Participatory Action Research: A Tool For Promoting Effective Assessment and Building the Pedagogical Content Knowledge of Secondary Geography Teachers

Rod Lane
Deputy Head of Department (Learning and Teaching), Department of Educational Studies, Macquarie University

Susan Caldis
PhD Candidate, Department of Educational Studies, Macquarie University

This paper describes the results of an action research project undertaken as a partnership between Macquarie University and Geography teachers from an independent school in regional New South Wales (NSW), Australia. The project focused on the teaching of river landforms and processes, a component of the Biophysical Interactions topic in the NSW Stage 6 Geography syllabus. The aim of the research was to provide four teachers with feedback about depth and accuracy of students' content knowledge, the teachers' knowledge of common student conceptions, and the extent to which the school's fieldwork program promoted cognitive disequilibrium and constructive confusion, affective states required for deep conceptual change. This feedback was used as a prompt for professional reflection and to stimulate conversations about improvements that could be made to the teachers' knowledge and practice. The findings suggest that this form of action research can be an effective tool for enhancing teachers' pedagogical content knowledge (PCK) including their knowledge of evidence-based assessment practices in Geography.

Background for the study and review of the related literature

It is now well understood that students construct mental models (or pre-instructional conceptions) about how the world works prior to formal instruction. Some of these conceptions are consistent with current expert thinking in the discipline and can act as bridges to further understanding (Greca & Moreira, 2000). Other mental models, however, may appear to be incomplete or theoretically incorrect to a discipline expert. These ideas, known as alternative conceptions, (Arnaudin & Mintzes, 1985; Dove 1999; Lin & Cheng 2000) have a number of common characteristics. Firstly, alternative conceptions are robust and difficult to shift through instruction because they have been constructed from the learners' personal experiences and are continually reinforced by everyday interactions with family, friends and the media. Secondly, they are widely held by students and adults and are neither idiosyncratic nor culturally dependent. Thirdly, they have a significant impact on learning processes because they act as a lens through which learners interpret and decode information in order to construct meaning (Driver, Squires, Rushworth, & Wood-Robinson, 1994). Finally, these ideas are used to solve real world problems and therefore appear to the learner to be functional, plausible and evidence-based.

In order to promote deep understanding, it is argued that Geography teachers need to develop a deep knowledge of the ideas commonly held by students in specific topics and of evidence-based strategies for diagnosing and addressing these ideas (Clough & Driver, 1986; Dove, 1999). This knowledge forms an important component of teachers' PCK (Lane & Coutts, 2015; Berry, Friedrichsen, & Loughran, 2015; Shulman, 1986). According to Shulman (1986, p. 10), an understanding of alternative conceptions that students develop prior to formal instruction, and the instructional conditions necessary for overcoming these beliefs, should be 'at the heart of our definition of needed pedagogical knowledge'. Knowledge of students' alternative conceptions is foundational for the development of strategies and representations for addressing students' common areas of misunderstanding. Equally, this knowledge is important for the development of valid and reliable assessments for diagnosing and addressing students' learning in schools. There is a significant body of research in science education demonstrating that instruction is most effective when it is informed by an understanding of the common alternative conceptions that students hold in specific topic areas (Park & Oliver, 2008). It is argued that teachers with well-developed knowledge in this area are in a better position to make sense of students' actions and beliefs and to develop strategies for addressing these ideas through instruction (Magnusson, Krajcik, & Borko, 1999).

Despite the importance of this knowledge base, recent empirical studies demonstrate that both Geography and science teachers have very limited knowledge of students' alternative conceptions across key areas of the curriculum and lack awareness of the importance of these ideas in the learning process (Lane, 2015). Teachers with an understanding of the role of alternative conceptions often lack knowledge of instructional strategies for diagnosing and addressing these ideas in real classroom settings (Lane & Coutts, 2015; Lane, 2015). In a study of experienced secondary Geography teachers from 16 comprehensive (non-selective) state, independent and catholic schools across three regions of Sydney (Sydney east, Sydney north and Sydney central, as defined by the NSW Department of Education and Communities), Lane (2015) found that many of the teachers were unaware of the importance of students' alternative conceptions in the learning process and/or held non-constructivist views of learning. Teachers with transmissionist beliefs about learning, for example, believed they could address misconceptions by telling students what they needed to know. The teachers lacked models of effective diagnostic assessment of students' ideas, and knowledge of evidence-based strategies for diagnosing and addressing these ideas. These findings are similar to those documented in science education (Berg & Brouwer, 1991; Halim & Meerah, 2002; Morrison & Lederman, 2003).

In response to the above the authors, in collaboration with the social science department of an independent school in regional NSW, developed a participatory action research project (PAR). The aim of the project was to help staff reflect on and improve their knowledge of alternative conceptions, diagnostic assessment approaches, and evidence-based strategies for improving students' depth and accuracy of understanding. PAR involves collaboration between academics, teachers, and community/organisation members to pool knowledge and develop solutions to problems (Greenwood & Levin, 1998; MacDonald, 2012). Several studies have shown PAR to be an effective approach for promoting professional learning in schools and initial teacher education programs (Burke, 2013; Draper, et al., 2011; Erdas-Kartal et al., 2018; Hales, 2017; Kemmis, McTaggart, & Nixon, 2014). In particular, these studies highlight the strengths of PAR as a tool for:

- improving collaboration and promoting the development of a community of practice – a group of teachers and academics who share a common goal of supporting student learning (Draper et al., 2011);
- promoting peer and student feedback (Burke, 2013);
- increasing the frequency and complexity of teacher discussion about professional practice (Hales, 2017); and
- shifting teachers' mind-sets and preconceptions (Erdas-Kartal et al., 2018).

Few studies, however, have looked at the role of PAR as a tool for assisting in-service secondary teachers to reflect on and improve their PCK, particularly their knowledge of, and work with, students' preconceptions. A review of the literature identified only three studies of this type. All were in science education. The first study in this area, conducted by Eilks and Markic (2011), aimed to improve the PCK of 10 chemistry teachers by engaging them in a PAR project with science education researchers over a six-year period. The results showed improvements in the PCK of the teachers including their attitudes towards teaching, and their ability to reflect on and improve their knowledge of learners and of strategies for promoting conceptual change. The second study (Williams, Eames, Hume, & Lockley, 2012) demonstrated how 'content representations' (CoRes), providing a holistic overview of an expert teacher's PCK in a particular topic, can be used as a tool for developing the PCK of early career science teachers. The most recent study in this area by Wongsopawiro, Zwart, and van Driel (2017) used a PAR approach to develop the PCK of 12 secondary science teachers. The teachers learned about new instructional strategies and assessment methods through literature reviews and discussions with peers. They also analysed and reflected on student learning as it happened in the classroom, and developed understandings that helped them select and apply instructional strategies to further promote student learning.

