A Reading Group for Science Educators: an Approach for Developing Personal and Collective Pedagogical Content Knowledge in Science Education

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Abstract

Reading, at its core, is a basic yet critical way to undertake learning and growth. This paper shares a professional learning and development initiative for science educators, which was underpinned by the popularity and premise of the reading group. In moving from simply being a vehicle for targeted discussion, the reading group facilitators sought to support the participants in taking a deeper dive into their practice with the impact ultimately being changes to their personal pedagogical content knowledge (PCK) for science. This small-scale qualitative study was informed by the voices of three science educators at different stages and career trajectories, who participated in interviews. The data revealed that their participation in the reading group informed the development of their personal and collective PCK by (a) creating conditions that encouraged meaningful links to be made between theory and practice, (b) encouraging the adoption of an inquiry stance as a means for engaging purposively with professional knowledge, and (c) initiating a transformation in their contemporary understandings of science and science education. By drawing on the participants' narratives, this study brings to the fore both the simplicity and depth of complexity that can be achieved through a reading group focused on professional learning and development. The implications of this research are wide reaching as the reading group as a concept can be applied to a variety of contexts and shaped to reach a variety of educational needs.

Keywords Reading group · Pedagogical content knowledge · Professional learning · Science education · Teacher education

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Introduction

Socially, many of us belong to a reading group—more commonly known as a book club—a significant cultural phenomenon of our modern times (Hyder, 2017). Being in a reading group is not only about connection and camaraderie but also an opportunity for cognitive stimulation and focused literary debate; we are required to bring a whole range of higher order thinking skills (e.g. critique, analysis, and sense making) to this process and expected to participate actively for one's own self-development rather than passively looking on (Burger, 2015). To promote this level of engagement, reading groups will usually be informed by protocols and norms that guide how people interact, such as identifying a facilitator for the discussion and having a set of guiding questions or provocations to work through (Petrich, 2015). While this may all seem quite formalised, reading groups are an energetic and inspiring way to engage with and be challenged by complex ideas and contemporary thought. Whether undertaken in a personal or professional capacity, reading, at its core, is a basic yet critical way to undertake learning and growth (Darling-Hammond et al., 2020). In the context of this special issue, it is important to consider that the professional learning of many science educators is often initially stimulated by self-guided reading. Reading, when combined with well-facilitated discussion, provides opportunities for science educators to test and exchange ideas about issues related to science learning, teaching, and practice. Drawing on aspects from the refined consensus model (RCM) of pedagogical content knowledge (PCK; Carlson et al., 2019), this paper seeks to examine the links between personal pedagogical content knowledge and collective pedagogical content knowledge as encouraged by a facilitated reading group. The intention of this study was to better understand how reading can play a role in the development of aspects of PCK for science educators. These constructs will be explained in more detail; in brief, personal PCK is the shifting yet accumulated knowledge and skills that individual teachers have based on their teaching and learning and on the contributions of others, including colleagues, students, and readings (Carlson et al., 2019). In contrast, collective PCK is an amalgam of multiple educators' contributions that results in a specialized knowledge for teaching that is shared by a group of educators for particular content, with particular students, in a learning context (Carlson et al., 2019).

In thinking about how this successful and social approach to personal enrichment could be applied in a work context, the Centre of Science, Mathematics and Technology Education at Monash University (based in Melbourne, Australia) established a professional reading group for science educators. This group became the chosen vehicle for development and learning in science education because the concept would be recognised as familiar, was achievable in terms of resourcing and time commitments, provided a nonthreatening environment, and had the potential to be repeated in different contexts. At the time this study was conducted, the reading group had been operational for 3 years. The participants were largely primary and secondary school teachers, academics, and research students from a range of sectors connected with science education. The reading

group would meet once a month during the school term for an hour to discuss an article chosen by the group's facilitators (the first two authors). The articles were related to an area of science learning and teaching that had been raised by a participant in the group as being of interest or in need of improvement. By meeting regularly as a reading group, participants were encouraged to share their interpretations of the set readings and engage in discussion about how these ideas were or could be incorporated within their science learning and teaching practices.

Other professional learning activities may include elements of reading such as recommended or required texts that inform and enrich parts of a workshop or post-graduate study. The reading group that formed the focus of this study differed from these opportunities in several key ways: cost free; flexible in terms of regularity of attendance and nature of content shared; low stakes (e.g. not assessed or graded); unlinked to a particular syllabus, curriculum, or learning outcomes; and driven by interest and passion rather than the implementation or upgrading of a particular skill set.

In light of this special issue being broadly focused on reading in science and mathematics education, this intervention aimed to trial an innovative approach to support professional learning for science educators. The intention of this study was to better understand how reading can play a role in the development of aspects of PCK for science educators. The question guiding this research was: *As a form of professional learning and development, how can a reading group create the conditions to support PCK transformations for science educators?*

Literature Review

In providing the conceptual framing that underpins this study, this section will unpack PCK, including introducing the RCM (Carlson et al., 2019). Then, we examine how PCK can be enhanced through professional development and learning opportunities; finally, we detail the role that teacher professional reading groups might play in PCK transformation.

