts and relate their learning with other concepts (Lammert et al., 2022) **[Value of dialogue]**
A teacher would assume that using structure-oriented arguments is needed for learning (students need to learn argument structures before the class and need to use them in a specific part of the inquiry) **[Value of argument]**	A teacher believes that immersive use of argument is an essential knowledge generation tool which helps students to construct knowledge and to make connections with the big idea (Chen et al., 2016) **[Value of argument]**
Replicative Ontology	**Generative Ontology**
A teacher would assume "one underlying reality that is the same for everyone. All children should receive the same type of instruction regardless of their individual circumstances, achievement, or context" (Olafson et al., 2010, p. 249) **[Sociocultural interaction of learning]**	A teacher would assume "different people have different realities and that these realities are constructed in social settings" (Olafson et al., 2010, p. 250) **[Sociocultural interaction of learning]**
A teacher would assume that teachers can control the students' learning in the classroom. A teacher would assume that students do not author their own learning in the classroom (teachers are seen as the authority of the learning) **[Control/Authority of learning]**	A teacher would assume that students have the ability to learn and have control over their own learning in the classroom. A teacher would assume that students author their own learning in the classroom (learners conduct the inquiry and collect evidence on their own) (Hand et al., 2021) **[Control/Authority of learning]**
A teacher would assume her role in the classroom as a source of knowledge who would transmit information to the student **[Role of teachers in the classroom]**	A teacher would assume her role in the classroom as a collaborator, a co-participant, and a facilitator of learning who works to meet the individual needs of students (Schraw & Olafson, 2008) **[Role of teachers in the classroom]**

Third, ontological orientations focus on "the beliefs about the nature of reality and being" (Schraw, 2013, p. 1). These are the last orientations in our codebook that we assume shape the teachers' views of teaching and learning. For example, if a teacher assumes that all students should receive the same type of instruction regardless of their individuality or context, she may have replicative ontological views about the sociocultural interaction of learning.

A two-step discourse analysis was applied to analyze the interview data qualitatively. The first step began with close reading of each transcript and identification of teachers' replicative and generative ideas related to teaching and learning. Then, in the second step, these ideas were mapped onto particular traits of epistemological, axiological, or ontological views. To respond to the first research question, a trait in each generative view was coded as "1" and each replicative view was coded as "-1". At TP1, a trait was coded as "0" if there is contradictory or no available data to interpret teachers' views. Similarly, contradictory data at TP2 were coded as "0". However, if there is no available data regarding a particular trait at TP2, we keep the same trait from TP1 to prevent any misinterpretations of teachers' transition. For example, the excerpt presented below was coded as "0" because the teacher shared contradictory information regarding her views on the control of learning:

> I can control how they … the parts and procedures part of it, the nitty-gritty, the directions part. The thinking and the wrap your brain around the idea, that's harder to control. It's almost impossible. They've got to come around to it … The easy part to control is the procedures, the do this, do this, do that, do this, move this, put that there. The hard part to control is how this experiment relates to the concept that we're talking about. Is it making pretty rainbows with liquid … a straw or does it relate to density? A lot of them will get it … Oh, it's so pretty. Not the point though. (T11, TP1 interview)

To test the validity and consistency of coding, a second coder was trained, and she selected two teachers randomly and analyzed their epistemological, axiological, and ontological views. The discrepancies were discussed until a consensus was reached and more descriptions were added to the codes of *conditions of uncertainty*, *sources of knowledge, and sociocultural interaction of learning* to improve their consistency in the coding scheme. Then, the rest of the data were analyzed by the first coder. Finally, teachers' replicative and generative views were summed up to reach total replicative and generative scores [−3, +3] which were used as data points on the levels of teachers' orientations. Teacher orientations were represented on a two-dimensional plane through the use of radar charts as a visualization tool.

To respond to the second question, teacher implementation levels were determined through classroom observations. After each observation session, the observer used a structured observation protocol (see supplementary material) to score the teacher's implementation across eight dimensions of science teaching. Each dimension of implementation was assigned a ranking of NA (0), low (1), medium (2), or high (3). By employing this procedure, a total implementation score ranging from 0 to 24 was obtained. If a teacher's total implementation score falls within the range of 0–8, their implementation level is categorized as 'Low'. For scores ranging from 9 to 16, the implementation level is categorized as 'Medium'. Finally, if a teacher's total implementation score is between 17 and 24, their implementation level is categorized as 'High'. The findings from these data contribute to what aspects of knowledge generation practice teachers change in their classroom implementation.