Methodology

In the project, the authors worked collaboratively with the Geography teachers of an independent school in regional NSW to gather and analyse data in order to improve the teachers' PCK and the effectiveness of their fieldwork program. This study, like most action research, involved a cyclical process of research, reflection and action (Kemmis et al., 2014). In each step of the process, the authors worked in partnership with the teachers to design and execute the project. The teachers outlined the issues that they were interested in, drafted research questions, and developed a method that would enable their questions to be answered. Following discussions with the teachers the following research questions were proposed:

1. What are students' existing conceptions about river landforms and processes? What is the accuracy and depth of their understanding?
2. What knowledge do Geography teachers have of students' existing conceptions and how do they use this knowledge in the classroom?
3. To what extent does the fieldwork program promote cognitive disequilibrium and constructive confusion?
4. What do the research findings suggest about adaptations that could be made to current pedagogy?

The project involved four phases:

1. **Phase 1 –** Assessment of students' depth and accuracy of knowledge of river features processes.
2. **Phase 2 –** Assessment of teachers' knowledge of students' common alternative conceptions and evidence-based strategies for promoting conceptual change.
3. **Phase 3 –** Assessment of the extent to which the fieldwork activity stimulates cognitive conflict.
4. **Phase 4 –** Assessment of teachers' responses to the data from Phases 1 to 3.

The phases of the project are outlined in greater detail below.

Description of the research context and participants

The research was conducted at an independent school in regional NSW. The school, with a population of over 1000 students, has an excellent reputation for its Geography program especially the quality of its fieldwork. For over twenty years, the school has consecutively offered the Stage 6 Preliminary and Higher School Certificate (HSC) Geography courses. In 2018, there were two classes of students completing the Preliminary Geography course in Year 11 (n = 43) and two classes of students completing the HSC Geography course in Year 12 (n = 30).

In alignment with syllabus requirements, the first 45% of course time focuses on Biophysical Interactions. This unit involves the investigation of biophysical processes and their contribution to sustainable management within a chosen sphere, and the examination of a related issue affecting a specific environment. The teachers responsible for the design and delivery of the program decided to focus on river regulation in the hydrosphere using an inquiry-based learning approach that included fieldwork. To effectively develop knowledge and understanding about biophysical processes in a riverine environment, students require an understanding of such threshold concepts as erosion, deposition, and the water cycle. The fieldwork program for this topic was designed to provide an immersive learning experience about these core concepts and to serve as a foundation for further investigation of a riverine environment within the Year 12 topic Ecosystems at Risk.

The participants in this study were purposefully sampled. There were four specialist Geography teachers and forty-three students who were completing the Preliminary Geography course in Year 11. The students comprised boarders (48%) and day-students (52%). There was an even split of boys and girls in the group. All students had studied Geography across Years 7 to 10 in accordance with the requirements of the New South Wales Education Standards Authority. The teachers participating in this study were all full-time, permanent members of staff who were accredited to teach Geography at the Stage 6 level. Two of the teachers were teaching both the Preliminary and HSC Geography courses. All of the teachers and students participated in the study voluntarily. They were informed that they had the right to withdraw from the study at any time and that their reponses would be deidentified in any publication of the data.

Phase 1 – Baseline data collection from students

The first phase of the project aimed to collect baseline data about students' depth and accuracy of knowledge about river landforms and processes. Consistent with the advice of Brewer (2008) and Brown and Hamner (2008), the study applied a range of assessment techniques to gain a rich and detailed image of the students' underlying conceptions. Forty-three students completed a questionnaire and drawing tasks designed to identify common alternative conceptions related to river processes. The 28-item questionnaire consisted of true or false items and a confidence scale. Students were asked to mark each item as either true or false, and place a cross on the scale to indicate the degree of confidence in their response. Each item was developed from the literature on students' intuitive ideas about river landforms and processes, and the questionnaire was validated by a hydrologist and an Associate Professor in Geomorphology.

The next step involved a sample of the students (n =10) participating in a semi-structured interview and drawing task. Students who answered more than 10 of the questionnaire items incorrectly were invited to participate in the interviews as they were most likely to hold robust alternative conceptions about river features and processes. A scaffolded approach was adopted for this phase starting with a drawing task and open-ended questions, followed by specific probing questions. The instructions asked participants to complete a diagram of a river, include labels to identify the direction of flow and key landform features, and explain their diagram as if they were speaking to a classmate or friend. Data analysis for Phase 1 involved ranking the questionnaire items in terms of difficulty (proportion of the sample answering each item incorrectly) then triangulating these data with the results of the drawing task and semi-structured interview. This enabled the identification of common alternative conceptions amongst the student group. Ideas were considered to be reliable when they were consistent across the questionnaire, drawing task and interview.

Students' interview responses and drawings were also analysed to determine their depth of understanding using the SOLO (Structure of the Observed Learning Outcome) taxonomy (Biggs & Collis, 1982). The SOLO taxonomy describes changes in the way learners structure their oral and written responses as they develop understanding. According to Biggs and Collis (1982), individuals develop the capacity to communicate in more complex ways as they learn. This involves both quantitative changes in the amount of detail provided as well as qualitative differences in structural complexity and integration. A five-level taxonomy to describe this sequence of development in the *quality* of students' responses shows that levels of complexity in understanding vary from *pre-structural* (where individuals miss the point or simply rephrase the question), through to *relational* and *extended abstract* levels where learners are able to explain the links between key concepts (relational thinking) and conceptualise key ideas at a higher level of abstraction (Biggs & Collis, 1982). Each additional level of the taxonomy subsumes and extends the levels below it as demonstrated in Table 1.

The SOLO framework was operationalised in the study through the development of a protocol for classifying the structural complexity and depth of students' responses as shown in Table 2. Classification judgments were made on balance using evidence from multiple data sources including students' questionnaire responses, their drawings, and answers to the semi-structured interview questions.