Current Understandings of Pedagogical Content Knowledge

PCK is used as the conceptual framework for this paper as it appropriately articulates the specialised knowledge that teachers have for effective teaching. PCK was first introduced by Shulman (1986, 1987) as the blend between content and pedagogy, it has been adopted as an important construct in science education, and it has been widely researched. This focus in science education stems from PCK being a key consideration for effective teaching in science (Kind, 2009). In particular, PCK appropriately acknowledges the specialised knowledge that science educators need for selecting concepts that are appropriate to teach to a given group of students while also considering ways to sequence them to maximise student understanding (Chan et al., 2019; Loughran et al., 2006). Similarly, when science teachers are in the act of teaching, PCK recognises how they use strategies to elicit student understanding

and adapt their practice based on that information while using topic-specific instructional strategies to support students as they develop their own conceptual framework (Chan et al., 2019; Lee et al., 2007).

While the PCK construct has been identified as an important consideration in science education, research around PCK in science education has led to different conceptualisations and models (e.g. see Carlson et al., 2019; Gess-Newsome, 2015; Magnusson et al., 1999; Park & Chen, 2012). Some researchers argue that PCK exists as a static or declarative form of knowledge that teachers draw from (e.g. Schmeling et al., 2013; van Driel et al., 2014), while others view it as a dynamic knowledge that manifests in the act of teaching (e.g. Alonzo & Kim, 2016; Loughran et al., 2001). Similarly, some researchers see PCK as a form of knowledge that is unique to a singular teacher (e.g. Hashweh, 2005), which contrasts others' views about PCK being a form of knowledge that belongs to a group of teachers (e.g. van Driel et al., 1998). In an effort to unite these divergent views and strengthen the PCK construct for science education, two PCK Summits were held in 2012 and 2016 where active PCK researchers shared their views and research on PCK in science education. After the first PCK Summit (see Carlson et al., 2015), Gess-Newsome (2015) reported a model of PCK that considered all participants' views that became known colloquially as the *consensus model*. At the second PCK Summit, that model was critiqued by PCK researchers in science education and refined further. A *refined consensus model* was reported by Carlson et al. (2019) and is the conceptualisation of PCK used to guide this study (Fig. 1).

To consider the various views of PCK outlined above and draw upon the discussion from the second PCK Summit, the RCM identifies three realms of PCK: personal PCK (pPCK), enacted PCK (ePCK), and collective PCK (cPCK). The

Fig. 1 Refined consensus model (RCM) of pedagogical content knowledge (PCK) for teaching science (Carlson et al. 2019)

realm of pPCK aligns with views of PCK being individual and declarative; it represents the specialised knowledge that a teacher has for teaching particular content to particular students (Carlson et al., 2019). In comparison, ePCK aligns with views of PCK being dynamic as it represents part of a teacher's overall knowledge (i.e. pPCK) that is being used in the moment when planning, teaching, and/or reflecting (Carlson et al., 2019). The introduction of cPCK showcases how this type of knowledge can be generated and shared within a group: from a canonical form (e.g. published best-practice guidance) to a contextualised form (e.g. teachers within a science department) (Carlson et al., 2019). A useful example to showcase what cPCK can look like is the use of content representations (CoRes), which are scaffolds that ask teachers to respond to pedagogical prompts about teaching specific content to specific groups of students and ultimately eliciting their PCK (see Carpendale & Hume, 2019; Loughran et al., 2006).

Additionally, the RCM highlights a knowledge exchange function (i.e. via the double-headed arrows in Fig. 1), thereby indicating how one realm of PCK can influence another. Through these knowledge exchanges, it is important to signal that the degree of influence can be moderated by factors that amplify or filter the effect (e.g. teachers' personal beliefs about teaching) (Gess-Newsome, 2015). The teachers' learning context will also influence the mediation of knowledge exchanges (Carlson et al., 2019).

As this study focused on understanding how reading groups can support the pPCK development of participants, the knowledge exchange function that exists between cPCK and pPCK is our locus. Thus, it is important to investigate appropriate ways to support teachers' pPCK development. This study did not explore the participating teachers' actions within a classroom; therefore, exploring ePCK is not appropriate.

Approaches to Enhancing Pedagogical Content Knowledge

There has been much research into teacher professional learning over time with many researchers articulating various conceptualisations and models about how knowledge can develop from interventions (e.g. Clarke & Hollingsworth, 2002; Desimone, 2009; McChesney & Aldridge, 2021). While inherently different, a common goal of such research is to articulate how the effectiveness of interventions can be maximised. Many researchers (e.g. Desimone, 2009; Garet et al., 2001; Griffith et al., 2014; Tellerico, 2014; van Driel et al., 2012) have converged on the identification of five key considerations for effective professional learning: content focus, active learning, coherence, duration, and collective participation. Of particular interest for supporting teachers' PCK development are active learning and collective participation, specifically referring to teachers actively collaborating with colleagues and discussing their views on teaching and learning of particular content (see Desimone, 2009). For instance, van Driel and Berry (2012) discussed that for PCK development to occur teachers must take part in collaborative discussions where they can share elements of their knowledge and practice and reflect on this

information. Ultimately, this process promotes metacognition and allows teachers to develop their knowledge further.