3. Results

3.1. Analysis of teachers' orientations

We begin this section with an overview of teachers' orientation levels regarding identified generative and replicative epistemological, axiological, and ontological views from TP1 to TP2 (see Table 4). To illustrate the overall patterns, teachers were categorized into three levels (low, medium, and high) according to their total orientation scores at TP1 and TP2. Based on our coding, the maximum total score is +3 in the generative direction, and the minimum score is −3 in the replicative direction. For each orientation, the number of high-level teachers increased, and the number of low and medium-level teachers decreased at TP2. Three out of four teachers were categorized under the high-level in terms of epistemological and ontological orientations, and two-thirds

Table 4
Teachers' levels of epistemological, axiological, and ontological orientations toward generative learning.

Teachers' Orientation Level	TP1	TP2
Epistemological Orientation Level	**n (%)**	**n (%)**
high (total score of +3)	5 (42%)	9 (75%)
medium (total scores of +1 and + 2)	5 (42%)	2 (17%)
low (total scores up to 0)	2 (17%)	1 (8%)
Axiological Orientation Level		
high (total score of +3)	3 (25%)	8 (67%)
medium (total scores of +1 and + 2)	6 (50%)	2 (17%)
low (total scores up to 0)	3 (25%)	2 (17%)
Ontological Orientation Level		
high (total score of +3)	6 (50%)	9 (75%)
medium (total scores of +1 and + 2)	2 (17%)	0 (0%)
low (total scores up to 0)	4 (33%)	3 (25%)

of teachers were categorized under the high-level in terms of axiological orientations at TP2. Overall, these results indicate that teachers changed their epistemological, axiological, and ontological views toward generative learning after the PD workshop.

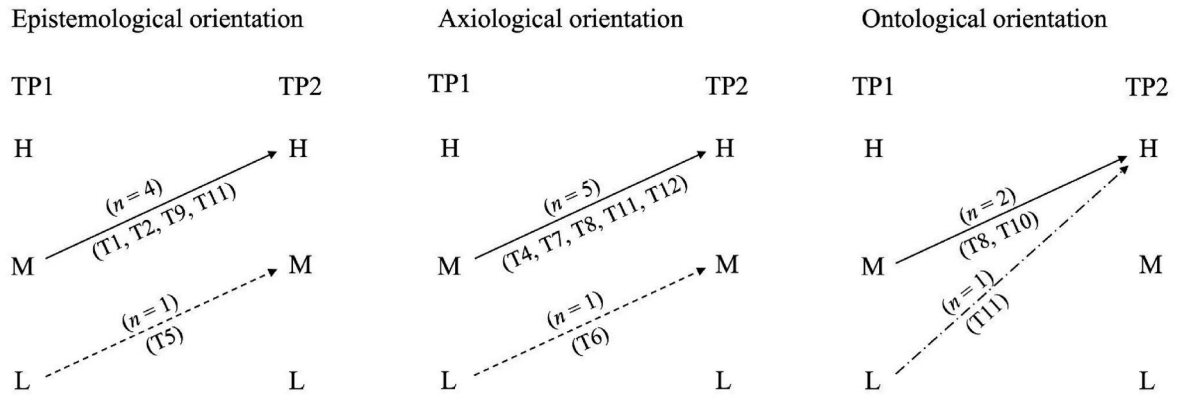
Fig. 2 illustrates the changes in teachers' orientation levels. Overall, five out of 12 teachers changed their epistemological orientation toward more generative. One out of 12 teachers moved from low to medium-level and four teachers moved from medium to high-level. The remaining teachers stayed in the same category that they were at TP1. Transitioning from low to medium-level, T5 changed her replicative ideas regarding the *acquisition of knowledge* toward generative. In her TP1 interview, T5 said "How our earth systems interact is what we are on right now. We are talking about the four spheres and it's like you're never going to know all of that because I don't know all of that." At this time point, she mentioned memorization and reported that "There are checkpoints. I look for vocabulary in kids and knowing that they – there are points where they seem to own that and so that would probably be one way, I could show growth and learning is owning words." On the other hand, at TP2, she highlighted knowledge generation and the connection between existing knowledge and new knowledge and said, "It's not what I thought it was … it is what they know and trying to make connections to new concepts to what they already knew." However, not every teacher managed to change their replicative views towards generative. For example, T3, the only participant who stayed at a low epistemological level at both time points, had replicative ideas regarding the *acquisition of knowledge*. She mentioned her ideas related to memorization and mastery of new knowledge during TP2 interview, "Just getting them to come up with the right answer. Sort of on their own, you know, kind of get them where I want them to be."