Phase 2 – Assessment of the teachers' knowledge of students' common alternative conceptions and evidence-based strategies for promoting conceptual change

The teachers' knowledge of students' ideas, and of instructional strategies for addressing common alternative conceptions, were assessed using semi-structured interviews. During the interview, teachers were asked, "What incorrect ideas about river landforms and processes would you expect the typical Year 11 student to hold prior to formal instruction?" and "What strategies do you currently use to improve the depth and accuracy of the students' understandings in this topic?" Data collected from these interviews were used to classify the teachers' level of understanding of

Table 1: Features of learners' responses at each stage of the SOLO taxonomy (Biggs & Collis, 1982)

SOLO Stage	Features of learners' responses typical of each stage
Pre-structural	Here learners are simply acquiring bits of unconnected information, which have no organisation and make no sense.
Uni-structural	Simple and obvious connections are made, but their significance is not grasped.
Multi-structural	A number of connections may be made, but the meta-connections between them are missed, as is their significance for the whole.
Relational	The learner is now able to appreciate the significance of the parts in relation to the whole.
Extended abstract	The learner is making connections not only within the given subject area, but also beyond it, and are able to generalise and transfer the principles and ideas underlying the specific instance.

Table 2: Protocol for classifying the structural complexity of responses

SOLO Stage	Features of students' responses typical of each stage
Pre-structural	Provides broad, non-specific or tautological responses. Misses the point and provides little evidence of relevant learning.
Uni-structural	Identifies or focuses on one concept relevant to river landforms and processes. Deals with terminology but little more. Can memorise, identify, recognise, quote, recall or recite the details of one relevant concept.
Multi-structural	Describes or lists two or more concepts relevant to river landforms and processes. Demonstrates a quantitative increase in knowledge from the uni-structural level. Focuses on knowledge telling rather than integrating ideas. Can describe, list, report, discuss, illustrate, select, narrate or outline the relevant facts and concepts.
Relational	Provides a cohesive, internally consistent explanation of river landforms and processes. Demonstrates a qualitative difference in understanding over multi-structural responses. Integrates conceptual components by explaining the relationships between two or more concepts. Can apply knowledge in familiar contexts, integrate ideas, analyse causal factors, and explain links.
Extended abstract	Demonstrates an ability to apply understanding of river landforms and processes to new contexts – can generalise, theorise or hypothesise. Demonstrates creative and/or original thinking.

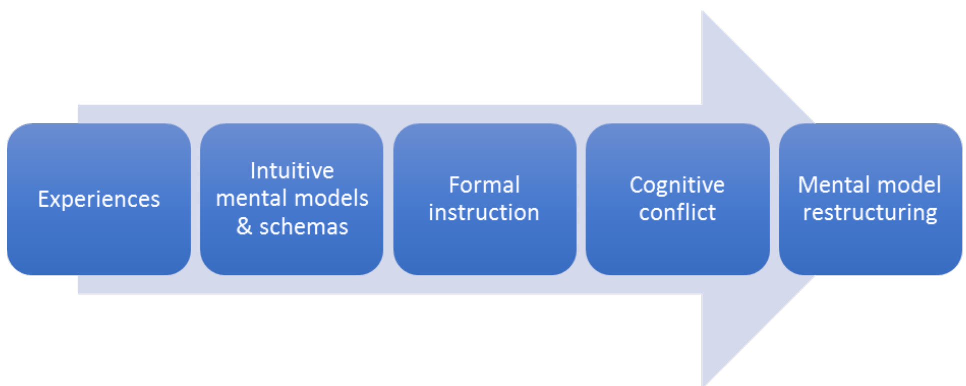
students' ideas and their awareness of evidence-based approaches for promoting conceptual change.

Phase 3 – Assessing the extent to which the fieldwork activity stimulates cognitive conflict

The aim of Phase 3 was to determine the extent to which the fieldwork activities promoted cognitive disequilibrium and constructive confusion. Cognitive disequilibrium, as defined by Calvo and D'Mello (2011, p. 19), is "a state of uncertainty that occurs when an individual is confronted with obstacles to goals, interruptions of organised action sequences, impasses, contradictions, anomalous events, dissonance, incongruities, negative feedback, uncertainty, deviations from norms and novelty". These authors argue that cognitive disequilibrium is essential for any deep learning or radical conceptual change. Constructive confusion is an affective state that is likely to occur when learning such complex concepts as erosion and deposition on meanders. While confusion is often seen as undesirable because of its potential to induce frustration and boredom, recent research highlights the vital role confusion can play in student learning (Arguel & Lane, 2015) (see Figure 1).

The fieldwork excursion involved 43 students canoeing for half a day along the Macquarie River in New South Wales. Along the way, they made several stops to discuss river landforms and processes as well as evidence of human impact. During the fieldwork experience the authors observed the types of activities given to students, noted the questions students asked,

Figure 1: The role of preconceptions and cognitive conflict in the learning process

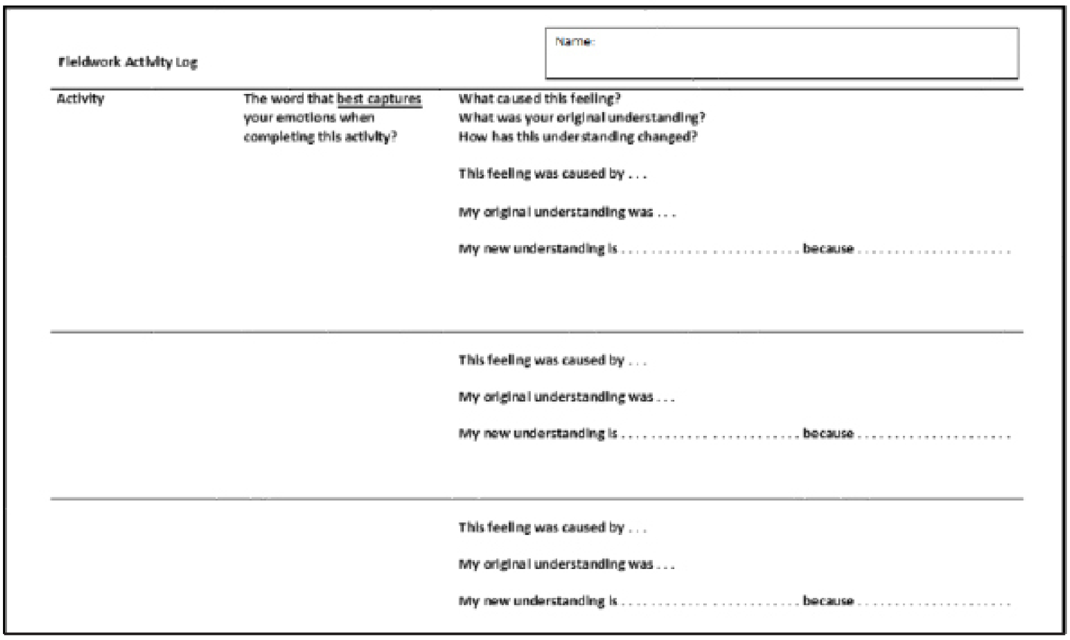


and the explanations provided by their teachers. At each stop, students were asked to think about the activities completed, the types of emotions experienced (affective states) when completing these activities (see Table 3), and any realisations made as a result of the activities. Students recorded their responses on a Fieldwork Activity Log (Figure 2). The frequency of self-reported