Similar to research on professional learning for teachers, the research on teacher collaboration has been conducted over a long period of time (see Hargreaves, 1994; Little, 1990; Vangrieken et al., 2015). In thinking about teacher collaboration, we draw on the views of Roschelle (1992) and see it as a process of building and maintaining shared conceptions of a problem, sharing expertise, distributing responsibility, mutually constructing, and negotiating cognition. We agree with Bausmith and Barry (2011) who highlighted the importance of teachers participating in professional development that fosters relationships through collaboration and collegial interactions. From this research, it is important to consider the nature of the collaboration to ensure learning is maximised. For example, Nelson (2009) recommended that teachers should take an inquiry stance during collaborative discussions, which shifts the nature of those discussions from sharing teaching activities to engaging in deeper exchanges. Such discussions allow teachers to engage their pedagogical reasoning and integrate their own and others' knowledge and practice while considering student learning (Nelson, 2005, 2009; Nelson et al., 2012). This stance aligns with the views on active learning and collective participation described by Desimone (2009) and the views of van Driel and Berry (2012) to elicit transformative effects of pPCK development. While needed for effective collaboration for PCK development, adopting an inquiry stance during collaborative activities can be challenging for teachers. Nelson (2009) suggested this stance can be supported through the use of critical questions and prompts that encourages teachers to engage their pedagogical reasoning and prompt in-depth discussions about teaching and learning. One possible way to support teachers to develop this stance in collaborative activities is by using reading groups.

The Role of Teacher Professional Reading in Professional Learning

Teachers' professional reading activities have been researched for decades. Kersten and Drost (1980) surveyed 126 educators and found that secondary/high school teachers (54%) read more professional journals than junior high school (37%) or primary/elementary school teachers (41%). Studies (Cogan & Anderson, 1977; Kersten & Drost, 1980; Koballa, 1987; Weimar, 2007) often focused on establishing which journals teachers read, leading to a general finding that primary/elementary teachers often read general education journals while secondary/high school teachers tend to read specific subject-matter journals that focus on resources that can be easily transferred for use in the classroom (Littman & Stodolsky, 1998). Common findings emerged and suggested that, while teachers were aware that professional literature can influence their beliefs and change their practice (Commeyras & DeGroff, 1998), very few teachers regularly engaged in professional reading (Kersten & Drost, 1980; Kitchen et al., 2015; Koballa, 1987). Kirsch and Guthrie (1984) indicated that any professional who participated in professional reading was doing so with a view to solving an immediate problem rather than acquiring general knowledge about their profession. However, Carroll and Simmons (2009) found that teachers who engaged

in professional reading often demonstrated a greater interest in their career development and progression. With the continual developments and changes in education, teachers need to be cognizant of new information and advance their knowledge of their field. To grow as 'an 'expert' in any field requires not only acquiring a body of knowledge about the field, but also developing dispositions that drive the search for new answers in light of problematic situations' (Broemmel et al., 2019, p. 16). Consequently, ongoing engagement with professional reading should be essential for teachers.

Littman and Stodolsky (1998) commented that continued study of teachers' professional reading activities was warranted due to both a lack of consistency in the way data have been collected, measured, and reported and a shortage of recent studies. Grossman and Stodolsky (1995) identified the need to consider the distinct differences that arose for teachers in different subject areas in relation to teachers' beliefs about the nature of teaching in their subject area. Implications from Broemmel et al. (2019) suggested that requiring teachers to engage in professional reading where there is some choice about the topics and types of reading would be valuable. The provision of supports that encourage teachers to read (e.g. communities of practice, learning communities, or reading groups where collegial support can be offered to discuss topics of mutual interest) were identified as making a difference (Darling-Hammond & Richardson, 2009; Mitchell, 2013). Bringing these ideas together, the current study investigated a professional reading activity for science teachers that sees science teachers coming together in a community of practice for a shared professional learning experience to discuss readings on a topic determined by the group.

Methodology

From a methodological perspective, it is important to acknowledge from the outset that this project is rooted in a small-scale research paradigm (Knight, 2002). Pragmatically, small-scale research can be driven by efficiencies around time and resources (Layder, 2013) but is equally informed by a desire to explore an emergent opportunity and illuminate different ways of thinking about a particular phenomenon or experience (Poulson & Wallace, 2003). While this approach can be deficit-modelled as a limitation, there are positives inherent in sharpening a research focus on a small group of participants for a specific purpose (Dexter & Seden, 2012). For this study, a small-scale approach was appropriate as it provided a way to sense-make the impact of a niche reading group on participant understandings and pPCK transformations related to science education, which are conceptualised as when an educator internalises new information about teaching and learning in science in ways that enhance their PCK.

