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Examining teacher transition pathways towards knowledge generation environments

Brian Hand[a], Gavin Fulmer[a] and Jee Kyung Suh[b]

[a]Teaching and Learning, University of Iowa, Iowa City, United States; [b]Curriculum and Instruction, University of Alabama, Tuscoloosa, United States

ABSTRACT
National standards that centre on the underpinning epistemic practices of the discipline has emphasised the need for teachers to focus much more on knowledge generation approaches to learning. Adopting a complexity perspective, we attempt to understand how teachers shift over time by examining their epistemic orientation to knowledge generation and their understanding of the nature of the epistemic tools of language, dialogue and argument that underpin these environments. Ninety-five teachers participated in a 2-year professional development programme to implement the Science Writing Heuristic (SWH) approach – a recognised generative learning approach. Using a longitudinal latent profile analysis of four waves of data, three different teacher profiles emerged (low, medium and high). Teacher transition to higher profiles was not uniform, took time, and required them to engage with the epistemic systems of orientation and tools. The results highlight that teacher PD needs to be tailored to promote richer transitions to implementing generative learning environments.

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Generative environments; teacher transition; latent profile analysis

1. Introduction

The new national standards have shifted the focus of teaching and learning to be much more aligned with the epistemic practices of the discipline. Being successful at implementing these contemporary standards requires that teachers move beyond routine pedagogical approaches towards the development of learning environments that respond flexibly to students' participation in knowledge generation. Shifting to more generative learning environments means that there is a need to address issues related to the shifts in orientation and practices that are required by teachers to be successful. For our disciplinary area of science, this requires that students utilise the languages of science (i.e. all the modal forms of representations) (Norris & Phillips 2003), engage in the generation of arguments (Driver, Newton, and Osborne 2000), and participate in the rich array of dialogical opportunities foundational to generative environments (Hand, Chen and Suh, 2021).

A critical element of the process of building this foundational knowledge is to understand that classrooms are 'epistemic systems' (Greene 2016) that are complex and need to

CONTACT Brian Hand brian-hand@uiowa.edu

be understood through a complexity perspective (Century and Casatta 2016, 200). As Bricker and Bell (2016) highlight classrooms are not just a 'physical space', but are 'material, social and cultural spaces' and need to be seen as places of 'interactions with others, across a variety of contexts, and over time' (pp. 200). Kienhues, Ferguson, and Stahl (2016) argue there is not enough understanding of how to promote the 'reconsideration, re-interpretation or rejection of prior assumption[s]' teachers need to engage with as they are challenged to adopt approaches that recognise the necessary epistemic practices for these generative classroom environments. This requires them to move beyond a shift in pedagogical practices or procedural knowledge to re-interpret and build understandings of generative learning and the role of epistemic tools (language, argument, dialogue). This raises two critical questions: how to help promote this change in teachers? and what model is best to help frame this transition?

To answer these two questions, Buehl and Fives (2016, 250) suggest that we first need to recognise the difference between teaching and learning. Importantly, teachers are learners and as such they 'are primarily focused on themselves with respect to what they understand and how their learning experience connects to their prior knowledge'. Bendixen (2016, 282) argues that building this understanding involves a process of change that moves through a three-stage process of '1) epistemic doubt, 2) epistemic volition and 3) resolution strategies'. Importantly, epistemic doubt does not lead to progression but requires further actions where the teachers, as learners, challenge themselves to resolve this doubt (epistemic volition) and generate new understandings for themselves (resolution strategies).

To understand this change process, Brownlee et al. (2016, 302) argue for a new perspective called an 'epistemological resources tradition' with its focus on envisioning 'personal epistemology as a set of context-specific epistemological resources'. Importantly, Brownlee et al. (2016, 302) emphasise that each teacher is an individual and the development and utilisation of such resources is 'highly variable between and within individuals depending on the context'. A critical concern is that each learner's 'views about learning are inseparably linked to views about knowledge and knowing' (Mason 2016, 381). We have to recognise that teachers will be guided by what they think about learning and how they believe their learners come to know the science concepts.

