Educative Curricula and PCK Development Driven by STEM Professional Learning in Rural and Remote Schools: A longitudinal Type IV Case Study

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Keywords: educative curricula, pedagogical content knowledge, astronomy education, rural and remote education

International Journal of Innovation in Science and Mathematics Education, *24*(4), 1-17, 2016.

Abstract

Science performance overall in Australia is flat-lining. Science teachers hold the key to addressing this issue. One way to improve the effectiveness of science teachers is to improve their Pedagogical Content Knowledge (PCK) through professional learning experiences, but doing so in the middle-school years in rural and remote settings through traditional face-to-face professional learning activities poses many challenges. Educative curricula designed to improve teachers' science PCK as well as learning outcomes for students provide an alternative to traditional face-to-face professional learning for teachers in isolated locations. The Middle Years Astronomy Project is an example of one educative curriculum currently in use in the middle years of some rural and remote schools. The research reported here employed a Type IV multiple-case, embedded mixed-methods case study design to collect data from four remote sites in Western Australia and four rural sites in Victoria. The results of this research indicate that the educative curriculum improved teachers' science PCK for most teachers. Reasons for this are presented. The findings also suggest that PCK development takes time and requires a planned and systematic approach to teacher career development with support from the employer. It also suggests that using educative curricula to improve the PCK of rural and remote science teachers, as well as science student learning outcomes, is a strategy worthy of pursuit.

Introduction

National and international student performance data indicate that students in rural and remote areas of Australia experience education disadvantage when compared to their metropolitan counterparts (Alston and Kent , 2006; Australian Council of Deans of Science, 2005; Council of Australian Governments (COAG), 2013; Department of Education and Early Childhood Development (DEECD), 2012; Mission Australia, 2006; OECD, 2013; The National Centre for Science, Information and Communication Technology, and Mathematics Education for Rural and Regional Australia (SiMERR), 2006). Rural and remote education disadvantage is demonstrated in a range of education measures including national achievement data (National Assessment Program for Science Literacy, 2003–2012), school survey data (DEECD, 2012; Program for International Student Assessment, 2012; Trends in International Mathematics and Science Study, 2013), and the findings of significant studies conducted by government agencies (e.g., Marginson et al., 2013; DEECD, 2013; Sidoti, 2000; Victorian Auditor-General's Office (VAGO), 2014). For the purposes of defining 'rural' and 'remote' students, this study uses the definitions provided by the Australian Statistical Geography Standard (Australian Bureau of Statistics, 2011).

Rural and remote education disadvantage includes *science* education disadvantage (Australian Senate, 2009; National Assessment Program-Science Literacy, 2003–2012; OECD, 2013; SiMERR, 2006; VAGO, 2014). The research reported here sought to explore the potential of educative curricula in developing teachers' PCK and improve teachers' ability to deliver quality, authentic science lessons. Educative curricula usually consist of 'ready–to–go' packages, such as those described in McKinnon (2005) and Fitzgerald et al. (2015), that guide teachers to improve their PCK by providing advice on the selection of instructional strategies, the selection of assessment tools and methods, and through the provision of correct science content knowledge within the curriculum materials. In addition, educative curricula for science also provide teachers with advice on common student alternative conceptions, how to devise interventions to challenge these, appropriate instructional strategies to deal with them, and the impact of science orientations on strategy selection. Educative curricula thus provide teachers with professional learning and materials that expedite effective implementation of classroom activities, as well as helping pedagogical decision–making, which facilitates the development and transferability of PCK to other teaching and learning situations (Davis & Krajcik, 2005).

This paper reports on teachers' development of PCK in rural and remote schools across two phases of a research study. This case study explored the implementation of the Middle Years Astronomy Project (hereafter, the Project) an integrated science, technology, and mathematics hands-on, inquiry-based approach to teaching science (McKinnon, 2005; 2012, Danaia 2007) targeted at upper primary and junior high school students. The Project is one example of how educative curricula can help assist teachers' professional learning and PCK, and move science learning towards the 'ideal picture' of science defined by Goodrum, Hackling & Rennie (2001, p. *ix*).