Positioning this study within qualitative traditions is an appropriate way in which to value the voices of the participants (Atkins & Wallace, 2012). Interpretive approaches are particularly valued as a lens for foregrounding lived experiences and insights, which subsequently lead to outcome generation such as recommendations or themes (Elliot & Timulak, 2005). A qualitative research approach drawing on the

traditions of narrative inquiry and analysis methods has been adopted in this paper to represent and critically examine the emergent themes in a way that would reflect and honour the participants' voices (Clandinin & Connelly, 2004). It is acknowledged that the small data set—one-off interviews with three science educators/researchers—impacts the ability of this research to be adopted in a full-scale narrative study, which requires the development of a relationship with participants over time, and that the study is not able to be generalised. However, the small sample size provides meaningful insights into the perspectives of the participants; by drawing on aspects of narrative inquiry, this paper can genuinely forefront their voices as valued informative sources (Guest et al., 2006). This study draws on the traditions of case study research paradigms (e.g. Stake, 2000) and, therefore, does not seek to make generalisations or examine typicality. Instead, this research seeks to explore the emergent theoretical insights connected with the experiences of three cases.

Participants

The reading group met monthly on a Monday night from 5 to 6 p.m. during school term time; it was held at a centrally located school in the staffroom or in a classroom space at a university; it was also possible to attend online. About a week before the meeting, reading group members were sent an email that contained a brief description of a topic, some questions, and one or two readings; they were asked to read at least one prior to the meeting. The topic for the next meeting was decided upon by the group at the end of each meeting. The email was sent to 58 reading group members who were all involved in science education and who attended as suited them; however, they were encouraged to forward the email to colleagues and networks. Participants in the reading group ranged from 5 to 25.

At the time of this study, the reading group had a regular attendance of approximately 10 participants per session and included science teachers, teacher educators, and higher degree by research (graduate) students. All participants were invited to take part in this research with 14 responding to an online anonymous questionnaire and three volunteering to participate in an individual interview. The three interviewees—Fleur, Mingfei, and Rana (pseudonyms)—were involved in science education either as a teacher (Fleur: early career secondary school teacher) or as a research student (Mingfei: international student; Rana: local student; both completing PhDs). None of the members of the reading group attended every session; however, the interviewees were regular attenders of sessions and noted contributors to discussion. This sample does not present itself as a representative cohort as there are several absent voices (e.g. primary school teachers, academics). Regardless, the insights gathered do shed light on the impact of participating in a reading group in terms of the ways these participants thought about science education.

Data Collection

This paper reports only on the qualitative component of this research by exploring the perceptions of three reading group participants as shared through their individual

interviews. By focusing on their experiences, it is hoped some insights will be provided into what value an activity like a reading group can have on the ways science education is considered and practiced in relation to the interplay between cPCK and pPCK. Semi-structured interviews were conducted to elicit specific examples of how the participants transferred what they experienced in the reading group to their science education practices and how this approach influenced the development of their pPCK in science education. See [Appendix 1](#) for the interview questions.

With these purposes in mind, a semi-structured interview format was the most practical and functional way of collecting this evidence (Stake, 2000). A research assistant conducted the interviews as a way of reducing any concerns relating to a possible power imbalance between the facilitators of the reading group (instigators of this research) and the participants. A convenient interview time and location was arranged with each participant. Each interview was approximately 45 min in length and was audio-recorded to enable transcription.

Data Analysis

As we were looking to identify the conditions that the reading group created for supporting pPCK transformations for science educators, a deductive thematic approach (Bryman, 2016) was used to analyse the transcribed interview data. Initially, the data were analysed independently by the first and third authors. Once the initial round of analysis was completed, these two co-authors compared the themes obtained to confirm inter-rater agreement. Once the themes were agreed upon, they were presented to the second author for confirmation. Then, the codes were agreed upon by all three authors, and the data were recoded to ensure the consistency of analysis. The deductive themes drew from the RCM in terms of looking for evidence of the participant espousing their pPCK or how their pPCK had evolved, the generation of cPCK, and the interplay between pPCK and cPCK. To appropriately identify aspects of these PCK realms, previous research about understanding PCK from qualitative data was used (see Carpendale & Hume, 2019; Chan et al., 2019; Lee et al., 2007), for example, identifying instances when participants discussed they contributed pPCK to the group, how those discussions generated rich discussion, and then the subsequent influence on their views and knowledge. In addition to these deductive PCK themes, the interview data were analysed for themes (a) relating to the conditions underpinning effective professional development considerations as identified by Desimone (2009) and Nelson (2009), such as environmental factors and the potential dynamism of professional learning activities, and (b) linking the previous analysis about when participants experience pPCK transformations in relation to cPCK generation.

Findings

We report our findings by considering the three key parts of our research question: *As a form of professional learning and development, how can a reading group create the conditions to support PCK transformations for science educators?* First,

we report the conditions that the participants identified as being supportive of their learning and that the literature indicates are conducive for supporting pPCK transformations for science educators. Next, we look at the way in which an inquiry stance was generated and that promoted shifts in the nature of the reading group discussions allowing educators to engage in deeper discussions about their pedagogical reasoning and integrate their own and others' knowledge and practice while considering student learning. Finally, we report data where pPCK transformations are evident. The quotes shared in this section were chosen as being illustrative of how the themes were articulated and represented in the data. The authors worked collaboratively to identify the most appropriate excerpts from the interview transcripts.