With respect to axiological orientation, half of the teachers changed their orientations toward more generative. One teacher moved from low to medium-level and five teachers moved from medium to high-level. The remaining teachers stayed in the same category that they were at TP1. In this study, axiological orientations of knowledge generation were identified as the value of epistemic tools—language, dialogue, and argument. For example, after the PD, T11 changed her views on the argument from structured to more immersive and she mentioned,

> Argument is a way to learn. Argument is a way to show that you're confident enough and you have enough confidence in your understanding of what's going on, to be able to, in front of all these people that you want to impress, all your peers, that you can stand up and say, this is what happened, and I can prove it. I'm sure of it. That was impressive to me, when they started to do that a little bit to do. I was like, oh, okay. (TP2 interview)

Lastly, three out of 12 teachers changed their ontological orientations toward more generative. One teacher moved from low to high, and two teachers moved from medium to high-level. The remaining teachers stayed in the same category that they were at TP1. For example, transitioning from medium to high-level, T10 changed her views on the *control/authority of learning*. After the PD sessions, talking about her current understanding of learning T10 commented, "I would say with science it's more of kind of showed us that it's not really like, it's more of seeing if they assessing them more on if they are able to like have arguments and have conversation with each other and talking a lot more, like going just talking more in dialogue more and having those debates, those arguments back and forth and trying to call up their own solutions" (TP2 interview). T10's ontological views moved toward generative as she mentioned students' control and authority over their own learning by conducting the inquiry in the classroom along with student-centered dialogic interactions.

The frequency of teachers who switched from replicative to generative ideas after attending the PD workshops is presented in Table 5. The results show that teachers changed their variety of replicative ideas to generative ones after the PD sessions. *Acquisition of knowledge* (E) had the highest frequency of change. Five out of 12 teachers (T1, T2, T5, T9, and T11) changed their replicative ideas of acquisition of knowledge toward generative. *Value of language* (A) (n = 4), *control/authority of learning* (O) (n = 3), and *value of argument* (A) (n = 3) were the other



Note. L: Low, M: Medium, H: High. Teachers who remained at the same level are not shown in the diagram.

Fig. 2. Teacher orientation level transitions from TP1 to TP2

Table 5
The frequency of teachers who changed their replicative ideas to generative ones after the PD workshops.

Orientation Traits	Frequency	Percentage
Acquisition of knowledge (E)	5	42%
Value of language (A)	4	33%
Control/Authority of learning (O)	3	25%
Value of argument (A)	3	25%
Role of teachers in the classroom (O)	1	8%
Sociocultural interaction of learning (O)	1	8%
Conditions of uncertainty (E)	0	0%
Sources of knowledge (E)	0	0%
Value of dialogue (A)	0	0%

Note. Total percentages add up to over 100% because some teachers changed their views on multiple traits.

frequent traits that were changed from TP1 and TP2. On the other hand, teachers' views did not change regarding some traits (n = 3). For example, two teachers (T3 and T6) still held replicative axiological views of the *value of dialogue* at TP2. The remaining 10 teachers had already generative views in terms of the *value of dialogue* both in TP1 and TP2.

Although there were changes in most of the traits, some of the traits remained with respect to a replicative viewpoint at TP2. One-fourth of the teachers still held replicative ontological views regarding *control/authority of learning* (T3, T6, and T9), and replicative axiological views regarding the *value of argument* (T2, T3, and T9). For example, responding to how students learn, T9 said "By telling me what we have talked about. By being able to have an experiment work correctly and have the results the way we want them to be" (TP1 interview). She held replicative ideas regarding control/authority of learning at TP2, "I think they came up with things that I didn't think they would, their ideas weren't what I thought they would be, I guess. So just kind of went in a different scope and direction that, yeah". Similar replicative views did not change for T3 and T6. For example, at the TP2 interview, T6 kept her replicative ideas "Okay. Yeah, I do agree that putting into their own words does help them still. I still think repetition is important for a lot of kids".