Professional development programmes need to identify and examine the resources that are essential to use, and the knowledge frameworks to be employed, by teachers to engage with in order to become much more adaptive within their generative classrooms. In terms of resources, we argue that there are three critical activities that form part of the learning environment when learning science – engagement in argument, utilising language, and experiencing dialogue at the small group and whole group levels. Helping students to fully utilise these resources requires teachers to develop knowledge that is orientated towards an epistemology aligned to knowledge generation.

To begin to understand the potential interplay between these different forms of knowledge, we implemented a professional development programme to introduce the Science Writing Heuristic (SWH) approach to K-5 teachers as a means to help them implement generative learning environments as envisioned in the NGSS (Hand, Chen and Suh 2021). To align the research with the complexities involved in generative learning environments, we were interested in simultaneously examining teachers' epistemic orientation to generative learning and their understanding of the epistemic tools of argument, language, and dialogue as critical elements of these environments. For us, understanding the transitions involves a movement away from examining teacher epistemic orientation and knowledge of each epistemic tool as decontextualised entities, but instead to examining them as a set of complex interactions.

We adopted a complexity framing for this study as this offers 'an explanatory framework that can be very helpful in acknowledging the everyday complexity and systemic interconnectedness inherent in teaching and learning environments'. We focused on treating the three strands of epistemic orientation, epistemic tools (interconnected systems – argument, language, and dialogue), and time as interconnected systems. That is, we believe that shifts in orientation and epistemic tool use are not independent of each other, but rather movement in one area will have different impacts in other areas. We have included time because as highlighted previously (Hand, Chen and Suh 2021) teachers generally take somewhere between 18 and 24 months to shift towards understanding and implementing generative learning environments. While recognising that micro-level features of complexity are best studied through qualitative methods, we believe that through quantitative analysis we can begin to look at the broader levels of these interconnected systems.

In examining the concept of complexity the researchers framed the study around the development of teacher profiles and to track these profiles over time. The study was guided following question:

(1) How can latent profile analysis help us understand teacher change over a two-year professional development experience?

2. Literature review

Enabling teachers as learners to participate in a knowledge-generation-focused professional development programme means that recognition has to be given to the concept that these environments are complex. Teachers and students draw on a number of different 'interacting' epistemic resources as part of the learning process (Davis and Sumara 2010). These resources can be seen as adaptive systems which interact with each other (Davis and Sumara 2010), are used simultaneously (Davis 2008), and require time to be fully utilised. This concept of time is important because changing from more traditional to generative frameworks is a long process and requires an understanding that such environments are ultimately 'created by the participants themselves in their everyday practices of teaching and learning'. However, Jörg, Davis, and Nickmans (2007, p.150) highlight that a critical component is the 'worldview' or 'epistemology' that participants have in order to understand and maximise the complexity of the various interactive resources within these classroom environments. Understanding how teachers as learners transition to these generative frameworks requires attention to two focal areas – development and understanding of epistemic resources and the teachers' epistemic orientation.

2.1. Epistemic Resources

The shift of emphasis in the NGSS requires a greater focus on the epistemic practices for generating knowledge in the discipline (Miller et al. 2018). Focusing on an epistemic resource perspective shifts the focus to examining what are the essential tools that teachers utilise as resources within the learning environments are. Recognising that cognition is a resource and knowledge an intellectual resource, we argue that within classrooms there is a need to shift teacher thinking about events that represent critical features of knowledge generation environments – language, argument, and dialogue. Understanding that there is a shift needed from thinking about each of these from a *learning-to-do* perspective (learning to argue, learning to dialogue, learning to use language) to a *doing-to-learn* perspective on each as a learning event (using language to learn, arguing to learn, dialoguing to learn) is critical for adapting to knowledge generation environments.

We build on the theoretical work of Halliday (1975) who focused on language, and argued that the process of understanding language as tool is framed around the concept of a learner learning about language, through using the language as they live the language (Hand, Chen and Suh 2021). This theoretical perspective shifts the use of language from being declarative or procedural knowledge, emphasising language as statements to be learned or associated practices for use, to an understanding of learners using the declarative and procedural components in living the language and coming to know why they use language – epistemic knowledge. Such a perspective enables a framing around the three forms of knowledge: declarative knowledge *about* language, procedural knowledge for *using* language, and epistemic knowledge for *knowing through* language (Hand, Chen and Suh 2021).