Conditions

Each participant commented that being in an environment where they could collaborate and discuss issues of learning and teaching science with other educators—and for some, being able to connect with experienced educators—was something that supported their learning. The following participant excerpts identify the conditions created by the reading group, which acted to support their professional learning and build their confidence as science educators. For example, Fleur identified specific content areas that she was not confident with and discussed the value she found in being able to hear from teachers with experience in these areas:

I'm not as confident [as a teacher], so being part of the reading group has sort of allowed me to further develop my understanding of different parts of science. ... Like the Earth sciences and biology and physics and just by discussing things with more experienced teachers.

Fleur then further specified that she was uncertain about practical tasks in physics and explained how even just talking about them had helped her:

It's [physics] not in my background so other more experienced teachers at the reading group are quite experienced in physics and they've talked about practical tasks they've done and because I'm not so experienced in physics, I almost am scared sometimes to do practical tasks with the students because I don't feel that confident so talking to them about it has made me feel more confident to try things they've suggested.

Similarly, Mingfei confirmed the value of talking with colleagues and how it influenced her views on enhancing students' learning experiences:

I think it's really important to get together with other teachers and just talk and I think what we talk about is really important about continuing to develop and enriching student experiences and just bringing out the best in student learning and I think it's incredibly valuable to get together and discuss all of that.

Rana referred to 'Listen[ing] to others and learn[ing] from other people' outside of her context, signalling that getting outside of a teacher's context provided the opportunity for the conversation to shift from being so focused on the shared

knowledge of administration- and school-related matters to being centralised around what are now the shared concerns of learning and teaching science in response to the readings.

Linked with these ideas is the importance of the topic of the readings and the alignment between these and the concerns of the teacher. Two participants commented on the importance of coherence for supporting their learning. For example, Fleur commented on her lack of time to do this for herself so it was helpful that the topics were aligned to her needs.

I don't really do that myself – go out and seek things unless I need it for school or one student's kind of triggered me to think I need to look up something about how I can teach science in this way or to this kind of student. I don't put aside time to do that sort of thing so it is good to have the reading group to make sure you do that.

Participants appreciated that the reading group topics, readings, and discussions aligned well with their needs and goals for teaching and learning science in their schools and classrooms, which Mingfei explained:

I find ... the readings that we do in this group are connected with the other readings I'm doing ... so it's relevant and for science education, thinking about science education, the current issues in science education and the past history and all these things, I can relate. I remember when John Loughran [eminent science education researcher] was a guest to our reading group; that particular reading was very closely related to my master's thesis topic, about reflection, classroom teaching and reflection. There were practitioners as well, some teachers from different high schools and also [de-identified university]; they had been reflecting on their practises so it was really, really interesting for me. I'm researching children's learning about science, so sometimes I go back to the folder to have a look at the readings [to see] if I could connect the readings with my work.

In summary, the science education reading group created the conditions for a professional learning environment that:

- Improved conceptual understandings and confidence in teaching certain concepts
- Provided a variety of voices and insights to listen to and learn from
- Identified key readings that spoke to current problems of practice and/or areas of interest
- Assisted in making connections to relevant researchers and/or research.

Inquiry Stance

Underpinning the formation of the reading group was a desire to generate an inquiry stance that aimed at shifting discussions with educators from being focused on tips and tricks of teaching science to something much deeper. These deeper conversations allowed participants to reflect on and challenge their

knowledge while considering others' knowledge and practices and how these could be integrated to improve student learning outcomes. The following excerpt from Fleur is illustrative of the impact of the reading group in causing participants to internalise the experience, as well as share with other colleagues, and consider ways to enact their learning in practice.

[The reading group] made me reflect on why some students disengage from science and why others can't get enough of science. That's pretty much [what I take away from the reading group], just reflect on it personally and then discuss it with colleagues. [I] try and implement things. I think it's really good to see what [other participants have] taken away from [the reading group] as well, and it's kind of like a catalyst for discussing what each of us do in our classrooms. Is one person doing something really well that could be taught to everybody or should we be [using] a school-wide approach for something? It gets us talking about different things that have been discussed at the [reading group]. I've only been to a handful of the reading groups, but I often think about it for a long time afterwards [in terms of] what I'm doing and am I doing what I should be doing in the classroom or how I can change things to make sure that my teaching is more effective and that [student] learning is enhanced. I think it's really important to get together with other teachers and just talk. I think what we talk about is really important as it supports continuing to develop and enrich student experiences and just bringing out the best in student learning.

The following excerpt from Mingfei's interview highlights the impact of the types of research discussions and that the presence of researchers in the reading group can significantly influence their own personal inquiry stance.

I think the discussions are mainly useful because when I read the readings and when someone like John Loughran or other Australian [researchers in science education] attended the group that greatly affected me. I don't know why, maybe it's you want to listen more and more to expert people, so that makes me more interested and sometimes makes the readings more interesting too.

