Routledge
Taylor & Francis Group

International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

Science teacher orientations and PCK across science topics in grade 9 earth science

Todd Campbell, Wayne Melville & Dawne Goodwin

To cite this article: Todd Campbell, Wayne Melville & Dawne Goodwin (2017): Science teacher orientations and PCK across science topics in grade 9 earth science, International Journal of Science Education, DOI: 10.1080/09500693.2017.1326646

To link to this article: http://dx.doi.org/10.1080/09500693.2017.1326646

Published online: 23 May 2017.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2017
https://doi.org/10.1080/09500693.2017.1326646

Routledge
Taylor & Francis Group

Check for updates

Science teacher orientations and PCK across science topics in grade 9 earth science

Todd Campbell[a], Wayne Melville[b] and Dawne Goodwin[a]

[a]Curriculum and Instruction, University of Connecticut, Storrs, CT, USA; [b]Faculty of Education, Lakehead University, Thunder Bay, Ontario, Canada

ABSTRACT

While the literature is replete with studies examining teacher knowledge and pedagogical content knowledge (PCK), few studies have investigated how science teacher orientations (STOs) shape classroom instruction. Therefore, this research explores the interplay between a STOs and the topic specificity of PCK across two science topics within a grade 9 earth science course. Through interviews and observations of one teacher's classroom across two sequentially taught, this research contests the notion that teachers hold a single way of conceptualising science teaching and learning. In this, we consider if multiple ontologies can provide potential explanatory power for characterising instructional enactments. In earlier work with the teacher in this study, using generic interview prompts and general discussions about science teaching and learning, we accepted the existence of a unitary STO and its promise of consistent reformed instruction in the classroom. However, upon close examination of instruction focused on different science topics, evidence was found to demonstrate the explanatory power of multiple ontologies for shaping characteristically different epistemological constructions across science topics. This research points to the need for care in generalising about teacher practice, as it reveals that a teacher's practice, and orientation, can vary, dependent on the context and science topics taught.

ARTICLE HISTORY
Received 9 June 2016
Accepted 1 May 2017

KEYWORDS
Pedagogical content knowledge; teacher orientations; teacher beliefs

This research seeks to challenge and further develop an understanding of the interdependence of two key aspects of pedagogical content knowledge (PCK): science teacher orientations (STOs) and the topic specificity of PCK, especially as it relates to teachers' practice in classrooms (Abell, 2007; Magnusson, Krajcik, & Borko, 1999). One of the most influential models of PCK for science teaching can be found in Magnusson et al. (1999). In their conceptualisation, PCK includes orientations towards teaching science, or what would later be referred to as STOs, which shape, and are shaped by, knowledge of (a) the science curriculum, (b) students' understanding of science, (c) instructional strategies, and (d) assessment of science literacy. In Magnusson et al.'s (1999) conceptualisation of PCK, orientations towards teaching science was understood as a teacher's 'general way of viewing or conceptualizing science teaching' (p. 97). Friedrichsen, Van Driel, and

CONTACT Todd Campbell todd.campbell@uconn.edu Curriculum and Instruction, University of Connecticut, 249 Glenbrook Road, Unit 2064, Storrs, CT 06269, USA

Abell (2011) proposed a further refinement to Magnusson et al. (1999) conceptualisation of orientations towards teaching science in order to address a lack of clarity within the model with respect to how researchers characterised and applied teacher orientations in their attempts to understand how orientations shaped planning and instruction. The clarity provided by Friedrichsen et al.'s model of STOs related to how it was conceptualised, and could be applied, and led to our adoption of this model in our previous research (Campbell, Longhurst, Duffy, Wolf, & Shelton, 2013; Campbell, ZuWallack, Longhurst, Shelton, & Wolf, 2014). In this current research, we have again adopted their model with its proposed three dimensions of STOs which include '[1] beliefs about the goals and purposes of science teaching, [2] beliefs about the nature of science, and [3] beliefs about science teaching and learning' (Friedrichsen et al., 2011. p. 373) in an attempt to understand how these dimensions might come together as a lens through which teachers view and shape classroom instruction. In taking this stance, however, we find ourselves contesting the notion that teachers hold a single way of conceptualising science teaching and learning, or unitary ontology, that we (Campbell et al., 2013), and others have (e.g. Friedrichsen et al., 2008; Schwartz & Gwekwerere, 2007), somewhat by default, attributed to STOs. While we recognise that much of the literature in science education that focuses on STOs makes mention of the multiplicity involved in considering this key aspect of PCK, it seems that this multiplicity is often set aside in the reported literature (e.g. Kapyla, Heikkinen, & Asunta, 2009). Rather, research findings in this area seem to ascribe what might be taken as a unitary ontology for teaching science (Campbell et al., 2014; Roehrig & Luft, 2004, 2006). Put more succinctly, researchers examining STOs have failed to consider that a given teacher might have more than one orientation to teaching science. Instead, researchers have assumed that a given teacher has a single orientation to teaching science, regardless of the content or topic being taught, and that this orientation informs their teaching practice. An example of this can be seen in our own work as we developed STO profiles to consider how dimensions of STOs push or pull on one another to shape teachers' beliefs (Campbell et al., 2013, 2014). In this work, we recognise that our lack of consideration of the potential for STOs to fluidly change as teachers engage in their work has, even if only by omission, painted a picture of a unitary ontology related to STOs.

Beyond a focus on STOs, researchers in science education have also sought to clarify the topic specificity of PCK. In this, researchers (Abell, 2007; Hashweh, 2005; Kind, 2009; Van Driel & Berry, 2012) have synthesised the literature to document how PCK is both topic- and situation-specific. In this, they have revealed how instruction within disciplines (i.e. at the topic-level) can vary. Collectively, we believe that the discussion of the variability related to teachers' STOs and the topic specificity of PCK could potentially explain the dearth of literature relating to how STOs (Abell, 2007; Friedrichsen et al., 2011) shape classroom instruction.

Given this, this current research sought to provide additional clarity related to STOs and PCK topic specificity, by examining a potentially promising theoretical framework that has not, to date, been applied in efforts to explain the potential multiplicity of STOs. More specifically, resource activation as a model of cognition (Hammer, Elby, Scherr, & Redish, 2005) was taken up in this current research, since it was seen as a potentially promising theoretical framework that could contribute significantly for moving the literature related to teacher knowledge and PCK forward. Given this, the following research question was explored: To what extent does the resource activation model of cognition help explain the application of orientations and topic-specific PCK by a grade 9 science teacher across topics in earth science?