We argue that both argument and dialogue can be considered epistemic tools, that is, both can be framed around the same framework as for language. We learn about argument, as we use argument as we live argument, and we learn about dialogue, as we use dialogue and as we live dialogue. Each of these three tools is essential element for any learning environment but are utilised much more effectively in knowledge generation environments (Yaman 2020). Importantly, they have been shown to work in parallel with each other regardless of a generative or traditional environment (Cikmaz et al. 2021). However, they were used much more effectively in generative learning environments.

2.2. Epistemic Orientation

Shifting classrooms towards generative learning environments requires teachers to fundamentally change their epistemic thinking (Bae et al. 2022). Suh et al. (2022) described these epistemic shifts through the concept of *epistemic orientation*, which refers to a way of thinking determined by beliefs around knowledge and the knowledge generation process. Epistemic orientation is deeply influenced by personal epistemological beliefs with research documenting a close link between teachers' epistemological beliefs and their expertise related to focusing on teaching goals (Kang. 2008), conceptions of teaching, curriculum selection, and implementation, and most importantly, instructional practices (Brownlee et al. 2011; Tsai 2003; Yadav and Koehler 2007). For instance, Hashweh (1996) found that teachers with constructivist epistemology tended to use more effective teaching strategies, including teaching for conceptual change. Further, Chan and Elliott (2002) reported that teachers' epistemological beliefs impact how they understand the intellectual essence of a task, and the process for choosing strategies when addressing complicated and uncertain tasks in a classroom. They suggest that these effect a teacher's ability to be adaptive.

Epistemological beliefs have often been defined broadly and inconsistently (Hofer and Pintrich 1997; Sandoval 2005), which limits the application of a specific theoretical stance for understanding teachers' instructional practices necessary to adapt to knowledge generation approaches. To address this concern, a model of epistemic orientation towards knowledge generation (EOTS-KG) was introduced as a comprehensive framework for examining different sets of interconnected beliefs (Suh et al. 2022), including beliefs about knowledge, learning, and teaching, which are inherently intertwined and consensual. We argue that aligning epistemic orientations with knowledge generation approaches (EOTS-KG) has two critical benefits. First, it helps teachers become learners willing to take on new ideas about teaching (Brownlee et al. 2017; Buehl and Fives 2016). Teachers with a strong EOTS-KG believe that knowledge can be changed with new evidence and are willing to change their own ideas and practices through new learning (Suh et al. 2022). This highlights that epistemic orientation can be a key driver for changes in other knowledge bases (Hand, Chen and Suh 2021). Second, a strong EOTS-KG helps teachers develop more willingness to use epistemic tools in alignment with their pedagogical goals (i.e. knowledge generation), so they can see the value of this approach for students and themselves in their teaching (Bråten et al. 2017).

3. Methods

This study comes out of a three-year, NSF-funded project (DRK-12 award XXXXX) that engaged elementary school teachers in professional development on a generative learning approach called the Science Writing Heuristic approach (SWH; Hand, Chen and Suh 2021). Participating teachers were grade K-5 science teachers in predominantly rural areas. Our purpose was to understand how teachers change over time in their understanding of generative learning and in their capacity to implement adaptable, generative learning environments in their classrooms. The study utilised a latent profile analysis design that identifies membership clusters based on patterns in observed measures. The first step was to identify the appropriate number of clusters at each time point, then to link the clusters over time. This allows the latent classes to be comparable even as individual teachers can change in their membership across time.

3.1. Research & Professional Development Context

The research context for the study is a two-year professional development experience with repeated cycles of summer and academic year sessions, led by the research term of university scholars, experienced SWH teachers, and our area cluster coordinators. Participating teachers attended 10-day professional development in each year: a cluster-based, 4-day early summer workshop held at the university or a regional educational agency (teachers from different districts coming together as a cluster); school-based, 2-day late summer planning session held at each school; and 4 days of ongoing support throughout the academic year through cluster-based, school-based, and individualised experiences.