For participants who attended the reading group over time, a confidence developed in terms of being able to make suggestions about areas of science education or strategies that would further enrich their understandings of science learning and teaching. This notion is captured by Rana:

I went with my very good friend [to a reading group session], so we were discussing whether we would agree or not [with the reading]. I put forward my idea and my friend said, 'This [strategy] is good but I was thinking this [strategy] is good and [while] they could've done this one, we could have done this one too'.

In drawing this theme together, the science education reading group supported participants in developing an inquiry stance toward their own professional learning and development through the following conditions:

- Providing a rich stimulus for further thinking and discussion
- Exposing participants to a variety of researchers through their published work and subsequent conversation
- Building confidence to share responses to readings that lead to different understandings of and ideas about pedagogical practices.

pPCK Transformation

pPCK transformations were evident in the data as each participant articulated shifts in their thinking about science and science education from taking part in the reading group. For Fleur, this is articulated as a widening of her science and science education knowledge:

I think my understanding has really developed, just from discussions and also from the readings that we're given as well. Then they talk about different concepts that are taught and perhaps student's misconceptions or how we can teach them in different ways, so it's really helped me to broaden my knowledge in a lot of ways.

Mingfei expressed that the reading group influenced understandings of contemporary issues facing science teachers in the classroom:

I think it [the reading group] helped me to think and reflect quite intensively on my thinking about science. What is science? ... about science education, what's happening in the classroom and what's the, as I say, the issues teachers are facing in real classroom teaching.

While Rana did not expand on the actual nature of the impact that the reading group had, she did comment that '[the reading group has had a] great impact, I still do feel like going there'. This excerpt illustrates that she still felt compelled to attend due to the extent of the learning and growth that had taken place for her.

In concluding, the science education reading group did assist in transforming the participants' pPCK by:

- Broadening their knowledge for teaching science
- Providing a reflective environment where participants could think critically about their own views of science and what is happening in science classrooms.

Discussion

To address the overarching research question shaping this paper, we interrogate the pPCK transformations that have taken place in relation to science education and consider the role of a reading group in nurturing this professional growth.

What Is pPCK Transformation?

Each and every teacher has their own unique pPCK and ePCK (Carlson et al., 2019). The participants in this study are a testimony to this consideration: three educators each at different stages and on different paths in terms of their journey in science education and each with their own set of beliefs, knowledge, and practice regarding science learning and teaching. As individuals share aspects of their pPCK with colleagues, they generate a form of cPCK (Carlson et al., 2019). As this understanding is co-constructed with knowledgeable others, it becomes a valuable shared insight. During this iterative process of sharing and discussion, the generation of cPCK can then influence a teacher's pPCK, forming a dynamic link between pPCK and cPCK that is mediated through a variety of learning contexts (Carlson et al., 2019; Gess-Newsome, 2015).

In this paper, we have interpreted this process of PCK transformation as educators internalising new information, which changes and influences the way they think about teaching particular content to particular students. In the context of this study, the transformational opportunity inherent in the reading group was identified from the data as two-fold. Firstly, the reading group provided a regular forum for discussion and knowledge sharing. Secondly, the reading group was orchestrated in a purposeful way (e.g. focal papers to discuss, careful selection of papers, supportive environment, and facilitators who prompted discussion) to create the conditions that would bring forth pPCK and be a vehicle for cPCK generation. Even with the best of intentions of generating sharing culture, certain considerations are certainly required for meaningful transformations to occur.

What Is Needed for pPCK Transformation?

For pPCK transformations to truly occur, however, discussion must go beyond sharing tips and tricks related to teaching practices. For a meaningful change, an inquiry stance is needed. Nelson (2009) identified an inquiry stance as being when educators discuss practice through a lens of reflecting on learning and teaching in light of what they are teaching and to whom. Nelson posited that the generation of an inquiry stance can be challenging but suggested that the use of questions or prompts to guide discussion will assist. Nelson's work aligns with research on effective professional learning by highlighting the benefits of collective participation and the need for educators to be active learners (e.g. Desimone, 2009). If they are to benefit, educators need to be actively and directly involved in the collaborative discussion. Further benefit is possible when there is coherence between the professional learning and development opportunity and the educators' needs or goals for their teaching practice (Desimone, 2009).

For this study, the reading element and exposure to a variety of perspectives (e.g. teachers, researchers, teacher educators) were the significant factors in moving the monthly discussion beyond the operational aspects of practice (e.g. What activities do you use to teach ecosystems?) to more pedagogically challenging dialogue that engages participants' pedagogical reasoning (e.g. Why do you teach in that way?

What is the impact on learners?). This approach to professional learning was viewed by participants as being accessible and nonthreatening, which contributed to a growing confidence around being able to contribute to the development of cPCK as well as deepen one's own pPCK in relation to science education.

What Is the Role of a Reading Group in PCK Transformation?

Key elements emerged from the participant interviews that revealed the conditions created in the reading group that supported taking an inquiry stance leading to pPCK transformation. In this case, these conditions were the provision of a curated experience for participants (e.g. accessible science education–focused readings) and opportunities that enabled and encouraged collaboration (e.g. sharing of teaching practices, problem-solving problems of practice). It is these key conditions that lead to an enriched knowledge and understanding of science education and, thus, a transformed pPCK.