Table 3: Definitions of emotions experienced during the learning process (D'Mello & Graesser, 2012; D'Mello, Lehman, Pekrun, & Graesser, 2014)

Emotional term	Definition
Anxiety	Being nervous, uneasy, apprehensive or worried about the participation in or completion of a task.
Boredom	Being restless or feeling tired due to a lack of interest in the activities or content of the task, or because the task is either too difficult or too simple.
Confusion/uncertainty	Being unsure about how to proceed; having difficulty understanding the activities or content of the task.
Curiosity	Being interested in acquiring more knowledge or learning more deeply about the activities or content of the task.
Delight	Being satisfied when challenges with the task are conquered or goals are achieved.
Engagement/flow	Being interested in the results of the task and wanting to remain involved with the task.
Frustration	Being dissatisfied or annoyed with the activities and content of the task because frequent mistakes are being made or there are regular interruptions preventing completion of the task.
Surprise	Being in a state of wonder or amazement, especially from an unexpected activity, learning episode or occurrence in the task.

Figure 2: Fieldwork activity log


Fieldwork Activity Log

Name:

Activity	The word that best captures your emotions when completing this activity?	What caused this feeling? What was your original understanding? How has this understanding changed?
		This feeling was caused by . . . My original understanding was . . . My new understanding is . . . because . . .
		This feeling was caused by . . . My original understanding was . . . My new understanding is . . . because . . .
		This feeling was caused by . . . My original understanding was . . . My new understanding is . . . because . . .

affective states (emotions) at each of the fieldwork stops was calculated and presented in graphic form (see Figure 4).

Phase 4 – Assessment of the teachers' responses to the data collected in Phases 1 to 3

Two weeks following the fieldwork excursion, the authors revisited the school to discuss the findings of the research with the Geography teachers and to promote collaborative reflection on these data. The one-day workshop provided feedback about Phases 1 to 3 and focused on research questions 1 to 4. During the workshop, the authors engaged the teachers in conversations about the data and in discussions about evidence-based conceptual change strategies suitable for topics in physical Geography. The discussions were audio recorded and transcribed. Responses were analysed and organised around the following themes:

1. Research findings that surprised teachers.
2. Lessons from the PAR process.
3. Changes teachers planned to make to their pedagogy.
4. Other reflections or observations about the project.

Results

Phase 1 – Assessing students' accuracy and depth of understanding

Student alternative conceptions about river landforms and processes

The incorrect responses to the questionnaire shown in Table 4, triangulated with the drawing task and responses from the semi-structured interviews, highlighted alternative conceptions about the following themes: source, direction and flow of water in a river; change over time in river processes; and the nature of groundwater.

Within this theme, three main alternative conceptions were identified. These included a belief that rivers flow inland from the sea (held by 19% of students); all rivers end in the sea (held by 26% of students); and the hemisphere in which the river is located determines the direction of flow (held by 23% of students). These beliefs were consistent with those elicited from students' drawings and their responses to the semi-structured interview questions.

Figure 3 provides an example of a student diagram showing an example of an alternative conception related to the theme of direction and flow of a river.

Examples of student interview statements related to this theme include: "I just reckon they [rivers] would, they are not going to flow out to the sea, they start from the sea and go inland." (Participant 5), and "All rivers end in the sea because on maps you see them go all the way through and you don't see them end anywhere" (Participant 4).

Additionally, a cause and effect relationship between "hemispheres" and "river flow" was evident in a number of the students' responses. Interestingly, one participant connected this belief to popular culture.

> Participant 4: I just thought maybe it's got something to do with toilets
>
> Interviewer: Do you mean the spin?
>
> Participant 4: Yes, it might be like that, it might all flow in the same direction . . . I saw it on The Simpsons and it is all the same in that hemisphere

Many of the students understood that the source of the river was at the top of the catchment but held the conception that the water always came from melting snow "Like when it rains and the snow melts and stuff, that's how it works [river flow] . . . the Blue Mountains have snow in the winter" (Participant 2).

Figure 3: The ocean is the source of water for a river

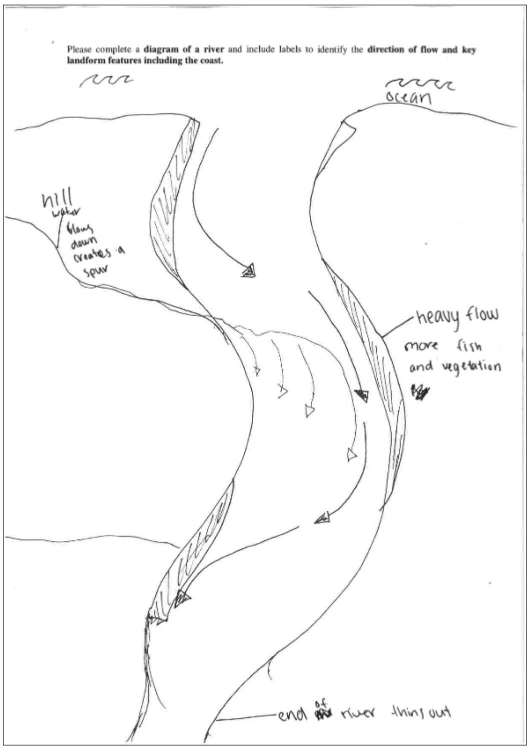


Table 4: Percentage of students providing incorrect responses to each questionnaire item Misconceptions are in bold.