This project involved discussions of learning theory, student knowledge development, and explicit attention on language, dialogical interactions, and argumentation. Wherever possible we focus attention on how the learner is learning rather than what the teacher is teaching. Teachers were asked to explore these ideas through an example generative learning experience, to negotiate these learning concepts in groups, and to plan for incorporating argument, language, and dialogue in their classroom learning environments. Because we emphasise an *approach* and not a *curriculum*, teachers were requested and supported to implement the approach across any and all science during the academic year.

3.2. Participants

Data come from 95 teachers recruited from rural areas of [a midwestern state] and [a southern state]. The participating teachers were drawn from K-5 classrooms, with teaching experience range from 1 year to 30 years, with only 3 male teachers within the group. Participating schools were drawn from a range of different counties in both states. These schools were located in rural areas where the free and reduced percentages ranged from 37% to 65%. The mid-west area was predominately white, while the other area ranged in African-American populations ranging between 50–70%. Participating teachers were asked to commit to participating for two consecutive years. They were asked to respond to the EOS and the three epistemic tool questionnaires twice per year over their two-year commitment: during the cluster-based PD session each summer, and midway through the following academic year each winter. Thus, we have collected data at 4 time points organised into 4 waves: Summer 2019, Winter 2020, Summer 2020, and Winter 2021. The waves were intended to be about 6 months apart, although exact dates varied due to the scheduling of PD sessions around district calendars.

3.3. Instruments

We implemented multiple instruments organised into two areas. First, we used three instruments to measure teachers' knowledge of using Argument, Language, and Dialogue as epistemic tools. The instruments consist of Likert-type items that examine how teachers understand the roles of the respective tool in generative environments. Each epistemic tool instrument is designed to be unidimensional, yielding estimated scores using anchored Rasch measurement models. The instrument on Argument has 14 items such as 'Any statement can be interpreted as a claim requiring evidence' and 'Students generate their own knowledge by arguing with other people' (Fulmer et al. 2023). The instrument on Dialogic Interaction, 12 items, such as 'Students' conversations with each other allows them to build up their own scientific knowledge" and 'Students engage in discussions more readily when they trust their group members' (Hand, Chen and Suh 2021). The instrument on Language has 15 items, such as 'Students cannot think through scientific ideas without language' and 'Students should be able to communicate their own ideas about what we have discussed in class' (Hand, Chen and Suh 2021).

Second, we used an instrument measuring teachers' epistemic orientation, the Epistemic Orientation Survey (EOS; Suh et al. 2022), which consists of 44 items in four dimensions: Epistemic Nature of Knowledge (8 items); Epistemic Alignment (24 items), Student Ability (4 items), and Classroom Authority (8 items). A score is computed on each EOS dimension by summing the item responses (Suh et al. 2022). The 4 dimensions of EOS and the three teacher's knowledge as an epistemic tool form an overall Teacher's epistemic knowledge. The data from these 7 measures at all 4 waves was used as manifest variables for the subsequent latent profile analysis.

3.4. Analysis Procedure

To form and interpret profiles of participating teachers over time, we use longitudinal latent profile analysis (LLPA) to determine whether we can form groups of participants based on their scores on the 7 questionnaires at every time point. The groups at any time point are latent classes, and these profiles are formed by looking at class membership over time. The notation for LLPA is taken from Bartholomew, Knott and Moustaki (2011) as cited in Demaray et al. (2021):

$$f(x_t) = \sum_{j=0}^{(k-1)} n_{jt} \prod_{i=1}^{p} g_{it}(x_{it}|j)$$

where X_t is the matrix form of the joint distribution of the individual responses at times t.

Before fitting a longitudinal profile, we began by exploring latent classes at each time point to determine how many distinguishable groups of teachers are appropriate. This allows us to model the appropriate membership in profiles across time and to impose measurement invariance to ensure that the same number of profiles created and the type of classes are comparable over time. This is because we do not assume that all participating teachers would start at a 'low' level, but rather we anticipate there may be teachers in any of the three profiles at any time point. We fit latent profile models with anywhere from 2 through 7 classes, and analysed the results to identify the most appropriate number of classes based on a variety of model indices.