Theoretical frameworks and empirical groundings

The theoretical framework and empirical grounding for this research were constructed by first relying on the notion of framing as a mechanism for conceptualising what compels teachers to activate various resources in shaping instruction. This is logically followed by connecting framing to resource activation as a model of cognition that might provide explanatory power for understanding the resources teacher activate to shape instruction. Especially relevant to this framework is how resource activation can be understood in terms of coherence, epistemic fragmentation and stability, and idiosyncrasy related to how teachers activate STOs and PCK topic specificity, or in the case of this research, science topics taught in the grade 9 earth science. More about each of these individual theoretical perspectives and their relation within the theoretical framework for this current research are elaborated next.

Framing

In seeking to address our research question, we are drawing on the integrative power of framing: 'the set of simple elements that organize the perception of a given situation' (Davis & Russ, 2015, p. 223). Frames are similar to the 'epistemic stances' of Bromme and Goldman (2014, p. 59), in that they provide teachers with a knowledge structure for understanding science and their roles and actions that shape instruction. Russ and Luna (2013) provide one example of evidence for the power of framing as they reveal how the particular framing a high school biology teacher used to organise her perceptions of a given situation activated different sets of knowledge resources that shaped instruction. In this, framing can be considered a 'set of expectations an individual has about the situation in which she finds herself that affect what she notices and how she thinks to act' (Hammer et al., 2005, p. 96). Framing can be considered as 'the activation of a locally coherent set of resources, where … the activations are mutually consistent and reinforcing' (Hammer et al., 2005, p. 99). More specifically related to teaching, framing is both dynamic and tacit, meaning that much of how framing activates teacher's professional knowledge is (at least initially) masked: '[t]eachers are not used to articulating their practical knowledge: they are more in a "doing" environment, than in a "knowing" environment' (Van Driel, Beijaard, & Verloop, 2001, p. 142). The work to unmask teachers' knowledge, and consequently understand how they make sense of the contexts in which they work, has been a focus of much research over the past decade (Davis & Russ, 2015). Given that framing is intimately bound to the dynamic interactions between teachers and their students in different contexts as they consider the material world, various cultures that interact with their work, their social interactions, and the differences between science topics they are teaching, framing by teachers can be seen as a 'process of regular and mutual negotiation of interaction' (Davis & Russ, 2015, p. 228). It is this process of negotiation that suggests that framing sets the stage for resource activation as a model of cognition that leads to the integration of STO and the topic specificity of

PCK in ways that give rise to cognitive states. Further in this exploratory research, we propose that through examining the interaction between this framing and cognitive states we can deepen our understanding of teachers and teaching. This leads us to describe the logical connection between framing and resource activation as a model of cognition taken up next.

Resource activation as a model of cognition for understanding PCK

In our work to date, we have – uncritically – accepted the idea that teachers with a reformed orientation to science teaching and learning would hold that orientation consistently across all topics that they taught (Campbell et al., 2014). The capacity, and ability, to teach from a reformed orientation would, we believed, be transferrable between topics; transfer being 'the ability to extend what has been learned in one context to new contexts' (Bransford, Brown, & Cocking, 1999, p. 51). However, such a stance is open to challenge, on the grounds that it signifies 'knowledge or ability as a *thing* that an individual acquires in one context and may or may not bring to another' (Hammer et al., 2005, p. 92, emphasis in original). To describe a 'particular piece of knowledge as an intact cognitive unit is to ascribe to a unitary ontology' (Hammer et al., 2005, p. 92). However, if knowledge and abilities are conceptualised from a manifold ontology, then they are comprised of 'many fine-grained resources that may be activated or not in any particular context' (Hammer et al., 2005, p. 92). Under a manifold conceptualisation of ontology, learning is not the acquisition of unitary cognitive objects, but a cognitive state in which the learner activates multiple cognitive resources related to the context. When confronted with a new context (e.g. teaching different science topics), a teacher would not transfer an intact cognitive object. Instead, a teacher would activate a variety of resources that may or may not be similar to a previous cognitive state (i.e. collection of resources activated in the previous context), depending on the extent to which there is compatibility between the different science topics in the new context, and depending on notions of coherence, epistemic fragmentation and stability, and idiosyncrasy explicated next.

Coherence, epistemic fragmentation and stability, and idiosyncrasy.

Coherence as conceptualised in this research is concerned with logical connections and consistency that exists between the resources teachers activate as they think about, construct, and enact instruction. As an example, we documented the logical connections and consistency between the STO beliefs teachers held as we constructed STO profiles in our earlier research (Campbell et al., 2013, 2014). In this earlier work, we found coherence in how teachers, whose beliefs about science teaching and learning were characterised as traditional and reliant on a focus on information and transmission, also held naïve beliefs about the nature of science that focused on students getting the 'right answers'. Additionally, these teachers held beliefs about the goals, or purposes, of science teaching characterised as being focused exclusively on 'the canon of orthodox natural science, that is, the products, while little to no emphasis … [was] placed on the "processes of science itself" … [or the how science might be leveraged for] "social purposes"' (Roberts, 2007, pp. 2–3). What was under-examined in this previous research on STOs, however, was the extent to which coherence in teachers' beliefs were established relative to the various science topics these teachers taught. Given that teachers have different experiences with, and levels of expertise, across the topics that they teach, and that there can be fundamental differences across these science topics, it is unrealistic to expect that a teacher's orientation could be fully, and consistently, coherent across the entirety of their teaching practice. To argue for such a consistency would be to ascribe 'stable, robust, context-independent concepts or intuitive theories' (Elby, 2010, p. 1) to a teacher. Instead, Elby (2010) and Hammer et al. (2005) suggests that resource activation is only locally coherent, being reliant on a 'context-dependent activation of finer-grained knowledge elements that are more loosely organized than "theories"' (Elby, 2010, p. 1). Given this, it is expected that as teachers resource activations are examined across contexts (e.g. science topics they teach) epistemic fragmentation and stability, as well as idiosyncrasy, would become apparent.