Statement	% incorrect*
14. Moving water can only change the surface of the earth over long-time periods. Changes do not happen over short-time periods (i.e. a day or a year).	63
27. A billabong is an old river channel.	47
12. Groundwater is clean and can be drunk by humans.	37
28. River deltas are formed by accumulated sediment when they reach the ocean.	35
5. All rivers end in the sea.	26
11. Groundwater exists only in underground lakes or cracks in the rock structure.	26
2. Rivers in northern hemisphere flow south, while those in southern hemisphere flow north.	23
18. Rivers flow inland from the sea.	19
19. Natural flooding has a long-term beneficial effect on plant and animal communities.	19
20. Floodplains are a build-up of sediment deposited by rivers.	19
24. River landforms are the result of accumulated sediment and/or erosion.	19
8. Water can penetrate rocks.	16
15. Rivers can transport materials including boulders.	16
1. Rivers do not carve valleys, but only passively flow down them.	14
3. Rivers are generally fed by a network of smaller rivers or streams.	12
4. Groundwater exists within the soil or rock layer.	7
6. River landform features are a result of the interaction between water flow, rock/soil type, vegetation and shape of the land.	7
10. River flooding is unnatural.	7
26. A small stream cannot wear away solid rock.	7
7. Human activities cannot affect hydrological processes e.g. river flow, flood cycles, etc.	5
23. Rock and soil type in a river catchment can determine water quality.	5
25. River flow is caused by the wind.	5
9. Rivers move water under the influence of gravity, from high to low points.	2
13. In the course of the earth's history tectonic activity has had an influence on the path of rivers.	2
17. Water cannot carry rocks and deposit them in a new location.	2
21. Towns were there before rivers.	2
16. Erosion can be caused by wind or water.	0
22. Erosion only occurs while rain is falling.	0

*The table shows the proportion of students who responded incorrectly to each statement.

Change over time including the processes of erosion, transportation and deposition

This theme focused on the temporal aspects of river processes including erosion, transportation and deposition. The majority of students in the sample (63%) held the alternative conception that moving water can only change the surface of the earth over long time periods and believed that changes did not happen over short time periods (i.e. a day or a year). This is in contrast to scientific consensus that change in river systems can be rapid (Fryirs & Brierley, 2012).

"I think they [rivers] change over a long period of time. It doesn't take just overnight to just erode something so fast . . . it's cows and the wind that change rivers really" (Participant 7).

Students also held alternative conceptions about the processes of erosion, transportation and deposition. Few students were aware that rivers could transport materials including boulders (16%). More than 10% of students also believed that valleys predated the rivers that flow down them: "They [rivers] look like they are flowing down [valleys], not carving them" (Participant 5).

The nature of groundwater

Over a quarter of students (26%) held the alternative conception that groundwater exists only in underground lakes or cracks in the rock structure. Other students believed that groundwater did not exist at all.

> Interviewer: Groundwater exists in the rock and soil layer? True or False?
>
> Participant 8: False, because in Science we learnt there's oil [in the ground] that we humans can use . . . they are drilling the oil for human use and taking away the farmers' land.

This is in contrast to scientific consensus that the Earth's crust consists of layers of which one is a groundwater-conducting porous rock that is underlain by an impermeable layer (Reinfried, 2006). To fully understand the concept of groundwater, students need to understand that rocks can be porous and penetrable (Reinfried, 2006). Only a small proportion (7%) thought that groundwater exists within the soil or rock layer and few students (16%) believed that water could penetrate rocks, "I don't even think that's true [water can penetrate rock] because rocks are just hard surfaces" (Participant 9); and "I doubt that water can penetrate rocks" (Participant 2). Additionally, many students (37%) believed that all groundwater was clean and could be consumed safely by humans.

Students' depth of understanding

After assessing the accuracy of students' knowledge, their responses were analysed for depth of understanding using the SOLO framework (see Table 2). Most of the students held either uni-structural or multi-structural understandings of river landforms and processes (see Table 5).

Phase 2 – Teachers' knowledge of alternative conceptions commonly held by students in this topic

When asked the question, "What incorrect ideas about river landforms and processes would you expect the typical Year 11 student to hold prior to formal instruction?", the teachers responded in a variety of ways. Only one teacher was able to identify any specific ideas that may be held by students. Teacher 4 noted that students might believe that: "Rivers don't change. The river always has water flowing in it and always exists. Humans don't negatively impact upon rivers. Rivers are natural and will always be there regardless of what humans do. Fish are the only living organism in the river. The only reason you have a river is to draw water for cattle" (Teacher 4). The responses of the other teachers can be organised into three themes:

1. The students do not have alternative conceptions prior to formal instruction. I don't see the students as having any dominant ideas in what they believe about river processes (Teacher 3). That's a hard one, I don't come up against any preconceived ideas to be honest . . . I've been on Year 9 and 10 Geography which has given me the opportunity to lead in to some of this [content]. I can't really think of anything (Teacher 4).
2. There were general issues with student understandings. A number of teachers were unaware of the difference between broad areas of difficulty and alternative conceptions, for example, "I don't think they see the greater picture of rivers inside a drainage basin" (Teacher 1). It could be that students and teachers don't understand the difference or they could not articulate the idea. Additionally, Teacher 4's comment, "There would be differences in understanding between town and rural kids", could be seen as an example of teachers being unsure about the nature of misconceptions.
3. Students hold particular opinions and perspectives. Several of the teachers identified opinions and perspectives that would be held by students, rather than alternative conceptions. One of the teachers commented "a number of students from farms will have opinions about irrigation such as 'I'm entitled

Table 5: Student depth of understanding

SOLO Stage and Number of students	Written/spoken responses representative of each SOLO stage
Pre-structural *(Tautological and provides little evidence of relevant learning)*	No examples were identified.
Uni-structural (4 students) *(Focuses on a single concept)*	Interviewer: "Can human activity do anything to change the river at all?" Participant 9: "I guess, like irrigation, take water out of it."
Multi-structural (4 students) *(Describes various processes but does not link them together)*	Interviewer: "Tell me more about erosion." Participant 8: "Erosion occurs when there's not much moisture in the soil . . . then it's [soil] going to get dry and then the soil particles are going to break down, then it becomes just sand over time . . . there's also deposition . . ." Interview: "What would you expect to see when the river reaches the coast?" Participant 6: "It [the river] would spread out and end up with a harbour, like Sydney Harbour, a really big area of water that joins to the ocean." Interviewer: "Where else could rivers end?" Participant 6: "In big lakes or places where the altitude is lower."
Relational (2 students) *(Integrates conceptual components and explains the relationships)*	Interviewer: "Is flooding beneficial [for river catchments] true or false?" Participant 6: "I would say true. I think generally the flooding, as it slowly subsides, leaves sediment and stuff for the plants and it's going to have nutrients in it. If the water has been contaminated by chemicals then it wouldn't be beneficial but I think generally it [flooding] would be really good for plant and animal life as it collects nutrients for them."
Extended abstract *(Demonstrates creative and/or original thinking)*	No examples were identified.