The data preparation was done using R 4.0.5 (R Core Team, 2021) and analysis was conducted using Mplus 8.6 (Muthen and Muthén 1998-2020). We have complete data on all 95 teachers during waves 1 through 3, during the initial year-and-a-half of the project before the news in January and February of 2020 about the emerging pandemic, and full responses for 82 of these teachers in wave 4. We therefore estimate our latent profiles and longitudinal profiles in Mplus with the Full Information Maximum Likelihood estimation, which is flexible to some missing data.

We compare models using information criteria, where a lower value indicates a better fitting model, including Akaike Information Criteria (AIC, Akaike 1974) and the Bayesian Information Criteria (BIC, Nylund, Asparouhov and Muthén 2007). We examine the proportions of profile membership, where each profile should not be overly small to lack meaning (Spurk et al. 2020), so we set a cut-off that a profile would only be acceptable if it contained at least 5% of the sample. We consider the entropy criterion (Celeux and Soromenho 1996), where higher is better and values above 0.80 are considered good (Clark and Muthén 2009). We also considered the Vuong-Lo-Mendell-Rubin likelihood ratio test (VLMR LRT; Tynjala 2001) and bootstrapped likelihood ratio test (BLRT; McLachlan and Peel 2000) for identifying better-fitting models. Analyses indicated that 3 latent classes at each time had the best combination of model fit indices with lower values for AIC and BIC, and satisfactory entropy levels. Moving to a higher number of latent classes not only resulted in some classes having insufficient membership percentages but also did not substantially improve the model according to likelihood ratio tests. Next, we modelled longitudinal latent profiles assuming 3 latent classes at each time point. Entropy for the LLPA was 0.916, indicating a very good classification of participants to a corresponding group.

4. Results

Our goal is to examine potential patterns in the changes in teachers' understanding of an orientation towards epistemic practices in science teaching and learning. An overall view of the data in Table 1 shows that teachers had apparent changes over time in their level on the 7 outcome measures, with a predominantly positive trend. Repeated measures analysis of variance showed statistically significant differences for each of the seven measures (F-values ranged from 4.259 to 54.776, $df_n = 3$, $df_d = 243$, all p-values $< .01$).

Despite an overall positive trend, we do not assume that teachers would remain in the same level or group over the course of the study – we expected that participation in the professional learning experience may result in different patterns of growth among the teachers on the various measures. Building on the concepts of complexity, we recognise that teacher changes will not be linear but will depend on a combination of shifts in understanding of their orientation to learning and the role of epistemic tools. Thus, applying the LLPA lets us model whether there are distinguishable groups at each time point. The LLPA findings help disambiguate that overall pattern by distinguishing three latent profiles: one group has relatively higher scores on all the measures, one group has relatively lower scores on all the measures, and one group hovers in the middle. Hence, we named the three classes higher, medium, and lower groups according to the estimated level of epistemic knowledge.

Additionally, because we do not believe that latent group membership is fixed over time, the LLPA allows teachers' classification to change over time. Our theoretical framework emphasises that learning is complex and may be nonlinear, so we model this such

Table 1. Descriptive statistics of observed variables by wave.

	Wave 1		Wave 2		Wave 3		Wave 4	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
Argument	95	−0.04 (0.32)	95	0.333 (0.42)	95	0.246 (0.49)	82	0.375 (0.56)
Language	95	−0.333 (0.63)	95	−0.203 (0.62)	95	−0.085 (0.52)	82	0.091 (0.66)
Dialogue	95	0.088 (0.39)	95	0.531 (0.58)	95	0.664 (0.59)	82	0.733 (0.60)
Knowledge	95	32.274 (3.34)	95	32.716 (3.46)	95	33.147 (3.09)	82	33.585 (3.14)
Alignment	95	93.505 (7.22)	95	97.242 (7.94)	95	97.958 (8.25)	82	99.585 (8.30)
Authority	95	30.389 (3.38)	95	32.421 (3.09)	95	32.600 (3.58)	82	33.159 (3.46)
Ability	95	17.495 (1.78)	95	17.579 (1.70)	95	17.768 (1.67)	82	17.988 (1.57)