More specifically, relative to considering epistemic fragmentation and stability, from the perspective of a manifold ontology, epistemic resources are fragmented, and their activation is dependent on topic-specific circumstances. Here, epistemic resources are understood as the wide variety of resources individuals use for constructing knowledge (Redish, 2004). In the case of this research specifically, epistemic resources would be those resources teachers use to construct knowledge about teaching and learning. If the activation of resources is 'mutually reinforced by each other and/or contextual cues', the result is a stable network of resources that is 'locally coherent' (Elby, 2010, p. 15). By stable, we mean the structural cognitive relationship between the person (i.e. teacher) activating resources and each topic, a relationship developed over time and through repeated activations of the same epistemic resources. Through these passive, repeated activations, the resources 'can become established to the point that it becomes a kind of cognitive topic, and so a kind of resource in its own right' (Hammer et al., 2005, p. 19).

However, within resource activation, there is a recognition that teacher cognition and subsequently teacher professional learning are complex and must take into account the idiosyncrasy of teachers' coherence seeking (Hammer & Sikorsky, 2015). This complexity arises through, among other things, the idiosyncratic thinking that teachers engage in, and the ideas that they hold, based on their unique past and present experiences within the world. Ultimately, the notion of idiosyncrasy within resource activation points to the dynamic, not static, ways in which resources are activated as teachers pursue, assess, and refine their ideas, as well as the coherence among their ideas over time. In this, idiosyncrasy is understood as teachers' coherence seeking in how they dynamically activate resources in context-specific ways as they recursively make sense of the similarities and differences of contexts and take up new ideas that influence these perspectives.

Methodology and method

This article is based on our work with a secondary science teacher in the western United States. In the five years before this particular research, the participant and the first author engaged in approximately 240 hours of professional development work together. The results of this previous research work were published in 2013 and 2014 (Campbell et al., 2013, 2014). This long period of shared work is important in building up the level of trust that facilitates, and supports, our investigation into the intensely personal nature of this teacher's work. Based on the previous work, and the trust that has developed, we believe that a narrative methodology was appropriate, given that narrative is 'increasingly seen as crucial to the study of teachers' thinking, culture and behavior' (Zembylas, 2003, p. 214).

The specific narrative methods that we employed were narrative analysis and analysis of narratives strategies, which are described by Polkinghorne (1995). Under the narrative analysis strategy, the previous research work constructed a narrative conceived of as a *standards-based reform teacher orientation profile* (Campbell et al., 2014). This narrative described the way that the three-dimensions of STOs coalesced to shape an individual teacher's STO. In the previous research, Max (a pseudonym) stood out as the only participant whose beliefs informed the construction of the reformed orientation. While he indicated a reform orientation to his teaching, no previous attempts were made to observe his teaching (Campbell et al., 2014).

With our evolving understanding of the topic specificity of PCK and epistemic resources, we began to consider the extent to which Max's identified orientation was reflected in his classroom instruction. This reconsideration is important since researchers have noted the dearth of literature investigating the interplay between STOs and classroom practices when teaching specific content (Abell, 2007; Friedrichsen et al., 2011). This reinterpretation of the narrative utilises the analysis of narrative method outlined by Polkinghorne (1995). Under this a priori strategy, the narrative of the *standards-based reform teacher orientation profile* was to be analysed using concepts 'derived from previous theory … and applied to the data to determine whether instances of these concepts are to be found' (Polkinghorne, 1995, p. 13). The three concepts that have been used in this work are STOs (Friedrichsen et al., 2011), the topic specificity of PCK (Hashweh, 2005), and the manifold ontology of knowledge and activation of cognitive resources (Hammer et al., 2005). To pursue this strategy, however, required the collection of data such as classroom observations of Max's teaching and a more forensic understanding of his topic-specific STOs.

Data collection

To pursue this line of inquiry, we required four additional sources of data; three interviews and the video recording of two topics of classroom instruction. Each of the three interviews was conducted through a webconference platform by the first author at a time of Max's choosing, and lasted approximately 90 minutes. The interview sessions were recorded and transcribed verbatim. To clarify any issues that were raised, Max was provided with the interview transcripts and opportunities were made available for further discussion.

The first interview was a semi-structured interview intended to triangulate, or contest, the STO previously developed for Max. According to Patton (2002, p. 343), a semi-structured interview allows the interviewer to 'explore, probe, and ask questions that will elucidate and illuminate that particular subject'. The questions were developed for this interview to elicit Max's topic-specific beliefs about the goals of science teaching and learning, the nature of science, and science teaching and learning (Friedrichsen et al., 2011). The questions for the interview were provided to Max before the interview in order to give him an opportunity to prepare focused responses and concrete examples

(Seidman, 2013). The following interview questions are representative of the questions designed to elicit Max's beliefs related to his STO:

(1) What do you think is most important for students to learn in your class? (Beliefs)
(2) To what extent do you agree with the following statement: 'science is objective' (Nature of Science)
(3) Describe what you would see as effective teaching in science? (Teaching and Learning)

Working from this initial interview, we recorded two topics of classroom instruction with Max teaching a Grade 9 science class, in order to better understand the relationship between his identified STO and his enacted classroom practices. It should be noted that Max taught Grade 9 in a middle school. The course focused on Earth Science. More specifically, the course focused on a range of different science topics (e.g. ranging from a focus on the physical processes that shape earth's systems to socio-scientific issues related to the use of and human dependency on earth's resources). The elicitation of video data that works in concert with interview data can be instrumental in prompting discussion, recall and reflection around a social phenomenon (Roth, 2007). Specifically, we recorded a pollution unit that lasted nine days and a subsequent oceanography unit that lasted seven days. It should be noted that the typical classroom period across the two units and 16 days observed was approximately 60 minutes (i.e. class periods at the school were 50 minutes on Mondays–Wednesdays & 90 minutes on Thursdays & Fridays). These recordings gave us access to his classroom instruction to compare to his STO identified in the initial interview. Related to the recordings, only one digital recording device was used. However, because a videographer was available, different groups of students were captured on video interacting with Max, which provided a more representative sampling of how he interacted with student groups in the classroom.

The need for a second, unplanned, interview emerged from the analysis of these video recordings. The initial analyses of the classroom videos appeared to reveal an anomaly: while Max's initial interview seemed to triangulate a *standards-based reform teacher orientation*, that orientation only appeared to significantly influence the teaching of the Pollution topic. This observation prompted a consideration of his perceptions of the topic-specific content, and his experiences teaching these topics. These considerations, our previous work, and associated readings led us to develop the research question that formed the basis of this article, and to develop a series of semi-structured interview questions for our final (i.e. third) planned interview.