3.2. Patterns between teachers' orientations and implementation levels

Addressing our second research question, we utilized teachers' classroom observation data to explore any relationship between teachers' orientation change and their implementation levels. The information presented in Table 6 displays teacher implementation levels which were determined through classroom observations, as well as the changes in their orientation levels during each timepoint. The results show that teachers' classroom implementation toward knowledge generation was beyond their epistemological orientations. In other words, besides epistemological orientations, axiological and ontological orientations appeared to play a critical role in teachers' implementation of a knowledge generation approach. Overall, teachers who still held replicative views under any orientation trait at TP2 stayed in the low or medium-level of implementation at TP3, and teachers who did not share any replicative views at TP2 stayed in the medium or high-level implementer category at TP3.

Table 6
Transitions of the overall implementation and three orientations.

Teacher	Implementation	Epistemological	Axiological	Ontological
	TP1→ TP2→ TP3	TP1→ TP2	TP1→ TP2	TP1→ TP2
T1	L– > M– > M	M– > H	H– > H	H– > H
T2	L– > M– > M	M– > H	M– > M	H– > H
T3	L– > M– > L	L– > L	L– > L	L– > L
T4	L– > H– > H	H– > H	M– > H	H– > H
T5	M– > M– > M	L– > M	H– > H	H– > H
T6	L– > M– > M	M– > M	L– > M	L– > L
T7	L– > H– > H	H– > H	M– > H	H– > H
T8	L– > H– > H	H– > H	M– > H	M– > H
T9	L– > L– > L	M– > H	L– > L	L– > L
T10	L– > M– > M	H– > H	H– > H	M– > H
T11	M– > M– > M	M– > H	M– > H	L– > H
T12	M– > M– > M	H– > H	M– > H	H– > H

Note. L: Low, M: Medium, H: High.

Fig. 3 illustrates teachers who had the highest number of replicative views at TP2. These teachers were struggling to accept the idea of knowledge generation. The charts demonstrate teachers' three orientations in a two-dimensional plane – the dominance of replicative ideas is represented by negative values, while positive values represent the dominance of generative ideas for each domain. T3 was the only teacher who did not make any changes toward knowledge generation (see Fig. 3 (a)). Her replicative traits from each orientation remained the same at TP2 (*sources of knowledge* (E), *acquisition of knowledge* (E), *value of language* (A), *value of dialogue* (A), *value of argument* (A), and *control/authority of learning* (O)). Her interview data shows that she did not value the epistemic tools (language, dialogue, and argument) underlying knowledge generation and her axiological orientation stayed at the total replicative side of the spectrum. We believe that these total replicative ideas of axiological orientation may cause difficulties in her transition to knowledge generation implementation. During her classroom observation, T3 did not utilize these epistemic tools. Specifically, according to her classroom observation scores, promoting the use of oral and written language, promoting students' engagement in small group and whole class discussions, and encouraging students' argumentation were either limited or did not occur. Her overall implementation level at TP3 was low.