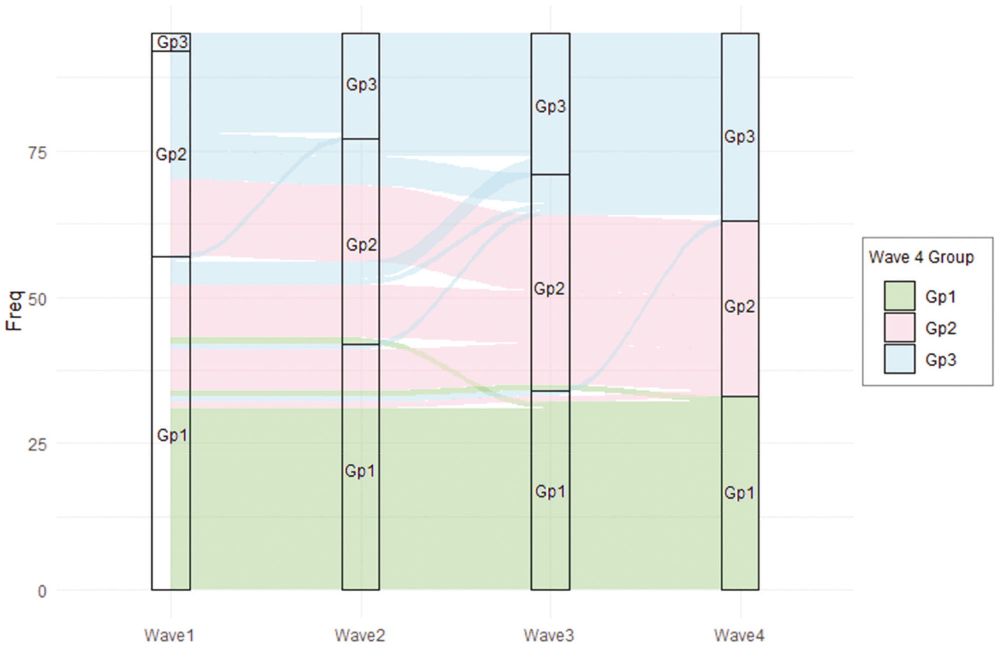

Figure 1. Flow diagram showing changes in profile membership over time. *Note*. The blocks at each Wave represent the number of members in the latent groups at that wave, with smaller blocks representing fewer persons and vice versa. The coloured bands connecting the blocks are coloured coded according to the group membership at Wave 4: light green for individuals in group 1 at Wave 4; light pink for individuals in group 2 and Wave 4; and light blue for individuals in group 3 at Wave 4. This shows the changes in group membership from the initial grouping through each wave until the end of the project.

that any particular teacher may be in a different group at any of those time points. Figure 1 shows a flow diagram indicating the number of teachers who change their latent class over time, colour-coded by their group membership at the end of the study: light green for individuals who move into the low group (Gp1) at Wave 4; light pink for individuals who move to the middle group (Gp2) at Wave 4; and light blue for individuals who move to the high group (Gp3) at Wave 4. As the figure demonstrates, there are some individuals in the low and middle categories who remain in this group over the entire study period. That is, light green strands that start in Gp1 at Wave 1 represent teachers who remain in Gp1 into Wave 4, and light pink strands that start in Gp2 at Wave 1 represent teachers who remain in Gp2 into Wave 4. However, we also note that there are a sizeable number of individuals who do change group membership. The greatest proportion of change involves 22 teachers (23.1% of participants) who changed membership from the middle group at wave 1 to the higher group by wave 4 - represented by light blue strands that start in Gp2 at Wave 1. Almost as many, 17 teachers (17.9% of participants), changed membership from the lower group at wave 1 to the middle group by wave 4 - represented by light pink strands that start in Gp1 at Wave 1. We also see 7 teachers (7.4% of the sample) who began in the lower group at wave 1 but ultimately shifted to the highest level by wave 4 - represented by light blue strands that start in Gp1 at Wave 1.