As with the first interview, the third interview used a semi-structured interview format with question crafted to provide us with a strategy for understanding Max's STOs, his PCK, and the activation of cognitive resources when teaching different science topics.

All research activity was conducted in accordance with the ethics requirements of each author's university. Max was also given an opportunity to critique drafts of this article.

Analysis

In terms of operationalising our analysis, all three researchers independently reviewed the interview transcripts for three main concepts driving our inquiry. More specifically, as we examined the first and third interviews, we looked for statements that were thought to reveal instances that could inform the re-examination of the STO profile that was previously constructed (Campbell et al., 2014). Additionally, we examined these interviews to look for statements that might give insight into the *topic specificity of PCK* (e.g. statements that might reveal how Max thought differently about the science topics and how this might have shaped his instruction). Finally, we examined the interviews to identify statements that might reveal how different *cognitive resources* were being activated in different contexts, particularly as Max described the pollution unit in comparison to the oceanography unit.

With respect to analysis of the recordings of classroom instruction, two of the three researchers reviewed the corpus of the video recordings to identify instances of the three concepts. The third researcher (i.e. second author) followed this, by reviewing all instances of the three concepts previously identified by the two other researchers. In analysing the classroom instruction, Max's statements and actions related to the three concepts were identified. The individual reviews of the data (both interview and classroom video) were compared at the time of analysis and debated, in order to identify the salient examples of the concepts and the linkages that bound them.

Finally, we believe that our work is trustworthy, based on the criteria established by Lincoln and Guba (1985). Our peer debriefings have been extensive, as detailed in our analysis of the data. Furthermore, having worked with Max for over six years gives us confidence in the integrity of the observations and the verisimilitude of Max's member checks. As an example, Max was asked in the final interview to review short classroom video episodes from the pollution and oceanography units to describe the reasons for his statements and actions during instruction. Through this process, Max was able to provide additional insight into the inferences we were making about specific parts of instruction we found to be different across the units, while at the same time helping to inform the interpretation of these statements and actions in ways that we might not have considered or that might have gone unnoticed.

Findings

This research investigated the impact that STOs have on instructional practice, and provides evidence that challenges our original understandings of a unitary ontology for science teaching. The research provides evidence to suggest that STOs may be perceived as both topic-specific and dependent upon the differing activation of resources for each topic. Our reporting of the findings here is organised chronologically to reveal our interpretation of the data as it emerged. Our original understanding of Max, drawn from data gathered from our previous research (Campbell et al., 2013, 2014) and triangulated in the first interview, was that he demonstrated what we previously described as a *standards-based reform teacher orientation*. However, in his practice, as exhibited in the videos from his classroom across two topics of instruction, the instruction appears to be aptly described as reformed in the pollution topic, but more traditional when teaching the oceanography topic (Luft & Roehrig, 2007). More explication of this is chronologically depicted in the presentation of our findings.

A unitary ontology for teaching science

From our previous research, Max was termed as having a *standards-based reform teacher orientation* (Campbell et al., 2014), which was described as follows:

> In this orientation, the participant held beliefs consistent … with a more holistic commitment to both products (canonical knowledge) and processes of science. … The participant was characterized by the reformed category described by Luft and Roehrig (2007) as focusing on mediating student knowledge or interactions. (Campbell et al., 2014, pp. 1835–1836)

In Campbell et al. (2014) and in the current research, especially entering this first interview, there was no mention or questions that pressed Max to articulate ideas about topic-specific PCK, since at the time, we were working from an undifferentiated notion of PCK. This is important to note, for once the discussion turned to topic-specific PCK in the third interview where reference was made to specific classroom topics, contexts, and episodes, our undifferentiated notion of PCK was contested.

The responses from the first interview provided additional evidence to triangulate the *standards-based reform teacher orientation profile* we had previously constructed. This can be seen as his beliefs about science teaching and learning espoused in the interview were characterised as responsive and reformed-based in nature. Luft and Roehrig (2007) characterised responsive beliefs focused primarily on collaboration, feedback, or knowledge development and reformed-based beliefs as focused on mediating student knowledge or interactions. Evidence of this can be seen as Max described the most recent lesson he engaged his students in, and why this lesson was important:

> Because they're doing real science … We've collected local weather data, online … but what does it mean and what relationships can we find between the data? I think it's important because it's real life science work. When they can come back and explain to me what they found out, then a lot more learning has taken place than if I read a text or just told them in a lecture.

Collectively, what we drew from this interview did not differ significantly from the STO we saw from Max in our earlier research, where he espoused reformed beliefs about the importance of mediating student learning, so that students were supported in constructing their own evidence-based knowledge claims (Campbell et al., 2014). Given this, we expected that his previously established reformed STO would be evident in the classroom in the two topics of instruction we recorded. This is where we turn next.

Actualised reformed teaching – pollution

When viewing instruction in the first topic, the pollution topic, Max's reformed orientation seemed to translate into planned opportunities for students to design filtration systems to purify water that would draw on naturally occurring filtration techniques. In this, the students spent the first three days of the unit using online resources in an effort to understand naturally occurring water filtration techniques, before deciding which techniques they could use in their designed filtration systems during the final four days of the unit. Max's role in this included active questioning designed to engage students both individually and class-wide in discussions and sense-making:

Sarah: [Question directed at Max] Can we use fire?
Max: You can use a hot plate. Will that work?
Sarah: Will it char a piece of wood?
Max: You want to burn wood? For what?
Sarah: We want to char the outside of wood and put it in as part of the water filter.
Max: You want to char the outside of the wood? What does that do?
Karen: We read about it … It absorbs the impurities.
Max: How does it do that?

In this episode, Max is found focusing the students on sense-making as he asks the students to consider what specifically the 'charred wood' they are considering including in their filtration devices does to purify water.

Throughout this topic, it appeared that there is consistency between the reform-based orientation originally identified for Max and his actualised classroom practices. Students' initial investigations of water quality using an online simulation that allowed them to manipulate and test how select variable affected water quality (Days 1–3 in the unit) and subsequent experimentation related to their water filtration designs (Days 4–7 of the unit) exemplified reformed visions of science teaching and learning, since students were encouraged to seek and value alternative modes of investigation as they constructed and tested the online investigations they completed and purification techniques they constructed. Additionally, students made predictions and devised means to test them and generated ways of interpreting evidence as they explored water quality data, all features of reformed instruction previously identified in the literature (e.g. Piburn et al., 2000).