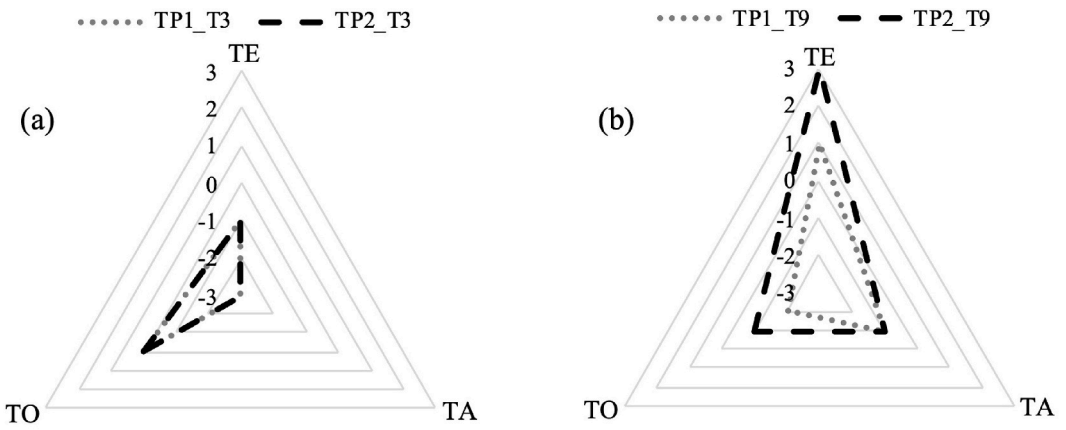
Another teacher who shared several replicative views at TP2 was T9 (see Fig. 3 (b)). In her TP2 interview, she still held some replicative traits from axiological and ontological orientations (*value of language* (A), *value of argument* (A), *control/authority of learning* (O), and the *role of teachers in the classroom* (O)). From an axiological perspective, for example, T9 assumed language as only a representation tool at TP1, "We draw pictures to show what things look like or to describe a vocabulary word." She did not value language as an epistemic tool for knowledge generation. She did not perceive the flexible use of oral and written language and the transition between everyday and academic use of language as a goal underlying generative science learning environments. In contrast, she highlighted a strict use of academic language in her TP2 interview, "So, I want them to use that academic vocabulary when they're telling me about what classifies a mammal is a mammal and a bird is a bird and those types of things."

On the other hand, T9 could manage to shift some of her replicative traits from TP1 to the generative counterparts after the PD sessions. Her views on the acquisition of knowledge (E) and sociocultural interaction of learning (O) shifted toward knowledge generation. For example, at TP2, T9 mentioned generative ideas regarding the acquisition of knowledge:

> I think it's getting kids to talk about ideas and topics and let them know that it's okay to be wrong like that we can, that not necessarily there has to be a right answer, like especially with science, but that they're just, they're doing more on their own than me just giving them the information. (TP2 interview)

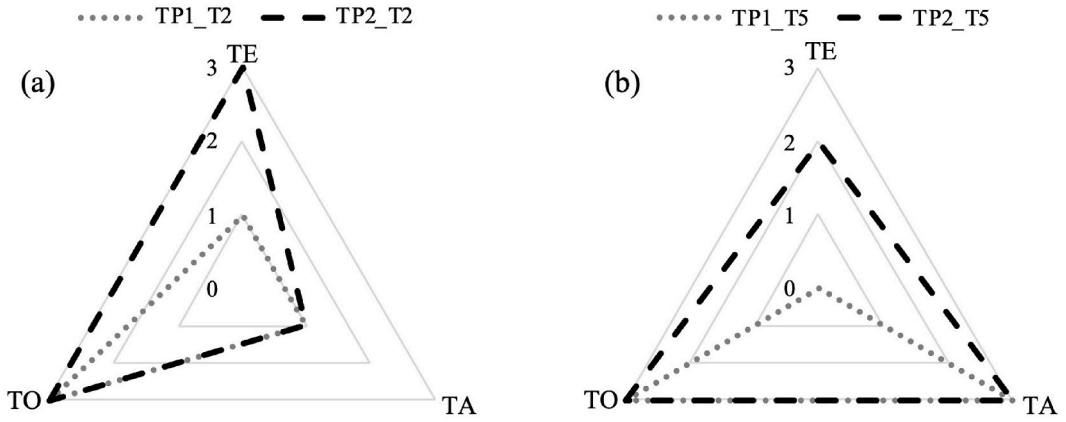
Despite these shifts toward generative learning, her overall implementation level at each timepoint was low. Although there were some episodes of encouraging student dialogic interaction, and student voice and teacher questioning were at medium-level in her observed classroom, promoting the use of oral and written language, and encouraging students' argumentation were either limited or none.

Fig. 4 illustrates teachers who shared replicative views regarding only one orientation at TP2. The charts demonstrate teachers' three orientations in a two-dimensional plane. Although both T2 and T5 improved their epistemological levels toward knowledge generative



Note. The number in the diagram indicates the degree to each teacher's orientation based on total epistemological score (TE), total axiological score (TA), and total ontological score (TO).

Fig. 3. Radar graphs for teachers with the most replicative views at TP2



Note. The number in the diagram indicates the degree to each teacher's orientation based on total epistemological score (TE), total axiological score (TA), and total ontological score (TO).