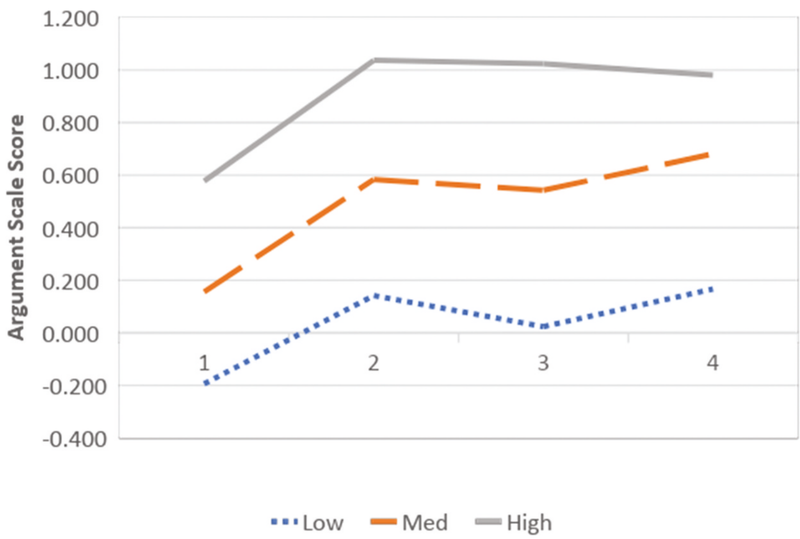

Figure 2. Argument questionnaire scores over time by latent group.

Table 2. Group means on argument and EOS Ability by wave.

		Wave			
Group	Measure	1	2	3	4
Low	Argument	−0.194	0.142	0.024	0.167
	EOS Ability	16.53	16.74	17.05	17.30
Medium	Argument	0.155	0.583	0.543	0.681
	EOS Ability	18.91	18.80	18.83	19.07
High	Argument	0.577	1.037	1.023	0.980
	EOS Ability	19.33	19.33	19.00	19.00

Note. Argument scores are computed as Rasch ability estimates. EOS Ability scores are reported as the raw factor score.

Even though some individuals do not change their group membership, we also recognised that it would be possible that an entire group could shift *en bloc*. Indeed, Figure 2 plots data from Table 2 to show how groups of participating teachers saw a change in their scores on the knowledge of argument as an epistemic tool, with a noticeable initial growth on the measure followed by apparent 'leveling off'. As Figure 3 shows, teachers in both the medium and high latent groups began with relatively more informed views of students' ability to generate knowledge, while teachers in the low latent group started with less informed views but changed over time. We do want to emphasise that latent group membership changes over time from wave to wave, so we observe individual growth and an overall sense of group growth, but there could also be minor fluctuations in group averages by wave.

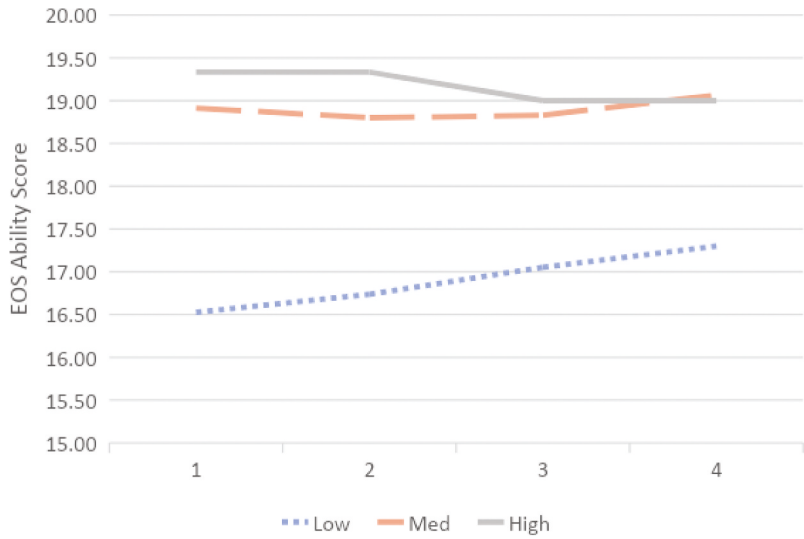

Figure 3. EOS Ability score over time by latent group.