Education in the Middle Years

There is a strong literature base that indicates the middle years are critical years for adolescents (e.g., Chadbourne, 2001; Dinham & Rowe, 2009; Western Australian DET, 2008), particularly in science education. The middle years are defined as students aged between 10 and 15 years (Dinham & Rowe, 2009). Science education is particularly important for these students as positive experiences in science before the age of 14 improve their engagement in Years 9 to 12 (Chubb, 2012, 2014; Goodrum et al., 2001; Goodrum, Druhan & Abbs, 2012; Lyons & Quinn, 2010; Marginson, Tytler, Freeman, & Roberts, 2013; OECD, 2006; The Regional Policy Advisory Committee of Victoria, 2013; Tytler, Osborne, Williams, Tytler, & Cripps Clark, 2008). Consequently, students require positive and engaging science education experiences in primary school education. However, Goodrum et al. (2001) revealed that science teaching is not in the 'comfort zone' of many primary teachers and this may negatively affect students' experiences. The low science teaching efficacy of primary teachers was reflected in an average self-reported figure of 59 minutes per week devoted to science (Goodrum et al., 2001), compared to the 'ideal' time allocation of 1.5-2.5 hours per week. The minimal instruction was reinforced by Angus et al. (2004) who reported an average of 41 minutes in schools in Western Australia. If students are receiving limited science education, they have less time to engage in positive science experiences prior to the age of 14, the age where they may be 'turned off' science (Chubb, 2012, 2014; Goodrum et al., 2001; Goodrum, Druhan & Abbs, 2012; Lyons & Quinn, 2010; Danaia et al., 2013; Marginson et al., 2013; OECD, 2006; The Regional Policy Advisory Committee of Victoria, 2013; Tytler et al., 2008).

If students are ‘turned off’ science in their own middle years of schooling, the scientific literacy of future teachers also declines as these students enter initial teacher education courses. Australian primary teachers already have a lower frequency of major study of science when compared with similar countries (Marginson et al., 2013; OECD, 2006). Appleton (2005) has shown that lack of science subject content knowledge affects primary teachers’ confidence to teach science and that many have not studied science during their senior school courses. The limited experience of science further acts as a barrier to teachers’ development of PCK, which involves having strong subject content knowledge (Kind, 2009a).

Another reason for focussing on the middle years of schooling is international and national testing results. Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA) assessment data (e.g., OECD–PISA, 2012; TIMSS, 2013) reveal that science performance in the middle years of schooling is ‘flat-lining’. Furthermore, Australia has a large range in student achievement in these tests, with the performance of Tasmania and the Northern Territory well below the OECD average in both PISA and TIMSS. The long equity tail in Australian international science assessment data has an overrepresentation of rural and remote students, Aboriginal students and low socio-economic status students. In particular, students in remote locations perform at a significantly lower level than their metropolitan peers and are over represented in the Below Proficiency Baseline in national assessment data (National Assessment Program for Science Literacy, 2003–2012).

Alston and Kent (2006), Mission Australia (2006) and Sidoti (2000) all report that school students in rural, remote, and isolated areas of Australia are disadvantaged. This was attributed to restricted access to the rich learning environments available to their metropolitan counterparts and to the lower value placed on education, and its relevance, by rural families. This disadvantage has a number of negative impacts including lower retention and completion of Year 12 (particularly for Aboriginal students), lower enrolment in tertiary education, higher absenteeism, and lower engagement in schooling. National assessment data show that students in remote and very remote areas perform at lower levels than those in provincial and metropolitan regions with means of 349, 381 and 400 respectively (Australian mean=394) (ACARA, 2012, 2013). In addition, Year 7 Numeracy data show increasing disadvantage with increasing isolation with students *not* meeting national minimum standard at 2.3%, 9.8% and 37.2% respectively (ACARA, 2014). A similar pattern exists in the 2011 TIMSS data where differences in metropolitan, remote, and very remote students equate to two years in schooling (ACER, 2013). It could be argued that improving the performance of students in rural and remote areas provides one means of raising the Australian average in both national and international assessments. Student performance, however, is reliant on the quality of instruction.

Science teachers working in rural and remote schools also face challenges. The Australian Council of Deans of Science (2005), The Australian Productivity Commission (2010), The Federation of Australian Scientific and Technology Societies (2002), The NSW Inquiry into Public Education (2002) and Sidoti (2000) all reported issues of general disadvantage and inequality in relation to science teachers in rural and remote Australia who have limited access to professional learning opportunities and to specialist science staff. Often, it is difficult to retain qualified teachers, with high annual staff turnover rates (> 20% per year) in remote schools (SiMERR, 2006).