Actualised traditional teaching – oceanography

Max's observed teaching practice in the pollution topic aligned with his reform-based orientation. However, when we followed his teaching practices into the subsequent oceanography topic, we saw what we would describe as traditional instruction that seemed misaligned with Max's reformed STO. More specifically, in the oceanography topic, lecture-based teaching was observed. In this, students were asked direct questions that were factually based with little opportunity for or requirement of student reasoning. Max delivered instruction from either the front or side of the classroom, with limited interaction with students, except to transmit information and monitor basic understanding of material covered by the lecture. In the following episode, Max is standing at the front of the classroom using powerpoint slides to teach students about the concepts of convergence, divergence, upwelling and downwelling:

> When the air is rotating to left and to the right in each respective hemisphere and the water does it even more, then you're going to get it diverging at the Equator and get the upwelling from the deep-water. There's this thing called the Ekman transport, so because of the Coriolis Effect, at a specific depth the water is deflected to the right of the surface and the water under that is deflected more and more and actually causes this spiral, like a spiral staircase, it spirals all the way down. So where you have the wind blowing that way on the surface which causes the Coriolis Effect, the duration of waves or currents to go a little bit off, it's deflected to the right in the Northern Hemisphere. Down in the bottom, deep in the ocean, the currents are actually going in the opposite direction.

Tim: Like a tornado?

Max: Yeah. So, it's going in the opposite direction. Overall, since this is a stronger flow, stronger current than down low, since you are losing energy as you go down. Overall, the water is moving that way, but it's moving slower. Kind of like the top is moving faster than the bottom. Top level ocean currents are a lot bigger than your bottom ones and then you also have the convection or the opposite direction, something moving in the opposite direction down low.
[Max moves to side of room to provide directions to students on completion of a worksheet.]

Max: So now on your paper where it says upwelling and downwelling, define these and write a method, that's on the bottom of the front page, if you haven't already done. So how are things upwelled and how are things downwelled?

Jack: What is upwelling?

In this episode, students struggle to create relevant connections to understand the concepts. One student attempts to reconcile his understanding of the Coriolis Effect by comparing the spiral staircase description to a tornado. While Max does answer in the affirmative for the student's connection, it would have been beneficial for the student to have a dialogue about why a connection was made between the tornado and the Coriolis Effect and how the student's understanding of the content or idea created that connection. In teaching this topic, Max's role was traditional, in that it focused on transmitting canonical knowledge. The students' role here was to receive teacher-disseminated knowledge and culminates in each student completing the same worksheet to demonstrate what they have understood from the instruction, the antithesis of Max's apparent reform-based STO.

Reconciling with manifold ontologies

In the second and third interviews, we sought to reconcile the anomaly that manifested itself in differences in instruction we found across the two topics. In the second interview, we called attention to the videos, and associated transcripts, to understand how he perceived his practice. His responses support our assertion that, in terms of both instruction and orientation, Max is heavily influenced by the content and context of the topics that he is teaching:

Interviewer: Thinking in terms of student takeaway messages about science. What might they [students] specifically say connected to your pollution unit or your oceanography unit as far as takeaway messages about science?

Max: Especially with the pollution unit, the one good activity we do, I want the takeaway to be going away from this informational driven teaching toward more of a sense-making experience. What I want them to take away from science is this is a way to make sense out of things and not so much here's a bunch of information that I learned that I can prattle off. There's connections within concepts I want them to take away, like how the pollution stuff and the ocean stuff relate to other systems, how you have energy flow, how matter moves in these systems, how humans interact with it. Beyond that, what they can do as critical thinkers to solve problems and to see problems and how we are going to do it with science.

Interviewer: As far as that objective goes, that would be for both of those units, both the pollution and oceanography?

Max: Yeah, the pollution one more so. I think that's a better unit as far as scientific takeaways, as far as having them do critical thinking skills than the oceanography unit. My takeaway from the oceanography unit was different than the pollution unit.

Interviewer: How was it different?

Max: With the pollution unit it was using data and critical thinking skills to analyze the data and come to a solution or a conclusion regarding the data, and then to develop a solution that would fix it if that were a problem. If you have pollution in a certain place, what's causing that pollution and how would you fix it? With oceanography, the general take-away would be I want them to see how earth's systems interact.

This excerpt highlights the influence of topic specificity on a teacher's instructional strategies. Max attempts to reconcile his teaching in terms of the manifold ontologies that he ascribes to the two units. The instruction in the pollution unit, the 'better unit' relies on a 'good' activity to promote a sense-making vision of science. In contrast, the oceanography unit is tied to a more prosaic vision of science, one in which students 'see … systems interact'. Later in the interview, Max explicitly laid out the interplay between the topic, and his teaching orientations.

> With the oceanography unit, I see myself as a teacher as kind of a traditional teacher, 'Here's a bunch a stuff I know. I hope you eventually know it too'. I have that back and forth. I'm trying to go the direction of, like the pollution unit I think is a little bit better that I'm more of a guide and a mentor to their learning. As a teacher, in the oceanography unit, I'm more of the director or administrator of their learning, which is a different role.

As previously stated, Max was able to reconcile that his practice was topic- and context-specific when asked what he wanted as an outcome for the students from both units. His initial perception of his original practice prior to the video observation was that both units were integrated seamlessly with a common goal of students making connections about the content and between the two units. He is able to recognise that differences in his roles between the two units, identifying himself as a guide or mentor in the pollution unit and as a director or administrator in the oceanography unit. He attributes this disparity in roles as a necessary component of each unit. In the pollution unit, his goal was to allow students to create their own understanding of the concepts and develop a conclusion to support sense-making and problem-solving related to a real-world situation. In the oceanography unit, his role was relegated to transmitting information about the world around them, but not supporting real-world application for the content. However, his understanding of student engagement and learning led him to believe that his teaching is topic- and context-dependent in what students 'take-away' from the units.

While Max could explicate these differences, he was, nonetheless, surprised by how he enacted his orientations in the two units:

Interviewer: You talked about when you looked at the selected transcript of an episode [a short 2-3 minute segment of video that was thought to be representative of patterns of instruction observed during the unit] from the your oceanography unit how you didn't know if that was as much about the experiences with problem solving you want students to experience in your classroom.

Max: Oh, yeah, when I read it, I was like, 'Wow, that sucks,' and then I read your email again and I was like, 'Oh, that was me'.