> to the water in the river, bugger the people downstream'" (Teacher participant 1). Another observed that "students can be short-sighted, blame catchment management authorities for not looking after water quality" (Teacher 2).

Phase 3 – The extent to which the school's fieldwork program promoted cognitive disequilibrium and constructive confusion

The frequency of different affective states (emotions) experienced by students at each stop during the fieldwork excursion are shown in Figure 4. The graph shows the dominance of *curiosity* and *engagement* as affective states experienced by students during the excursion. Few of the students reported that they felt confused, anxious or uncertain.

Phase 4 – Teachers' responses to data from Phases 1 to 3

In the final stage of the project, the teachers were provided with a summary of the results from Phases 1 to 3 and were asked to comment on aspects of the findings that surprised them, what they had learnt from the PAR process, changes they would make to their pedagogy, and any other reflections or observations. The teachers' responses indicated that they were surprised about two elements of the research findings. Firstly, the nature of the students' preconceptions of river landforms and processes and secondly, the lack of confusion (cognitive disequilibrium) generated by the fieldwork activities. The nature of the students' ideas were particularly alarming for several of the teachers who found it difficult to believe that students could construct mental models that were so inconsistent with expert thinking in the discipline.

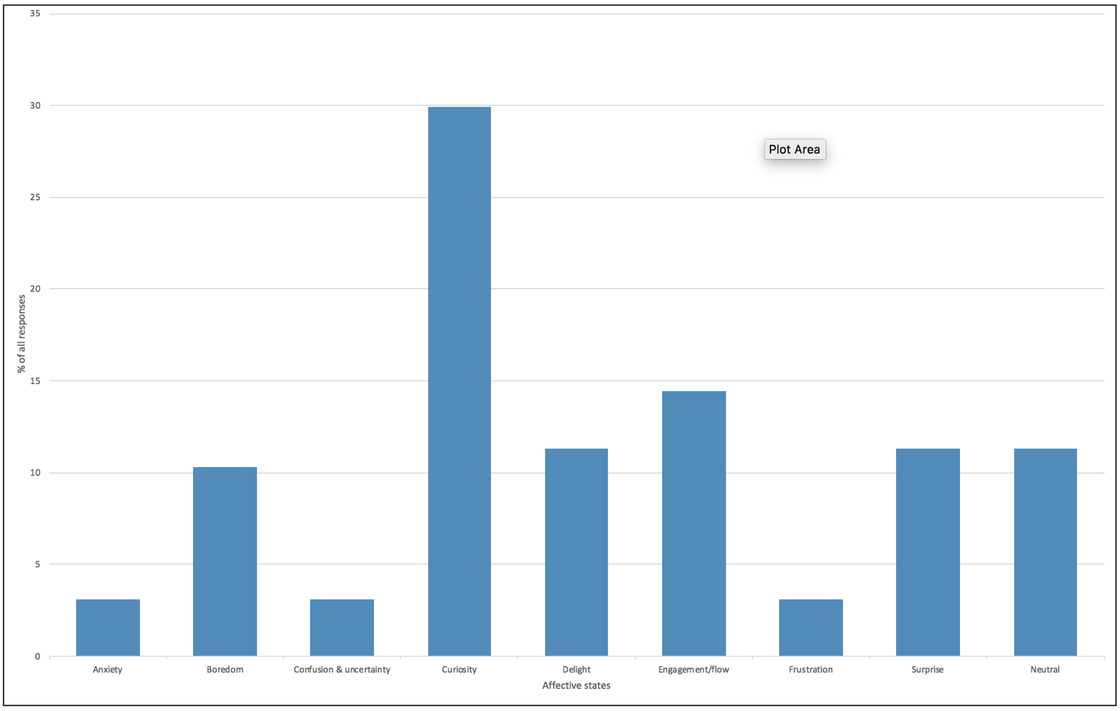
> The results of the student surveys highlighted some misconceptions that I found alarming. Students not knowing which direction rivers flow was particularly surprising for Year 11 students. Having taught river systems to Year 8 and 9 students in the past, this is a concept I have taught before and felt would be straight forward, or a "given", for Year 11 students to understand (Teacher 1).

> [There were] a few surprises, for example, water flowing inland from the coast was a big one . . . [and] students' lack of knowledge about erosion, deposition, water flow, cross sections, and upper-mid-lower sections of a catchment (Teacher 2).

> The [misconception about] direction of flow of rivers was most surprising, even alarming.

> Their limited understanding of the role of topography and river processes . . . that was the "fall off your chair" moment for me. I was really amazed at that [finding] . . . The students do have preconceptions and I cannot assume they have a solid

Figure 4: Reported affective states during the fieldwork activity



conceptual foundation to start with (Teacher 3).

The second aspect of the data that surprised the teachers was the reported affective states during the fieldwork activity. The results suggest that many of the students were curious about their experiences on the fieldtrip, however, few of the activities prompted the confusion and uncertainty associated with cognitive disequilibrium and conceptual change (D'Mello & Grassier, 2014). Comments made by students in their fieldwork activity log (Figure 2) suggested that contextual factors such as "lack of food" and the social nature of the fieldtrip dominated their attention. Both of the teachers leading the fieldtrip were surprised about this finding which prompted reflection about changes that could be made to future fieldwork activities.

When asked about what they learnt from the research process, all of the teachers noted the need to regularly review, critique and adjust their practice. The teachers' responses focused on the need to create opportunities for students to share their knowledge at regular intervals throughout a teaching, learning and assessment program. The PAR process also made them aware of the non-linear nature of student learning and the role of student-teacher relationships in the conceptual change process.

> My key learning came from the reading regarding the cognitive space students must be in to truly change their understanding of a concept. Finding the root cause of a students' misconception and shattering this to correct their understanding seems the most important first step to improved learning (Teacher 1).