Ensuring science students in rural and remote settings have access to effective science teachers requires a conscious effort to ensure that they have the skills through teacher training, and both on- and off-site professional learning. (Fishman, Marx, Best & Tal, 2003). It also requires an understanding of the specific skills that effective science teachers possess so that these skills can be nurtured and continually improved (Birman, Desimone, Porter, & Garet, 2000; Tinoca, 2004). Finally, it requires an understanding of the challenges facing rural and remote science teachers so that they can nurture, maintain and grow their professional skills to become highly effective (Sheffield, 2004).

Pedagogical Content Knowledge (PCK)

Loughran (2010) argues that the focus of our understanding of the work of teachers as 'teaching alone' needs to shift to thinking about the interplay between teaching and learning, and learning and teaching. Thinking of teachers' work in this way challenges notions of teaching as 'telling' and learning as 'listening', which is counter to the meaning of pedagogy as an inquiry process involving interaction between teacher and students. Teaching is therefore interrelated with, and dependent on, student learning (Fishman et al., 2003). In this view, building the pedagogical reasoning skills of teachers to respond to specific students for specific purposes in specific teaching and learning environments at specific times becomes critical to achieving effective teaching and learning (Abell, 2008; Kahle, 1999). Adapting, transferring, and applying pedagogical reasoning skills to new teaching and learning environments with new students to achieve effective learning signifies growth in teacher knowledge of practice (Angell, Ryder, & Scott, 2005; Cochran-Smith & Lytle, 1999; Davis, Petish, & Smithey, 2006; Grimmett & MacKinnon, 1992).

Magnusson et al. (1999), building on the work of Shulman (1986a, b), offers a definition of PCK comprised of five elements. Combining these elements with those proposed by Kind (2009b) indicates that PCK comprises the following eight elements, which provide a framework for understanding, and therefore developing, PCK:

1. Knowledge of instructional strategies designed to elicit effective science learning;
2. Knowledge of subject matter and of the curriculum, which features that subject matter;
3. Knowledge of one's personal orientation to teaching science;
4. Knowledge of assessment;
5. Knowledge of students' understanding of the subject including their alternative conceptions;
6. Knowledge of one's orientations towards teaching (knowledge of and about the subject, beliefs about it, and how to teach it);
7. Knowledge of teachers' efficacy to teach science; and,
8. Well-adjusted emotional attributes.

Something extra is obtained by moving fluidly and holistically amongst these elements of PCK as in–the–moment decisions are made in the learning environment to improve student learning. Kind (2009b) and Magnusson et al. (1999) found it challenging to describe clearly the 'extra' but suggest that it can be observed in the highly effective science teacher's ability to continuously scan their environment to assess the effectiveness of their chosen instructional strategies to achieve the desired learning outcomes. Where their chosen strategy is not achieving the desired learning outcome, in-the-moment responses are made. Mitchell et al. (2015) describe this as 'pinball pedagogical reasoning'. This process of continuously scanning the environment and making adjustments requires a sophisticated development and implementation of PCK in the teaching and learning environment. In recent years there has been evidence for the benefit of developing PCK in initial teacher-education courses, as described Bybee (2014) and McKinnon, Danaia and Deehan (in review). Beginning PCK development early in teacher education provides opportunity for early career teachers to practice moving fluidly and holistically amongst the elements of PCK in their teaching.

Methods

This study was premised on the need to support rural and remote teachers to improve their PCK in science. An educative curriculum was offered as one model to support science and STEM learning for both teachers and students in rural and remote schools where face-to-face professional learning was problematic. The researchers sought to answer three research questions:

1. Does the Middle Years Astronomy Project (the Project) have any potential for improving teachers' science PCK in rural and remote areas with the concomitant potential to redress educational disadvantage?
2. If the Project does/does not have this potential, what are the reasons for this?
3. What, if any, are the implications from this study for supporting teachers of science in the middle years of schooling in rural and remote areas to improve their PCK?