Fig. 4. Radar graphs for teachers with replicative views regarding only one orientation at TP2

from medium to high and from low to medium respectively (see Fig. 2), they still held replicative views at TP2. T2 shifted her ideas about the *acquisition of knowledge* (E) toward the generative side, however she still held replicative ideas regarding the *value of argument* (A) after the PD workshops. In her TP2 interview, even though she mentioned that she liked the idea of argumentation in science learning, she still believes students need to learn argument structures before the class unless valuing the immersive use of argumentation, "I like the concept of it (argumentation). I just think there's going to be a lot of teaching behind it, and I think that will be easier for us as the years go because they will hopefully have had it throughout our other grade levels coming up. The group I have this year makes me a little nervous because there are some argumentative ones just naturally—not in a good way." T2 had concerns about using argument as an epistemic tool. Her interview data also shows that some of her students did not grasp the view of *we negotiate ideas, not people*. Her TP3 overall implementation level is medium with low scores regarding implementing argumentation.

T5 was the teacher who shared replicative views regarding epistemological orientation at TP2 (see Fig. 4 (b)). Similar to T2, T5 shifted her replicative ideas regarding the *acquisition of knowledge* (E) toward the generative side. However, she still shared contradictory views regarding the *conditions of uncertainty* (E) after the PD workshops. In her TP2 interview, when sharing her ideas about learning, T5 mentioned replicative views regarding the *conditions of uncertainty* (E), "because there's what I like the learning I have in my head, but then it's different when they (students) start to talk out loud with it. And so, I think that I'm just adding onto what I thought I knew and what I knew then was just there are kids making sense of it." Later in the same interview, she shared more generative views regarding the tentative nature of knowledge while she was talking about her current understanding of the argument, "I need to be sure what I understand and then go into a conversation and be willing to listen to others and be willing to be able to change my opinion based on that conversation."

On the other hand, T5 had already brought generative ideas regarding axiological and ontological orientations. For example, she highlighted student ownership which indicates her generative views regarding students having the authority over their own learning at TP1. T5 brought a medium-level implementation before the PD workshops but could not manage to develop her implementation toward knowledge generation. Her overall implementation level was medium for all three timepoints. She had knowledge generative ideas regarding ontological and axiological orientation however she could not fully shift her

epistemological views.

Seven out of 12 participant teachers held no replicative views after PD sessions at TP2 and were willing to accept the idea of knowledge generation. Fig. 5 illustrates two of the teachers who changed all their replicative views to generative ones at TP2. These two teachers had high implementation scores during their observed classrooms at TP3 and were categorized under high-level implementation. They both improved their implementation toward knowledge generation from low to high throughout the first year of the PD program. Both T7 and T8 shifted their views on the value of language toward knowledge generation after the PD sessions. For example, T7 highlighted the role of oral and written language use on students learning at TP2. T7 said,

> They are notebooking, they're drawing, they're labeling, you know, they acquire language and knowledge in different ways. It doesn't necessarily have to be in my mind, verbal or written, especially for those students who- I had two in here last year that really challenged my thinking … I think sometimes it's more than that, you know processing, you know, I'm using arrows and diagramming in their notebooks to get at what, how they are formulating new vocabulary, new language, new learning. (TP2, interview)

She perceived language not only as a representation tool but also as an epistemic tool for knowledge generation. She also highlighted the importance of the use of multimodal representations and verbal and written use of language in the classroom. Furthermore, in her observed classroom, student voice, teacher questioning, and language use were scored high. However, student argumentation in her class was limited. Although she shared generative views regarding the value of argument in her interview, her observed class did only include limited argumentation.