5. Discussion

Recent research has begun to highlight the complexity associated with learning (Century and Casatta 2016). Befitting this complexity, our results highlight the 'non-linearity' of the process through which teachers learn about knowledge generation learning environments. The profiles were generated on responses to survey instruments on orientation to generative learning and understanding of the role of epistemic tools. The results show that initial understandings varied between teachers, with the direction of growth appearing to be based on initial orientation and the growth in understanding of each epistemic tool varying depending on orientation. By encouraging teachers to build their own knowledge related to generative learning as a critical element of the PD, along with developing pedagogy aligned to their understanding, we suggest that the potential for paradigm shift is increased. Importantly, once teachers shift to a higher profile they do not appear to fall back to a lower profile; that is, once they engage in the paradigmatic shift, they appear not to fall back.

The complexity perspective emphasises that each individual responds in unique ways that are impacted by his/her own prior experiences, which will/may result in very individualised, idiosyncratic trajectories of growth. The findings of our latent transition analysis indicate that the teachers can be clustered together to show a few meaningful patterns of growth over the four waves. We are not arguing that there is uniformity within each profile in how the teachers understand the role of, and interaction between, each of these systems. The professional development programme was orientated on challenging teachers' conceptual knowledge around these systems, not providing certainty in terms of particular pedagogical strategies to use, or pushing a particular curriculum product and, as a consequence, teachers were encouraged to resolve their uncertainties about the systems based on their own particular school setting. This emphasis on encouraging teachers to generate their own understandings means that their pathways are unique but may exhibit similarities in their responses on measures of their understanding and orientations.

Recognising that each teacher brings a unique set of background experiences, knowledge and resources into the professional development environment requires the implementation of a complexity perspective in trying to understand the learning which arises from such a programme. The results from this study begin to highlight that there are different profiles of teachers and development varies over time. Teachers are learners, and as a consequence, frame their own learning from their background knowledge, that is, teachers' engagement with, and understanding of, these different aspects of orientation and tools are driven by the knowledge they have coming into the PD. Building the foundational knowledge to enable them to be adaptive within their own classroom settings requires the development of multiple interconnected systems of epistemic orientation and epistemic tools. This is a complex, dynamic, multidimensional process that requires them to have a rich understanding of these critical elements and respond to the unfolding events within classrooms to maximise learning opportunities for students.

This unique pathway balanced against the appearance of clusters requires more research into the role of PD and teacher's development of understanding of the complex interaction between orientation and tools. Research needs to focus on more in – depth studies of the change process as teachers move through PD. We argue that this must be qualitative to enable richer engagement in teacher thinking and implementation within their own classroom settings. Change is complex and while analysing the survey instruments provides us with recognition of this complexity, richer insights through qualitative designs will unpack this complexity in richer ways. In terms of PD, the outcome of clusters may provide us with a pathway that can 'tailor' PD to promote richer and faster transitions to higher levels of paradigmatic shifts. For example, by tailoring PD, can we reduce the time for shifting to higher profiles than the 18–24 months previously reported (Hand, Chen and Suh 2021)?

Our framing of the professional development programme focused on science while addressing generative learning concepts that positioned the teachers as learners who were engaged in building their own understandings and exploring how to use them in their own settings. Teachers were challenged about learning theory, and the roles of language, argument, and dialogue within generative learning environments. The intention was to promote epistemic doubt (Bendixen 2016), and provide reflective opportunities to move towards resolving and generating understandings for implementing generative environments within their classrooms. In structuring the PD (Hand, Chen and Suh 2021), we did not provide teachers with a focus on the what (declarative knowledge) and the how (procedural knowledge) of implementing generative learning environments. Rather, the emphasis was on teachers generating an understanding of why (epistemic knowledge), based on their own classroom environment, these epistemic resources promote student generation of knowledge. We argue that the ability of the teachers to be adaptive and respond to the dynamic and fluid nature of these generative learning environments is framed upon their epistemic orientation and their utilisation of the tools epistemically.

While our findings show that there are detectable patterns among teachers' responses across waves that allowed for identifying latent classes and, especially importantly, transitions among these classes over time, it is not without limitation. One of the key issues with any latent classification procedure like LPA is whether the class membership is meaningful and defensible. We attempt to control for this by confirming the optimal number of classes at each time point before forming classification across wave, and by checking for differences among the groups over time. Future work could explore the potential differences among these profiles through follow-up work or case study methods. This future work could challenge or corroborate these classifications, and add detail to the interpretation of group differences that may emerge over time.

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Ethics approval

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