From this study, providing a curated experience in reading groups for participants has four considerations. The first consideration is ensuring that the articles chosen align with the participants' interests, needs, and goals. By providing participants with more than one article, the likelihood of alignment increased. These articles were chosen by facilitators who had a holistic understanding of the field and could readily access a range of sources unlike most of the participants. Secondly, articles should be drawn from various authors to provide a variety of voices and insights. Changing focus from the articles to the reading group process, experienced facilitators should be used to moderate discussion using prompts, for example, asking questions that push discussion beyond the sharing of stories about tips and tricks for teaching science into a deeper, more reflective discussion where questions of teaching for quality learning could be asked and explored. Additionally, these facilitators can continually draw from the participants' contributions. The final consideration for this curated experience is to develop a positive environment that allows for rich discussion and for participants to share their knowledge and views on teaching.

In addition to providing a curated experience for participants, the other critical element was ensuring there is opportunity for collaboration. The participants in this study valued the opportunity to discuss their knowledge and views on teaching science with colleagues who had different experiences. Being able to engage their own pedagogical reasoning and critique others' ideas in a positive and collaborative way, an environment was developed where participants could share their tacit knowledge in an explicit way. It is through this knowledge-sharing process that a dynamic space was created that elicited metacognition; as participants shared and examined their own pPCK, transformations to that knowledge could occur.

As depicted in Fig. 2, thinking about the key conditions outlined earlier can support the reading group process to promote pPCK transformation. Such transformation that was seen in the interview data in this study included participants improving conceptual understanding and confidence for teaching certain concepts, developing confidence to share their response to readings and to support the generation of divergent ideas about pedagogical practices, broadening their views on the purposes of

Fig. 2 A representation of how key conditions of a reading group process and support pPCK transformations

science and science education, and developing insights about the realities of teaching and learning in contemporary science education settings.

Implications and Conclusions

Our data signals that reading groups can be an effective means in which to create the appropriate conditions to support science educators' pPCK transformations and nurture developments in their own inquiry stance. While this study is somewhat niche in nature, there are three key recommendations that could be applied to different contexts in enriching the professional learning and development of educators through a reading group.

1. Choose articles for the reading group carefully while empowering participating educators to have input into the decision-making process (see Appendix Table 1 for a sample of some of the readings used). Reading selection should be based on participant need so that there is interest and investment in the focus area. Variation in the format, style, and length of readings is important for interest and engagement. Teachers need some flexibility in what they read and engage with so that they can manage the additional work on top of their teaching responsibilities. Reading group facilitators play a key role in finding the big issues for discussion and how to ensure some alignment between the intent of the reading group and the needs of the participants. It is important to select readings that highlight or connect with classroom practice so that teachers can make links with what is being said in the readings.
2. Create a space where educators can discuss and consider the chosen reading group articles beyond the application and scope of the classroom to really engage their

pedagogical reasoning and take a deep dive into their practice and reveal areas of challenge and opportunity. This is where bringing special guests into the reading group can be most impactful and enlightening.

3. Encourage facilitators to moderate the discussion using purposeful prompts (see Appendix Table 2 for an adapted version of the CoRe pedagogical prompts) to allow educators to reflect on their knowledge and practice through the lens of intended student learning (i.e. moving beyond simply sharing teaching tips, tricks, and strategies).

We acknowledge that these recommendations echo those of early papers about teacher reading broadly (Broemmel et al., 2019; Darling-Hammond & Richardson, 2009; Mitchell, 2013). This reading group initiative, however, was focused on the professional development of teacher knowledge (in particular, pPCK) using the reading of science education–focused journal articles and book chapters as an innovative vehicle for creating the conditions to develop personal and collective PCK in science educators. This study highlights that the achievement of pedagogical transformation does not need to be complex or complicated; rather, it can be thoughtfully constructed and skilfully enacted to enable educators to engage with deep and meaningful discussions about and questioning of teaching practice.

Appendix 1. Interview protocol

The following questions will be discussed in the semi-structured interviews to better understand the experiences of participating in a science reading group.

Describe how your participation in the reading group has impacted (or not) your science learning and teaching practices.

Describe how your participation in the reading group has impacted (or not) your thinking about science.

Describe how your participation in the reading group has impacted (or not) your thinking about science education.

Think about when you attended a reading group session. Can you explain what factors help and/or hinder your participation?

After a reading group session – what happens next? Can you explain what use you make of the reading group experience?

If you were facilitating the reading group sessions, what changes would you make?

Do you have any other comments that you would like to add about the science reading group and your experiences?