> I learnt a hell of a lot from the research process . . . I take student prior knowledge for granted as being quite linear. [The] analogy of student conceptions being a bowl of spaghetti I think is fantastic. The research illustrated to me most definitely that my assumptions were incorrect. Just because they [students] have done this [rivers] before does not mean they will understand it. I assumed their understandings were linear when the reality is that nothing is straight forward about their understandings. The role of their environment is so important – farming background or what they had heard their parents say (Teacher 3).

> You have prompted us to think "how is my teaching going and how are [students] learning based on that [my practice]?" . . . It comes back to junior Geography [which is] an opportunity to develop a relationship with the students. If you taught a kid in Year 9 and 10 and you have a relationship with them and they choose your subject in Year 11 and 12 you're continuing a relationship, and that is a factor that is at play with most teenage boys and girls which is important to their learning and engagement (Teacher 2).

During interviews, teachers identified a number of changes they had already made to their practice or planned to make in the future. The teachers responsible for delivery of the Year 11 course noted the need to modify the learning and teaching program to ensure that students have a sound understanding of the core concepts prior to the fieldtrip. They planned to achieve this through the use of a number of evidence-based conceptual change approaches. One of these strategies was the use of Socratic questioning:

> As a result of the research project I have introduced strategies that challenge students to think and talk through their understanding with simple prompting questions, such as "What makes you say that?" Students hate these questions because you can almost visibly see their brains switch on and dig through their thoughts . . . But it's effective. In addition, modelling concepts, using diagrams accurately or utilising fieldwork as the process for shattering misconceptions will be my preferred methods moving forward, rather than reading text, passively watching videos or even lecturing concepts (Teacher 1).

Other teachers planned to use targeted feedback, peer instruction and scale models of physical processes to address students' misconceptions.

> I have moved towards providing better feedback from class activities and assessments, which can improve students' learning & understanding. I am thinking about pre-tests to get an idea of the start point for students (Teacher 2).

> We have new activities [for class time]: the bull-ring, peer to peer learning, and feedback. In the bull-ring activity, Year 12 students teach Year 11 for 5 minutes then swap roles. This activity provides an opportunity to see what prior understandings the students have [as they] unpack the idea . . . If you have a "teaching" student state a misconception (such as rivers flow inwards from the ocean), the "listening" student is likely to say "Can you explain this?" and often, the teaching student struggles to do so. I [as the teacher] don't need to be the fount of

all knowledge, because the students learn from each other (Teacher 2).

> We have changed the teaching and learning in response [to the research findings]. I did a lesson where students build a catchment out of sand, empty some water bottles in to it and look at how water flows through different areas of the catchment. I did this post-fieldtrip but will obviously be doing this at the start of the course next year. I put up some of the [student] preconceptions on the board after your workshop and we discussed them as a group. The students unpacked their reasoning which helped to transform their understandings (Teacher 3).

The teachers also recognised the need to be more conscious of potential barriers to the development of deep understanding including students' existing mental models of key concepts such as transportation and deposition. As noted by Teacher 3, the study "compelled everyone in the department to think more deeply and critically about their practice in terms of what they do, how lessons are received by their students, and what can be done to further improve the teaching and learning."

Discussion

Consistent with the literature, this study demonstrates the value of PAR for assisting in-service secondary teachers to reflect on and improve their PCK, particularly their knowledge of and work with student ideas. Key areas of value include enhanced collaboration (Draper et al., 2011); the development of a community of practice (Erdas-Kartal et al., 2018); shifting mindsets and assumptions about learning (Eilks & Markic, 2011; Erdas-Kartal et al., 2018; Hales, 2017); and the promotion of peer and student feedback (Burke, 2013). These benefits of PAR are connected and provide the framework for discussion of the research findings below.

The project provided strong evidence of the capacity of PAR to challenge teachers' assumptions about learning processes, students' prior knowledge and the extent to which particular activities promote constructive confusion (Eilks & Markic, 2011). Prior to commencing the project, several of the teachers assumed that the foundational concepts covered in junior school Geography curriculum (e.g. erosion, deposition and the water cycle) would be well understood by their Year 11 students. As noted by Teacher Participant 3 – "I took it for granted that [the learning process] was quite linear". The PAR process provided a feedback loop for teachers (Burke, 2013) that prompted them to challenge many of these assumptions. Analysis of the Phase 1 data made the teachers aware that students did not have the required prior knowledge for understanding river processes and that many of the students held alternative conceptions that were likely to interfere with their learning of complex concepts in the Stage 6 syllabus. Teachers also became increasingly aware of the robust and deeply entrenched nature of alternative conceptions and the dangers of students interpreting new experiences through these erroneous understandings (Dove, 1999). The results of the PAR also challenged the teachers' assumptions about the effectiveness of the fieldwork experience as a conceptual change strategy. The data did not provide evidence of the kinds of emotional responses you would expect from students questioning and reworking their conceptions of river landforms and processes (Calvo & D'Mello, 2011). Further research is required to identify fieldwork activities that best promote cognitive conflict and constructive confusion.

The project also helped to build a community of practice and enhance collaboration within the social science department by stimulating conversations between teachers and authors about evidence-based approaches for identifying and addressing alternative conceptions (Draper et al., 2011; Erdas-Kartal et al., 2018; Hales, 2017). Consistent with the findings of Wongsopawiro et al. (2017), these formal and informal conversations formed an important part of the teachers' professional learning throughout the project. One outcome of these conversations was the identification of evidence-based approaches for improving professional practice that could be piloted with future Year 11 Geography classes. Examples of these strategies include the use of pre-tests and three-dimensional models to demonstrate river processes. The peer-teaching strategy outlined by Teacher Participant 2 is another example of an intervention developed as a result of the project to help teachers identify and address common alternative conceptions. A key strength of the PAR approach was the involvement of teachers in all stages of the research and in the process of decision making about how to respond to the data. Throughout the project, teachers developed a greater understanding about the importance of ongoing data collection about student learning and the need to reflect on the implications of these data to inform their future practice (MacDonald, 2012).