The study involved implementing a Type IV multiple-case, embedded mixed-methods longitudinal design (Yin, 2014, pp. 51–56), to explore the efficacy of educative curricula to improve teachers' science PCK in multiple schools in rural and remote locations. Multiple sources of data, embedded within sites, were elicited from students, teachers, a Key Learning Area consultant, administrative officers and parents. A case study approach is particularly relevant when the behaviours that the researcher is seeking to investigate are not open to manipulation, and when a rich descriptive real-life account is required to understand the case being investigated (Burns, 2000; Merriam, 1998; Yin, 2014). Specifically, this study was based on the Project as one educative curriculum that includes integrated, authentic learning experiences in science as well as the other STEM subjects. The case study approach allowed researchers to interact with the teachers implementing the Project in the context of their 'real–life' settings. Similarly, it was necessary to interact with students in their schools to determine the project's effectiveness (Burns, 2000; Merriam, 1998; Yin, 2014). Within these cases, it was also possible to collect multiple sources of data, both quantitative and qualitative, which were necessary to facilitate triangulation of results (Yin, 2014).

The Project develops PCK in teachers by using the approach of CoREs (Content Representations) and PaP-eRs (Pedagogical and Professional-experience Repertoires) suggested by Kind (2009b) and Loughran et al. (2006). The Project included one intensive professional learning day for participating teachers and a set of electronic materials with background information and learning activities for students. These activities were linked to the students' results from an Astronomy Diagnostic Test (ADT), where students' alternative conceptions identified in the test formed the basis for the sequence of the learning activities selected by the teacher (Danaia & McKinnon, 2008; Deming & Hufnagel, 2000; Hufnagel, 2002; Slater, Hufnagel, & Adams, 1999). All of the activities link to State or National Curricula.

Structure of the Research Study

The study was structured in two phases. Phase 1 occurred in a remote region of Western Australia and involved exploring the impact of the Project in one rural and three isolated schools: one rural middle school for Years 7–9, two remote F–12 schools, and one remote distance education school for Years F–7 (F=Foundation year or Kindergarten). The context for Phase 1 was an Australian Telescope National Facility (ATNF) led project, *Wildflowers in the Sky*, that gained Federal funding under the Australian Schools Innovation in Science, Technology and Mathematics (ASISTM) scheme and which is reported in the overall evaluation (Tytler, Syminton, Smith, & Rodrigues, 2009). As part of the ASISTM project, teachers were required to assist students to implement hands–on activities and engage them in inquiry–based learning to observe such things as the day and night sky using a range of technologies from the unaided eye to remotely controlled telescopes via the internet. A key component of the project was the development and delivery of effective professional learning over the longer term. The initial teacher workshop was held in a regional centre proximal to the collaborating schools, attracting more than 20 teachers from those schools. It was proximal only in the sense that there was nothing else between the participating schools and the common location. All teachers in the other schools had to travel varying distances up to 450 km.

Phase 2 took place in rural Victoria and involved exploring the impact of the Project in four Foundation to Year 6 primary schools. Specialist Key Learning Area (KLA) and cross-curriculum consultants formed part of a resource base to help lift school-achievement data in the region. One of these was a specialist Science KLA Consultant who provided support to schools, including: science curriculum, assessment and pedagogical advice; teaching and learning resources; and professional learning support designed to improve science curriculum outcomes based on the AusVELs (Victorian) science curriculum (DEECD, 2012, 2013). The professional learning support included provision of face-to-face sessions, online support and mentoring and direct coaching during school visits. The aim of implementing the Project was to support science as well as to improve literacy and numeracy outcomes within a cross-curriculum educational approach. Access to a remotely controlled telescope in Wyoming, USA was provided and allowed in–class observing of the night sky during the students' normal class time.

Data Collection

Six primary sources of data were employed in this research. These sources were: documentary; archival records; interviews of participants; direct observations; physical artefacts; and, student tests. For the sites in Phase 1, documentation consisted of newsletters, teacher lesson notes, and school profile information presented to the researcher, data collected from school websites and student performance in the Astronomy Diagnostic Test. For Phase 2, documentary sources comprised school newsletters, teacher lesson plans and school websites.

Archival records refer to past records of stored materials, usually of a historical nature, used in conjunction with other sources of evidence to illuminate a case study. Two documents of a historical nature assisted in generating data: a copy of the ATNF *Wildflowers in the Sky* ASISTM report to the Curriculum Corporation (Hollow, 2007); and, a report by Tytler et al. (2008) detailing 16 ASISTM case studies that illustrate better science innovative practice, and in which *Wildflowers in the Sky* was one project described.