Table 1 Sample topics and readings used for the reading group

Reading group topic	Readings
Values in science education	<p>Ratcliffe, M. (2007). Values in the science classroom - The enacted curriculum. In D. Corrigan, J. Dillon, & R. Gunstone (Eds.), <i>The re-emergence of values in science education</i> (pp. 119–132). Sense.</p> <p>Hildebrand, G. (2007). Diversity, values and the science curriculum: Which curriculum? What values? In D. Corrigan, J. Dillon, & R. Gunstone (Eds.), <i>The re-emergence of values in science education</i> (pp. 45–60). Sense.</p>
Teaching for understanding	<p>Gunstone, R., & Mitchell, I. J. (1998). Metacognition and conceptual change. In J. J. Mintzes, J. H. Wandersee, & J. D. Novak (Eds.), <i>Teaching science for understanding: A human constructivist view</i> (pp. 134–163). Academic Press.</p>
Science explanations	<p>McNeill, K. L., & Krajcik, J. (2008). Inquiry and scientific explanations: Helping students use evidence and reasoning. In J. Luft, R. Bell, & J. Gess-Newsome (Eds.), <i>Science as inquiry in the secondary setting</i> (pp. 121–134). National Science Teachers Association Press.</p> <p>Rennie L. (2007). Values of science portrayed in out of school contexts. In D. Corrigan, J. Dillon, & R. Gunstone (Eds.), <i>The re-emergence of values in science education</i> (pp. 197–212). Sense.</p>
Extending gifted students	<p>Kidman, G. C. (2016). Extending the gifted science student: What the teacher needs to know during enquiry-based teaching. In K. S. Taber & M. Sumida (Eds.), <i>International perspectives on science education for the gifted: Key issues and challenges</i> (pp. 154–165). Routledge.</p>
Supporting ESL science learners	<p>Morris, J. (2006). <i>Science education and the English second language learner</i> [Unpublished doctoral dissertation]. Curtin University.</p> <p>Lincoln, F., & Beller, C. (2004). English language learners in the science classroom. <i>Science Scope</i>, 28(1), 28–31.</p>
Teaching argumentation	<p>McDonald, C. V., & Heck, D. (2012). ‘How do we teach argumentation in the new Australian Curriculum?’ Secondary science teachers’ experiences in an argumentation-based professional development program. <i>Teaching Science</i>, 58(3), 22–28.</p>

Table 1 (continued)

Reading group topic	Readings
Citizen science	<p>Podcast from Radio National's the Science Show from May 2014. http://mpegmedia.abc.net.au/rn/podcast/2014/05/ssw_20140517_1211.mp3 (~30 min)</p> <p>Short video from Behind the News (BTN) TV from August 2013. http://www.abc.net.au/btn/story/s3814896.htm (4 min)</p> <p>Website from Barbara Hardy Institute showcasing its citizen science projects. http://www.unisa.edu.au/Research/Barbara-Hardy-Institute/Research-1/Citizen-Science/</p> <p>Zeegers, Y., Paige, K., Lloyd, D., & Roetman, P. (2012). 'Operation Maggie': Inspiring teachers' professional learning through environmental science. <i>Australian Journal of Environmental Education</i>, 28(1), 27–41.</p>
STEM to STEAM	<p>Bonamici, S., & Schock, A. (2014). STEAM on Capitol Hill. <i>The STEAM Journal</i>, 1(2), Article 6. https://doi.org/10.5642/steam.20140102.6. Available at: https://scholarship.claremont.edu/steam/vol1/iss2/6. http://www.exploratorium.edu</p>
Reimagining science teacher professional learning—teachers as self-directed learners	<p><i>No more bad coffee: Professional development that honors teachers: Sheryl Chard at TEDxABQED</i> https://www.youtube.com/watch?v=aiW0s6_83dw</p> <p>Opfer, V. D., & Pedder, D. (2011). Conceptualizing teacher professional learning. <i>Review of Educational Research</i>, 81(3), 376–407. https://doi.org/10.3102/0034654311413609</p>
The future of STEM education: What happens next?	<p>http://monash.edu/education/events/deans-lecture-series/deb-corrigan.html</p> <p>Panizzon, D., Corrigan, D., Forgasz, H., & Hopkins, S. (2015). Impending STEM shortages in Australia: Beware the 'smoke and mirrors.' <i>Procedia - Social and Behavioral Sciences</i>, 167, 70–74. https://doi.org/10.1016/j.sbspro.2014.12.644</p>

Table 2 Reworded CoRe pedagogical prompts

CoRe prompts	Reworded
What do you want students to learn about this idea?	What are the ideas in these readings that resonate with you and your teaching practice?
Why is it important for students to know this?	Why are these ideas important?
What else you might know about this idea (that you don't want students to know yet)?	With what other ideas are these ideas connected?
Difficulties/limitations with teaching this idea?	What could be the strengths, weaknesses, opportunities, or threats to planning/enacting/reflecting these ideas into your teaching practice?
Knowledge about students' thinking that influences your teaching of this idea.	How might these ideas support your students and their learning?
Other factors that influence your teaching of this topic.	How will you share these ideas with your colleagues and support them if they wish to pursue these ideas in their teaching?
Teaching procedures (and particular reasons for using them to engage with this idea).	What is your plan for enacting these ideas in your practice?
Specific ways of ascertaining students' understanding or confusion around this idea.	How will you reflect on the enactment?

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