Now referring to video clips of instruction in the above-mentioned episode:

> Those videos, those were rough to watch … it's indefensible. I'm just talking about things like it's going to somehow stick in their heads and they're going to walk away and be like, 'Yeah, Ekman's spiral, it's the' – like they're not going know – or Ekman transport. They're not going to know what that is just because I said it in class, you know?

Max is able to reconcile from his reflections, that he is not specifically a reform-based teacher, into an understanding that his teaching orientation appears to instead be more topic-specific. He suggests that his goal of teaching is to allow students to develop an understanding of the interconnectedness of the two units, specifically between the hydrosphere and the geosphere and the impact of human activity on each. He seeks to help students understand how human actions impact the environment to allow them to utilise critical thinking skills to develop a solution.

> That's not as clean-cut, as easy, factual answers. It's a little more complicated. You get into climate change and those kinds of things. Like, what are the problems? How does that relate to the ocean? How does it relate to the atmosphere? How can we fix this? What are solutions? I want them to think along those lines rather than just knowing stuff about the atmosphere or the hydrosphere … It allows students to debate, to use critical thinking skills, to go into those deeper modes of thinking. That's the takeaway. I hope to try to push each year more into that realm where they have the deeper thinking processes rather than just information.

However, in the third interview, Max begins to reconcile his earlier espoused unitary belief about his teaching with the reality that his teaching is different across the two units and that he is transmitting information in the oceanography unit. Furthermore, in the third interview, we considered Max's level of understanding of the content knowledge in each of the topics, particularly oceanography, since we were aware of studies suggesting that when teachers lack a deep understanding of a science topic, they tend to use a more traditional style of teaching reliant on lecture, so that they can control classroom discourse (e.g. Carlsen, 1993; Hollon, Roth, & Anderson, 1991). While this could have played a role, it did not seem to provide a comprehensive enough explanation since Max reported having similar coursework in oceanography with both an undergraduate and graduate course, compared to two environmental science courses that supported his disciplinary understandings central to teaching the pollution unit. In his own words, he shared that his preparation in both topics was 'about the same'.

Similarly, we also considered Max's knowledge of instructional strategies as a possible explanation for what was observed across the two units, since this is an important influence on STOs in the Magnusson et al. model of PCK. In this, Max admitted, '[i]f I could find a similar thing for oceanology, I would do a similar thing'. In this, he was referring to the simulation he used in the pollution unit that allowed students to investigate how different variable influenced water pollution. This hints at how knowledge of instructional strategies potentially played a role in the instruction he shaped for students in the Oceanography unit. However, evidence was also found to suggest that he thought about the two topics in different ways (see previous direct quote from Max above). These findings related to Max's content understandings across the two units and his knowledge of instructional strategies collectively, leave open the possibility that something more than what has typically been explained as a lack of content knowledge or lack of knowledge of instructional strategies might be useful in explaining the differences that manifest across the two topics that were observed.

Discussion

In this article, we considered the following research question: To what extent does the resource activation model of cognition help explain the application of orientations and topic-specific PCK by a grade 9 science teacher across topics in earth science? Working with Max, we were intrigued as to how what we originally interpreted as a globally strong reform-based orientation did not appear to be matched by his actualisation of reform-based teaching across topics in his grade 9 class. Even within the same class, Max would move from engaging students through the actualisation of his orientation to teaching in such a way that even he thought 'wow, that sucks'. In considering our discussion, we are mindful of the need to be careful in our deliberations based on 16 days of classroom video from two instructional units of video data and two 90-minute interviews. However, the fact that Max openly acknowledged that he needs to be aware of the actualisation of his orientation in order to improve his teaching practice gives us confidence in framing the answer to our research question in terms of teaching coherence, epistemic fragmentation and stability, and idiosyncrasy.

Coherence

Teaching from a reformed orientation involves seeing (and teaching) science as simultaneously a body of canonical knowledge and the practices by which that knowledge develops. For a teacher to actualise a reformed orientation within a specific topic, then, is to facilitate learning that allows students, over time, to integrate canonical knowledge with the practices of science. For a teaching experience to be fully coherent, therefore, a teacher would need to consistently actualise: 'a sequence of topics and performances consistent with the logical and, if appropriate, hierarchical nature of the disciplinary content' (Schmidt et al., 2011, p. 2). As teachers are also learners, such an experience is 'dependent on the myriad different ideas that students [or in this case Max] draw on and try to make sense of in the moment' (Hammer & Sikorsky, 2015, p. 425). As explained earlier, it is widely recognised that teachers have different experiences and levels of expertise related to the topics that they teach. Given this, along with the fact that there can be fundamental differences across the different science topics in earth science specifically and even more so for Grades 6–8 science, it is problematic to expect teachers' STOs to be consistent and coherent across their instruction of all science topics they teach. Instead, the data in this research point to the possibility that STOs are topic- and context-dependent, indicating that there are likely multiple ways in which teachers conceptualise science teaching and learning. More specifically, the data suggest that Max's actualisation of his orientation is locally coherent within a topic, being reliant on a 'context-dependent activation of finer-grained knowledge elements that are more loosely organized than "theories"' (Elby, 2010, p. 1).

In the first interview, Max professed a sophisticated, strongly reform-based orientation towards the teaching and learning of science. He spoke of student engagement and scaffolding students towards autonomy in investigating scientific phenomena. There was no mention, or even consideration, of any potential for this orientation to be differentiated across the topics he was teaching. As a teacher, Max held to a coherent unitary ontology in which his reform-based orientation would be consistently enacted across topics. The videos, however, revealed to Max that this was not the case.

Interpreting the video data of the pollution topic as an example of reformed teaching would appear to support Max's professed belief in a reform-based orientation. He enacted active questioning designed to engage all students, clarified instructional understanding, actively monitored small group work, scaffolded learning to facilitate student sense-making and understanding, and effectively built on their background knowledge and interests. Interpreting the video data of the oceanography topic as an example of traditional teaching, however, was to challenge Max's reform-based orientation. In teaching this topic, he enacted lecture-based teaching and asked direct factually based questions that did not extend student thinking, and limited student engagement by transmitting canonical knowledge. This suggested that different epistemic resources were being activated across the different topics, resulting in incoherence between Max's reform-based orientation and his enacted cognitive states. Seeking to understand this incoherence led us to consider fragmentation of epistemic resources.