Short (about 30 minutes) semi-structured interviews (Burns, 2000; Rubin & Rubin, 2011) with key agents were undertaken at each site with those involved in implementing the Project, and carefully planned to include a list of focus questions. Respondents included teachers, principals, middle-school leaders, the Science KLA consultant and the Cluster Coordinator. During Phase 2 of the research, some parents were also involved in data collection, as they interacted with the researchers while visiting the school. These unrecorded interviews formed

part of the set of observations gathered during visits to the sites. Interviews were also undertaken with all of the teachers who were implementing the Project at all the sites.
Student interview questions were derived from the same set of questions as those asked of teachers and followed the same semi-structured format, which provided latitude to keep the flow of the interview going with respondents who were often quite shy. In order not to intrude too much into student-lesson time, and for reasons of manageability, it was decided to interview a sample of students at Sites 1, 2, 3, 4, 7 and 8. In addition, the Science KLA Consultant and the Cluster Coordinator employed by the schools also provided interview data.

Site visits were conducted for the purpose of gathering interview data and provided the researchers with multiple opportunities to make direct observations concerning the work of staff and their interactions with students as well as environmental factors operating at the sites (e.g., the students' thematic decorations of their classrooms and the apparent engagement of pupils during their lessons). Such observations were recorded in a journal and were supported by photographs and videos acquired from the teachers. In Phase 2 of the study, the Cluster Coordinator created a password-protected Dropbox location for participating sites to share support material, implementation ideas, and teacher– and student–generated videos. Copies of videos provided by Principals at Sites 5, 7 and 8 were used to augment and triangulate other data. There were three types of teacher- and student-generated videos:

- Teacher-produced pretest/posttest videos for the purpose of demonstrating students' understanding of astronomy and space, made at the commencement and end of the study;
- Teacher-produced images and videos illustrating students at work on key astronomical concepts (e.g., working on the scale of distances to the planets and to the nearest star from the Sun, or working on explanations for the seasons); and,
- Student-produced videos at the end of a topic, demonstrating students' knowledge of astronomical concepts.

In the Project, the materials suggested that teachers should probe their students' alternative conceptions about celestial phenomena before they began teaching the content. This involved students completing the Astronomy Diagnostic Test (Danaia & McKinnon, 2008; Deming & Hufnagel, 2000; Hufnagel, 2002; Slater, Hufnagel, & Adams, 1999). These tests were completed and collected on both pretest and posttest occasions to determine the differences in students' conceptions of astronomy.

Data analysis and interpretation

Following data collection, analyses occurred at the site level then by the phases of the research to look for emerging patterns using the descriptors 'remote' for Phase 1 sites and 'rural' for Phase 2 sites. Convergent– and divergent–based patterns then emerged. The process of triangulation tested each pattern. In this way, explanation building occurred to account for occurrences at the individual and aggregated site levels for Phase 1 and Phase 2 of the study. The process of explanation building by triangulating the data involved developing rival explanations and incorporating emerging propositions to create new explanations where data supported this. Examining data for evidence of PCK growth through using the educative curriculum involved applying the framework developed (Davis & Krajcik, 2005; Kind, 2009b; Magnusson et al., 1999). No attempt is being made here to attribute causality. Rather, this framework is used to indicate changes in teacher PCK.

Findings

The research findings are presented for each phase of research in Tables 1 and 2, followed by a short comparison of the two phases. When individual participants are discussed, the following code applies:

- The initial letter denotes the participants' role: P for principal, T for teacher;
- The cardinal number denotes the different participants at each school (e.g., T1 is the first teacher and T2 is the second teacher for a site); and,
- The subscript indicates the site at which the participant was located (e.g., $P1_{S1}$ is the principal at site 1 and $T3_{S2}$ is the third teacher at site 2).

Summary for Phase 1 Remote Schools

Phase 1 included Western Australian sites 1 through 4. Table 1 shows the development of each teacher's PCK, based on the framework developed from the literature (Kind, 2009b; Magnusson et al., 1999 and Shulman, 1986b). The findings from this phase suggest that the Project had the most positive impact on teachers who adopted either all or some of its elements and only two of whom had studied science at a tertiary level. These two teachers were teaching science in Years 8 and 9 (the middle years of schooling in Western Australia).