Conclusion

This paper reports the results of a PAR project which aimed to improve the PCK of in-service secondary Geography teachers. The aim was achieved by providing teachers with targeted feedback about: their students' depth and accuracy of knowledge of river landforms and processes; their personal knowledge of students' common alternative conceptions in this topic; and the effectiveness of current fieldwork practices in promoting cognitive disequilibrium and constructive confusion. The results suggest that PAR can provide feedback that can be used by teachers as a prompt for professional reflection and to stimulate conversations and professional learning about improvements that can be made to Geography teachers' PCK, assessment practice and pedagogy for promoting conceptual change. While the authors acknowledge that this study involved a single case study of four Geography teachers, the results suggest that involvement in a PAR process can improve Geography teachers' PCK by helping them to better understand the nature of students' alternative conceptions and the importance of ongoing formative assessment. The results are also important as they add to the limited body of literature examining the nature and development of secondary Geography teachers' PCK in specific topic areas (see, for example, Lane, 2011, 2015; Reitano & Harte, 2016). What remains unknown is the extent to which engagement in PAR results in sustained changes in teachers' knowledge and practice and whether this results in measurable improvements in the depth and accuracy of students' knowledge. This is an important area for future research.

References

Arguel, A., & Lane, R. (2015). Fostering deep understanding in geography by inducing and managing confusion: An online learning approach. In T. Reiners, B. R. von Konsky, D. Gibson, V. Chang, L. Irving, & K. Clarke (Eds.), *Globally connected, digitally enabled*. Proceedings ascilite 2015 (pp. CP:22–CP:26). Perth: Australasian Society for Computers in Learning in Tertiary Education.

Arnaudin, M., & Mintzes, J. (1985). Students' alternative conceptions of the human circulatory system: a cross-age study. *Science Education*, *69*, 721–733. https://doi.org/10.1002/sce.3730690513

Berg, T., & Brouwer, W. (1991). Teacher awareness of student alternative conceptions about rotational motion and gravity. *Journal of Research in Science Teaching*, *28*, 3–18.

Berry, A., Friedrichsen, P., & Loughran, J. (2015). Re-examining pedagogical content knowledge in science education. *Teaching and Learning in Science*. Oxford, UK: Routledge.

Biggs, J., & Collis, K. (1982). *Evaluating the quality of learning: The SOLO taxonomy (structure of the observed learning outcome)*. New York: Academic Press.

Brewer, W. (2008). Naive theories of observational astronomy. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 155–204). New York: Routledge.

Brown, D., & Hammer, D. (2008). Conceptual change in physics. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 127–154). New York: Routledge.

Burke, B. M. (2013). Experiential professional development: A model for meaningful and long-lasting change in classrooms. *Journal of Experiential Education*, *36*, 247–263.

Calvo, R., & D'Mello, S. (Eds.). (2011). *New perspectives on affect and learning technologies*. New York: Springer.

Clough, E., & Driver, R. (1986). A study of consistency in the use of students' conceptual frameworks across different task contexts. *Science Education*, *70*, 473–496.

D'Mello, S., & Graesser, A. (2012). Dynamics of affective states during complex learning. *Learning and Instruction*, *22*, 145–157.

D'Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction*, *29*, 153–170.

Dove, J. E. (1999). *Theory into practice: Immaculate misconceptions*. Sheffield, UK: The Geographical Association.

Draper, R-J., Adair, M., Broomhead, P., Gray, S., Grierson, G., Hendrickson, S., Jensen, A. P., Nokes J. D., Shumway, S., Siebert, D., & Wright G. (2011). Seeking renewal, finding community: Participatory action research in teacher education. *Teacher Development*, *15*, 1–18.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary science. Research into children's ideas*. London: Routledge.

Eilks, I., & Markic, S. (2011). Effects of a long-term participatory action research project on Science teachers' professional development. *EURASIA Journal of Mathematics, Science and Technology Education*, *7*, 149–160.

Erdas-Kartal, E., Cobern, W. W., Dogan, N., Irez, S., Cakmakci, G., & Yalaki, Y. (2018). Improving science teachers' nature of science views through an innovative professional development program. *International Journal of STEM Education*, *5*(30), 1–10.

Fryirs, K. A., & Brierley, G. J. (2012). *Geomorphic analysis of river systems: an approach to* *reading the landscape*. Chichester, UK: John Wiley & Sons.

Greca, I. M., & Moreira, M. A. (2000). Mental models, conceptual models, and modelling. *International Journal of Science Education*, *22*, 1–11.

Greenwood, D. J., & Levin, M. (1998*). Introduction to action research: Social research for social change*. Thousand Oaks, CA: Sage.

Hales, P. (2017). Shifts in teacher-talk in a participatory action research professional learning community. *Studia Paedagogica*, *22*(4), 31–53.

Halim, L., & Meerah, S. (2002). Science trainee teachers' pedagogical content knowledge and its influence in Physics teaching. *Research in Science and Technological Education*, *20*, 215–225.

Kemmis, S., McTaggart, R., & Nixon, R. (2014). *Action research planner: Doing critical participatory action research*. Singapore: Springer.

Lane, R. (2011). Exploring the content knowledge of experienced geography teachers. *Geographical Education*, *24*, 51–63.

Lane, R. (2015). Experienced geography teachers' PCK of students' ideas and beliefs about learning and teaching. *International Research in Geographical & Environmental Education*, *24*, 43–57.

Lane, R., & Coutts, P. (2015). Working with students' ideas in physical geography: A model of knowledge development and application. *Geographical Education, 28*, 27–40.

Lin, H., & Cheng, H. (2000). The assessment of students' and teachers' understanding of gas laws. *Journal of Chemical Education*, *77*, 235–238.

MacDonald, C. (2012). Understanding participatory action research: A qualitative research methodology option. *The Canadian Journal of Action Research*, *13*(2), 34–50.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In Gess-Newsome, J., & Lederman, N. G. (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95–132). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Morrison, J., & Lederman, N. (2003). Science teachers' diagnosis and understanding of students' preconceptions. *Science Education*, *87*, 849–867.

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, *38*, 261–284.

Reinfried, S. (2006). Conceptual change in physical geography and environmental sciences through mental model building: The example of groundwater. *International Research in Geographical and Environmental Education*, *15*, 41–61.

Reitano, P., & Harte, W. (2016). Geography pre-service teachers' pedagogical content knowledge. *Pedagogies: An International Journal*, *11,* 279–291.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.

Williams, J., Eames, C., Hume, A., & Lockley, J. (2012). Promoting pedagogical content development for early career secondary teachers in Science using content representations. *Research in Science and Technological Education, 30*, 327–343.

Wongsopawiro, D. S., Zwart, R. C., & Van Driel, J. H. (2017). Identifying pathways of teachers' PCK development. *Teachers and Teaching*, *23*, 191–210.