Epistemic fragmentation and stability

In seeking to explain this incoherence, Max was re-interviewed, and we called attention to transcript clips from the videos to understand how he perceived his actualised practice across the topics. As Max began to explain what he wanted his students to learn, his commitment to a reformed orientation appeared foundational, as he indicated a commitment to students' sense-making. Yet, when questioned in the light of his actualisation of a traditional teaching practice, Max's response highlighted a fracturing of how he viewed the topics, and the stability of the relationship of knowledge to his orientation: 'my thinking is a little bit different about these units … [pollution] is a better unit as far as having them do critical thinking skills than the oceanology unit'.

As revealed in the theoretical framework, from the perspective of a manifold ontology, epistemic resources are fragmented, and their activation is dependent on topic-specific circumstances. If the activation of resources is 'mutually reinforced by each other and/or contextual cues', the result is a stable network of resources that is 'locally coherent' (Elby, 2010, p. 15). By stable, we mean the structural cognitive relationship between Max and each topic, a relationship developed over time and through repeated activations of the same epistemic resources. In other words, while Max may have claimed an overarching reform-based orientation to his teaching, his activation of topic-specific epistemic resources has resulted in two locally coherent, but different actualisations of teaching. These were actualisations that he was not aware of until confronted with video transcripts. After viewing the videos, Max described himself as having two different, topic-specific, actualisations as a teacher.

This topic-specific, local coherence can be understood in terms of framing – the orienting lens for interpreting what is going on in a specific social activity (Elby & Hammer, 2010). By situating their teaching actualisation in relation to the expectations that they hold for a topic, these expectations can shape what a teacher attends to in their teaching of the topic (Elby & Hammer, 2010). Furthermore, if a frame is accepted (perhaps subconsciously) as topic-specific, then traditional teaching actualisations might be activated without reference to a more globally held reformed orientation (Elby & Hammer, 2010; Sandoval, 2005). The risk for teachers claiming a reformed orientation, therefore, may be a failure to recognise that their teaching actualisations may be topic-specific 'local coherences rather than global coherences resulting from an intuitive meta-theory' (Elby, 2010, p. 15). This realisation brought us to the notion of idiosyncrasy.

Idiosyncrasy

Teacher professional learning is complex, and to challenge the perpetuation of teachers' attitudes and practices requires a 'substantial disequilibrium in teachers thinking' (Wheatley, 2002, p. 9). For science teachers, this means a shift from emphasising the transmission of 'teaching knowledge and skills by lecture [to] one of inquiry into teaching and learning' (Yager, 2005, p. 17). To achieve that shift, however, requires teachers to be epistemic agents and have (or make) opportunities to pursue, assess and refine their practice (Hammer & Sikorsky, 2015). Here, an epistemic agent is understood as someone who takes responsibility for shaping their knowledge and practice (Scardamalia, 2002; Stroupe, 2014). A teacher acting as an epistemic agent is also likely to engage in idiosyncratic teaching. Our interpretation of the data indicates that such idiosyncrasy may well be topic-specific.

Max wanted his students to understand the 'interconnectedness between the different units that we teach'. When questioned about his current teaching practice, however, Max posited that the units shaped his teaching: '[the] pollution [unit is] a better unit as far as having them do critical thinking skills than the oceanology unit. In turn, for "the pollution unit I see myself as a mentor … the oceanography unit I see myself as traditional"'. While Max ascribed a reformed orientation to his (global) practice as a science teacher, the reality is that his orientation in practice was localised and topic-specific.

Conclusion and needed future research

This research was undertaken as an exploratory 'proof of concept' examination of whether preliminary evidence could be found of a teacher's negotiation of context-dependent teaching states through the interactions of orientations, PCK topic specificity, and the activation of knowledge resources. This focus emerged out of an attempt to address, among other things, gaps in the literature related to how STOs shape classroom instruction (Abell, 2007; Friedrichsen et al., 2011). However, because of the diachronic nature of the findings in comparison to what was expected, a revisiting of the literature occurred, not only to consider research related to teacher knowledge (e.g. Hashweh, 2005), but also research on models of cognition (e.g. Hammer et al., 2005) that show promise in accounting for the somewhat unanticipated emergent findings. In the end, what we present here is evidence of differences in one teacher's teaching across two topics, with the contribution to the research literature residing in the early promising evidence related to the explanatory power of context-specific cognitive states, based on Hammer et al.'s resource perspective of cognition.

Beyond offering a potentially powerful theoretical perspective for how teachers' epistemic resources (e.g. PCK, STOs) shape instruction, this research also points to the additional research that is needed to continue to understand the role of context in activating the fine-grained resources teachers draw on to shape instruction. In this, it is worth exploring how research like Muis, Bendixen, and Haerle's (2006) review of research on personal epistemologies might offer a possible mechanistic explanation for understanding more specifically how context might be responsible for shaping resource activation. The work of Muis et al. leaves open the possibility of the existence of both domain-general and domain-specific beliefs serving as resources for shaping instruction. In this, Muis et al., conceptualise domain-general and domain-specific beliefs relative to, among other things, the degree to which there is a relation between justifications for knowing across domains, or in this case of earth science, across the different science topics taught (e.g. socio-scientific issues, physical processes that shape earth's systems). While Muis et al.'s findings are not examined in great detail in this current research, it does provide one possible area of needed future research, especially since those critical features of contexts that activate resources have, to date, been underexplored. Lastly, as discussed in the findings, while there are other explanations that have been put forth to explain this disjuncture found in how teachers shape instruction across science topics related to a lack of content knowledge in one discipline (e.g. Carlsen, 1993; Hollon et al., 1991) or knowledge of instructional strategies (e.g. Magnusson et al., 1999), this research offers at least another potentially powerful framework for understanding how teachers think about and construct experiences for their students.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Directorate for Education and Human Resources [grant number 1020086].

References

Abell, S. K. (2007). Research on science teacher knowledge. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 1105–1149). Mahwah, NJ: Lawrence Erlbaum Associates.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Bromme, R., & Goldman, S. R. (2014). The public's bounded understanding of science. *Educational Psychologist*, *49*, 59–69.

Campbell, T., Longhurst, M., Duffy, A. M., Wolf, P. G., & Shelton, B. E. (2013). Science teaching orientations and technology-enhanced tools for student learning in science. *Research in Science Education*, *43*(50), 2035–2057.