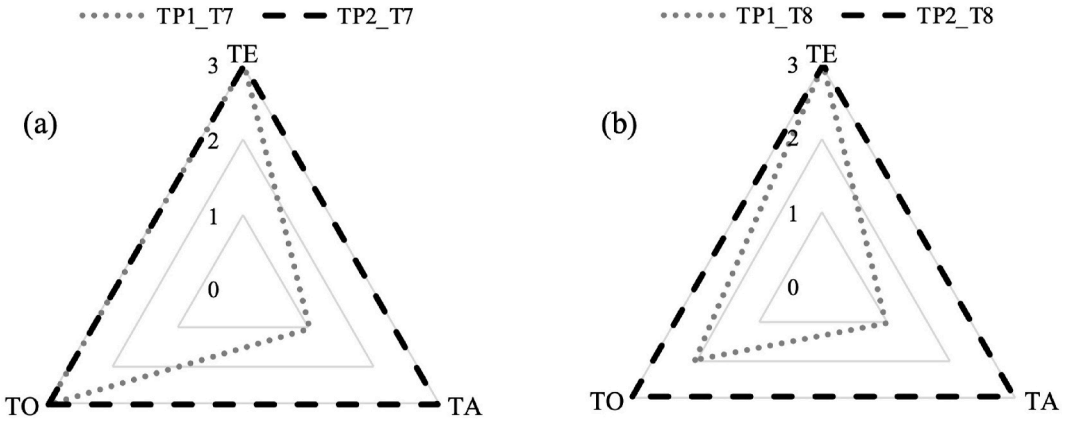
Moreover, T8 shifted her views on the control/authority of learning toward knowledge generation at TP2 (see Fig. 5 (b)). In her TP2 interview, she mentioned her goal would be to increase the students' ownership and authorship in the classroom. T8 said, "my challenge will kind of be taking that idea of learning forward, giving the kids more opportunities to plan some investigations or kind of plan some of the design. Really give them true, truly more ownership over the questions that we explore." She had high scores on encouraging student dialogic interaction and promoting the use of oral language during her observed classroom. In her classroom, student voice, teacher questioning, and students' argumentation were medium-level. Overall, her epistemological, axiological, and ontological orientations were traced in her practice of teaching at TP3.

4. Discussion

Prior studies that have noted the importance of teachers' epistemological orientations in their classroom implementations (Feucht et al., 2017; Rott, 2020; Sengul et al., 2020) have left open the question of are there other orientations beyond epistemology that impact teacher change (Garner & Kaplan, 2019; Kelly, 2020). To address this question the present study was designed to examine changes in teachers' epistemological, axiological, and ontological views as they participated in a PD program framed on introducing knowledge generation learning perspectives and to determine the effects of these changes in their classroom implementation. The current study found that teacher transition toward understanding and implementing knowledge generation learning environments was impacted by more than their epistemological orientations. Axiological orientations, which for this study is centered on the value of epistemic tools (language, dialogue, and argument), and ontological orientations related to authority of knowledge generation, appeared to play an important role in teacher change. These results further support the idea of the intercorrelated relations between epistemological and ontological worldviews (Mansour, 2015; Olafson et al., 2010) and shed light on the role of axiology along with epistemology and ontology in teacher education.

As mentioned in the literature review, epistemological and ontological beliefs reflect teachers' knowledge and views of the world of teaching (Kelly, 2020). Prior studies that have noted the importance of epistemological moves and beliefs have shown the relationship between teachers' epistemological beliefs and their pedagogical practices (Avgitidou et al., 2013; Mansour, 2015; Sengul et al., 2020), and students' practical epistemology which influences knowledge generation (Berland et al., 2016; Lidar et al., 2006). The current study found that the *acquisition of knowledge* had the highest frequency of change (n = 5) related to teachers' epistemological orientation shift after PD. Five out of 12 teachers (42%) shift their replicative ideas of acquisition of knowledge (memorization and mastery of new knowledge) to more generative (learners' ability of knowledge generation by connecting existing and new knowledge). Although this epistemological shift related to the acquisition of knowledge is critical, the results of this study indicate that the paradigmatic shift toward generative learning goes beyond a shift in epistemology.

Results from this study highlight that axiological and ontological orientations were found to influence teachers' shift toward understanding and implementing generative learning environments. The current study found that there were axiological and ontological shifts toward generative ideas such as regarding the *value of language* (A) (n =



Note. The number in the diagram indicates the degree to each teacher's orientation based on total epistemological score (TE), total axiological score (TA), and total ontological score (TO).

Fig. 5. Radar graphs for teachers with no replicative views at TP2.