There are a number of inferences that can be made from Table 1. Firstly, the data suggest that the Project's educative curriculum improved the science PCK on five of nine growth indicators for half or more of teachers involved in implementing the Project. For all nine growth indicators, the data suggests two or more teachers improved their science PCK for that particular indicator. For the PCK indicator *Improved student-science learning outcomes* the data suggest student engagement and enjoyment with astronomy at all sites improved and at some sites students' alternative conceptions moved towards more accepted scientific explanations for particular phenomena as measured by the Astronomy Diagnostic Test. There was evidence of improved science knowledge, skill and vocabulary at most sites. Seven of the teachers across all sites held evening sessions using telescopes donated by ASISTM project. Students particularly enjoyed these evenings, and also commented favourably on engaging with projects such as investigating and measuring crater impacts and keeping a Moon Journal. Site 3 chose to deliver the project through establishing an Astronomy Society, which was an enjoyable experience for the students.

Secondly, measured by the number of teachers showing improvement in a PCK growth indicator, the data suggest that for teachers at the remote sites, the Project's educative curriculum had the greatest impact on improving:

- Knowledge of science instructional strategies and their implementation;
- Knowledge of science content and the science curriculum;
- Improved teacher confidence to teach science;
- Improved personal attributes; and,
- Improved student science-learning outcomes.

Eight of nine teachers improved their *Knowledge of science instructional strategies and their implementation* based on the materials provided. While confidence varied, the personal assessment made by teachers showed they all felt they had improved as a result of the project.

Table 1: Phase 1 summary of data showing growth in PCK

	Phase 1	Number of Teachers
	Teacher Codes: $T1_{S1}$, $T2_{S1}$, $T3_{S2}$*, $T4_{S2}$, $T5_{S3}$, $T6_{S3}$, $T7_{S4}$, $T8_{S4}$, $T9_{S4}$	**Maximum 9**
Indicator of PCK growth		
1. Holistically scanning and fluidly moving between components	$T4_{S2}$, $T7_{S4}$ beginning to do so	2
2. Knowledge of science instructional strategies and their implementation	$T1_{S1}$, $T2_{S1}$, $T4_{S2}$, $T5_{S3}$, $T6_{S3}$, $T7_{S4}$, $T8_{S4}$, $T9_{S4}$	8
3. Knowledge of areas of science students find difficult to understand together with strategies to remedy this	$T1_{S1}$, $T2_{S1}$, $T7_{S4}$, $T9_{S4}$	4
4. Knowledge of one's personal orientation to teaching science	$T7_{S4}$, partially for $T4_{S2}$,	2
5. Knowledge of science assessment	$T7_{S4}$, $T8_{S4}$,$T9_{S4}$	3
6. Knowledge of science (astronomy) content knowledge and curriculum	$T1_{S1}$, $T2_{S1}$ $T4_{S2}$, $T5_{S3}$, $T6_{S3}$, $T7_{S4}$, $T8_{S4}$, $T9_{S4}$	8
7. Improved teacher confidence to teach science	$T1_{S1}$, $T3_{S2}$*, $T4_{S2}$, $T5_{S3}$, $T6_{S3}$, $T7_{S4}$, $T8_{S4}$, $T9_{S4}$	8
8. Improved personal attributes	$T1_{S1}$, $T2_{S1}$, $T4_{S2}$, $T5_{S3}$, $T6_{S3}$, $T7_{S4}$, $T8_{S4}$, $T9_{S4}$	8
9. Improved student science learning outcomes	All teachers for: • enjoyment; • engagement; and, • content knowledge and skills	9

* $T3_{S2}$ implemented her own program at Site 2

The least impact, in terms of science PCK development, was for the following indicators:

- Knowledge of one's personal orientation to teaching science; and,
- Holistically scanning and fluidly moving between components.

Being able to holistically scan the teaching and learning environment and move fluidly amongst PCK components is the hallmark of the expert teacher and takes time to develop. The fact that many of the teachers in Phase 1 of the study were at an early career stage may have been a mitigating factor to acquiring this *integrative* component of PCK based on only one experience with an educative curriculum.

Summary for Phase 2 Rural Schools

This phase of the research was conducted in Victoria, at sites 5 through 8. Table 2 shows the development of each teacher's PCK from this phase, based on the framework applied (Kind, 2009b; Magnusson et al., 1999 and Shulman, 1986b). None of the teachers who participated in this phase had ever undertaken any formal science training.