Campbell, T., ZuWallack, B. A., Longhurst, M., Shelton, B. E., & Wolf, P. G. (2014). An examination of the changes in science teaching orientations and technology-enhanced tools for student learning in the context of professional development. *International Journal of Science Education*, *36*(11), 1815–1848.

Carlsen, W. S. (1993). Teacher knowledge and discourse control: Quantitative evidence from novice biology teachers' classrooms. *Journal of Research in Science Teaching*, *30*(5), 471–481.

Davis, P. R., & Russ, R. S. (2015). Dynamic framing in the communication of scientific research: Texts and interactions. *Journal of Research in Science Teaching*, *52*(2), 221–252.
Elby, A. (2010). Coherence vs. fragmentation in student epistemologies: A reply to Smith & Wenk. *Electronic Journal of Science Education*, *14*(1), 1–22.
Elby, A., & Hammer, D. (2010). Epistemological resources and framing: A cognitive framework for helping teachers interpret and respond to their students' epistemologies. In L. D. Bendixon & F. C. Feucht (Eds.), *Personal epistemology in the classroom: Theory, research, and implications for practice* (pp. 409–434). Cambridge: Cambridge University Press.
Friedrichsen, P., Abell, S., Pareja, E., Brown, P., Lankford, D., & Volkmann, M. (2008). Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program. *Journal of Research in Science Teaching*, *46*, 357–383.
Friedrichsen, P., Van Driel, J. H. V., & Abell, S. K. (2011). Taking a closer look at science teaching orientations. *Science Education*, *95*(2), 358–376.
Hammer, D., Elby, A., Scherr, R. E., & Redish, E. F. (2005). Resources, framing, and transfer. In J. Mestre (Ed.), *Transfer of learning: Research and perspectives* (pp. 89–120). Greenwich, CT: Information Age.
Hammer, D., & Sikorsky, T. R. (2015). Implications of complexity for research on learning progressions. *Science Education*, *99*(3), 424–431.
Hashweh, M. Z. (2005). Teacher pedagogical constructions: A reconfiguration of pedagogical content knowledge. *Teachers and Teaching: Theory and Practice*, *11*(3), 273–292.
Hollon, R. E., Roth, K. J., & Anderson, C. W. (1991). Science teachers' conceptions of teaching and learning. In J. Brophy (Ed.), *Advances in research on teaching* (Vol. 2, pp. 145–185) Greenwich, CT: JAI Press.
Kapyla, M., Heikkinen, J. P., & Asunta, T. (2009). Influence of content knowledge on pedagogical content knowledge: The case of teaching photosynthesis and plant growth. *International Journal of Science Education*, *31*, 1395–1415.
Kind, V. (2009). Pedagogical content knowledge in science education: Perspectives and potential for progress. *Studies in Science Education*, *45*, 169–204.
Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, CA: Sage.
Luft, J. A., & Roehrig, G. H. (2007). Capturing science teachers' epistemological beliefs: The development of the teacher beliefs interview. *Electronic Journal of Science Education*, *11*(2), 38–63.
Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education.* (pp. 95–132). Dordrecht: Kluwer.
Muis, K. R., Bendixen, L. D., & Haerle, F. C. (2006). Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review*, *18*(1), 3–54.
Patton, M. Q. (2002). *Qualitative research and evaluation methods*. London: SAGE.
Piburn, M., Sawada, D., Turley, J., Falconer, K., Benford, R., Bloom, I., & Judson, E. (2000). *Reformed teaching observation protocol (RTOP): reference manual* (ACEPT Technical Report No. INOO-3). Tempe, AZ: Arizona Collaborative for Excellence in the Preparation of Teachers (Eric Document Reproduction Service, ED 447 205).
Polkinghorne, D. E. (1995). Narrative configuration in qualitative analysis. In J. A. Hatch & R. Wisniewski (Eds.), *Life, history and narrative* (pp. 5–24). London: Falmer.
Redish. (2004). The theoretical framework for physics education research: Modeling student thinking. In E. F. Redish & M. Vicentini (Eds.), *Research on physics education* (pp. 1–56). Amsterdam: IOS Press.
Roberts, D. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 729–780). Mahwah, NJ: Lawrence Erlbaum Associates.
Roehrig, G. H., & Luft, J. (2004). Constraints experienced by beginning secondary science teachers implementing scientific inquiry lessons. Research report. *International Journal of Science Education*, *26*, 3–24.

Roehrig, G. H., & Luft, J. (2006). Does one size fit all? The induction experience of beginning science teachers from different teacher-preparation programs. *Journal of Research in Science Education*, *43*, 963–985.
Roth, W. M. (2007). Epistemic mediation: Video data as filters for the objectification of teaching by teachers. In R. Goldman, R. Pea, B. Barron, & S. J. Derry (Eds.), *Video research in the learning sciences* (pp. 367–382). New York, NY: Routledge.
Russ, R., & Luna, M. (2013). Inferring teacher epistemological framing from local patterns in teacher noticing. *Journal of Research in Science Teaching*, *50*(3), 284–314.
Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education*, *89*(4), 634–656.
Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Jones (Ed.), *Liberal education in a knowledge society* (pp. 67–98). Chicago: Open Court.
Schmidt, W., Leroi, G., Billinge, S., Lederman, L., Champagne, A., Hake, R., … Williams, P. (2011). *Towards coherence in science instruction: A framework for science literacy*. Michigan State University Research Report, 8.
Schwartz, C. V., & Gwekwerere, Y. N. (2007). Using a guided inquiry andmodeling instructional framework (EIMA) to support preservice K-8 science teaching. *Science Education*, *91*, 158–186.
Seidman, I. (2013). *Interviewing as qualitative research* (4th ed.). New York, NY: Teachers College Press.
Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education*, *98*(3), 487–516.
Van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching*, *38* (2), 137–158.
Van Driel, J. H., & Berry, A. (2012). Teacher professional development focusing on pedagogical content knowledge. *Educational Researcher*, *41*(1), 26–28.
Wheatley, K. (2002). The potential benefits of teacher efficacy doubts for educational reform. *Teaching and Teacher Education*, *18*(1), 5–22.
Yager, R. E. (2005). Achieving the staff development model advocated in The National standards. *The Science Educator*, *14*(1), 16–24.
Zembylas, M. (2003). Emotions and teacher identity: A poststructural perspective. *Teachers and Teaching: Theory and Practice*, *9*(3), 213–238.