4), *value of argument* (A) (n = 3), *control/authority of learning* (O) (n = 3). These differences in teachers' orientations after PD can be explained in part by the proximity of axiological and ontological orientations. In reviewing the literature, there are few empirical studies found on the association between axiological orientations and education. However, this study provides support for the role of axiology in education (Biesta, 2015) and shows valuing epistemic tools such as language, argument, and dialogue is an important factor in promoting teacher change toward generative learning.

Another important outcome was that teachers' ontological shifts toward generative ideas were identified after PD. The results show that the *control/authority of learning* had the highest frequency of change (n = 3) related to teachers' ontological orientation. Teachers who shifted their ideas regarding this trait changed their replicative views of controlling students' learning and being the only authority in the classroom. These results corroborate the ideas of Packer and Goicoechea (2000), who suggested that learning requires a change in both person and the social world and is not only related to epistemological transformation. In this case, the ontological transformation that occurred in teachers' beliefs had a direct influence on their relationships with students and shaped their views as active participants in the learning community (Kelly, 2020).

One interesting finding is that one-fourth of teachers still held replicative views regarding control/authority of learning (O) and value of argument (A) after the PD sessions. Teachers' orientation toward viewing students having control and authority over their own learning and valuing argument as an epistemic tool to construct knowledge is critical for generative learning environments (Hand et al., 2021). Interestingly, the teachers who retained replicative views in these areas also demonstrated low or medium implementation levels throughout the year. However, as the scope of the current study is the first year of the PD, these results need to be interpreted with caution, particularly as we have reported earlier that teacher change takes between 12 and 18 months. Thus, the lack of significant change in these particular areas may be attributed to the need for more time for transformative shifts to occur. Prior studies have noted the importance of the duration of PDs and included the time span of the PDs as one of the core characteristics of effective PD models (Darling-Hammond et al., 2017; Desimone, 2009). Another factor that could explain these findings is related to the teachers' initial motivation and commitment to attending the PD sessions. The teachers who still held replicative views regarding these traits mentioned that their participation in the PD program was driven by their school's request rather than personal motivation. As previous research highlights, teacher motivation plays a crucial role in successfully incorporating PD into practice (Osman & Warner, 2020). The lack of initial motivation among these teachers may have hindered their transition towards embracing generative learning approaches.

The second question in this study sought to determine the effects of teachers' orientation changes in their classroom implementation. The results show that teachers' epistemological, axiological, and ontological orientations appear to impact their teaching practices toward implementing knowledge generation learning environments. Teachers who still held replicative views under any orientation trait at TP2 stayed in the low or medium-level implementation, while teachers who did not share any replicative views at TP2 stayed in the medium or high-level implementation at the end of the year. While previous studies have linked effective PDs and change in teachers' implementation (Desimone, 2009; Sengul et al., 2020), the results from this study suggest that teacher change in implementation is not only related to epistemological orientations but also associate with axiological and ontological orientations.

4.1. Limitations and future directions

One of the aims of this paper is to methodologically contribute to teacher education studies. Although the codebook provided in this study was detailed under three orientations, the scope of the data analysis was limited in terms of the orientation traits that were adapted from the related literature. As teachers' orientations toward teaching and learning are very complex, there may be several other factors in terms of assessing teachers' orientations. Another source of weakness in this study which could have affected the measurements of teacher implementation was observing only one classroom per teacher to determine the implementation levels in each semester. A unit-long or semester-long observation of the classrooms may provide better insights into teachers' change in practice.

Although our findings indicate that teachers' changes go beyond their epistemological orientations, additional research is necessary to explore the significance of their axiological orientations—how teachers value knowledge generation. The current study analyzed only the initial year of the professional development data. To obtain a comprehensive understanding of how teachers evolve in their axiological orientations, it would be beneficial to conduct further investigations examining their changes over multiple time periods.

4.2. Conclusion

Taken together, the results from this study suggest that improving teacher change is more than a shift in epistemological orientation and implementation of procedural pedagogical practices, but rather is centered on orientation toward ontological and axiological perspectives. We believe that by moving beyond an epistemological orientation, we can begin to uncover what are the necessary changes teachers need to make in order to undertake a paradigmatic shift from a replicative perspective for teaching and learning to one in which students have the opportunities to generate their own knowledge. While we agree that teacher change is complex, the results of this study begin to provide insight into potential new ways of thinking about this change process.

5. Funding

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tate.2023.104264.

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