Table 2. Phase 2 summary of data showing growth by PCK indicator.

	Phase 2	**Number of Teachers**
	Teacher Codes: $TP1_{S5}$, $TP2_{S6}$, $TP3_{S7}$, $T10_{S5}^{***}$, $T11_{S8}$, $T12_{S8}^{***}$	**Maximum 6**
Indicator of PCK growth		
1. Holistically scanning and fluidly moving between components	$TP1_{S5}$, $TP3_{S7}$, $T11_{S8}^{***}$	3
2. Knowledge of science instructional strategies and their implementation	$TP1_{S5}$, $TP3_{S7}$, $T10_{S5}^{***}$, $T11_{S8}$, $T12_{S8}$	5
3. Knowledge of areas of science students find difficult to understand together with strategies to remedy this	$TP1_{S5}$, $TP3_{S7}$, $T11_{S8}$, $T12_{S8}^{***}$	4
4. Knowledge of one's personal orientation to teaching science	$TP1_{S5}$, $TP3_{S7}$, $T11_{S8}$	3
5. Knowledge of science assessment	$TP1_{S5}$, $TP3_{S7}$, $T11_{S8}$	3
6. Knowledge of science (astronomy) content knowledge curriculum	$TP1_{S5}$, TP2, $TP3_{S7}$, $T10_{S5}^{***}$, $T11_{S8}$, $T12_{S8}^{***}$	6
7. Improved teacher confidence to teach science	$TP1_{S5}$, $TP2_{S6}$, $TP3_{S7}$, $T10_{S5}^{***}$, $T11_{S8}$, $T12_{S8}^{***}$	6
8. Improved personal attributes	$T11_{S8}$	1
9. Improved student science learning outcomes	All teachers for: • enjoyment; • engagement; and, • content knowledge and skills	6

*** $T10_{S5}$ and $T12_{S8}$ were teachers of F–2 students who were included due to the joint nature of curriculum planning in small rural schools. $TP3_{S7}$ included the whole school from F–6 when implementing the Project for the same reason.

The data from Table 2 suggest that the Project's educative curriculum improved science PCK on eight of nine growth indicators for half or more of teachers and teaching principals involved in implementing the Project. For the PCK indicator *Improved student science learning outcomes*, the data were similar to Phase 1 in suggesting high student engagement and a move towards more accepted scientific explanations for some students as measured by the Astronomy Diagnostic Test. The data show the Project led to increased involvement of the school communities at viewing nights. These also attracted members from the wider community, often in the form of amateur astronomers and other interested people, to engage with the Project and bring science to life for the students. This also appeared to improve learning outcomes.

Secondly, measured by the number of teachers and teaching principals showing improvement in a PCK growth indicator, the data suggest that for Phase 2 there was the greatest impact on:

- Knowledge of science content and the science curriculum;
- Improved teacher confidence to teach science;
- Improved student science learning outcomes; and,
- Knowledge of science instructional strategies and their implementation.

The data suggest the Project's educative curriculum had the least impact on improving PCK growth indicator of *Improved personal attributes*. One reason for this could be the career profile of Phase 2 teachers who possessed more experience and many more years of teaching experience in relatively stable teaching and learning environments. $T11_{S8}$, $TP1_{S5}$ and $TP2_{S6}$, already had well-developed personal attributes including strong reflective practitioner skills, high levels of resilience and the ability to provide and receive constructive feedback. This latter attribute occurred often as part of the professional learning network of colleagues in this high functioning cluster of schools. It was, therefore, more difficult for the data to show evidence of growth in these personal attributes for the participants, although $T11_{S8}$ did demonstrate a willingness to try the Project's integrated inquiry–based, investigative approaches using technology when she had initially felt very uncomfortable about using any digital technology.

Comparison of Phase 1 and 2 Findings

In terms of similarities for the Phase 1 and Phase 2 sites, the data indicate that all bar one of the participants in both phases improved their PCK in the areas of *knowledge of science instructional strategies and their implementation*, *knowledge of science (astronomy) content*, *the astronomy science curriculum contained in the Project*, *improved teacher confidence to teach science* and, *improved student science learning outcomes*.

The single biggest difference in results between Phases 1 and 2 of the study is in *improved personal attributes* where this PCK growth indicator was present for eight of nine teachers in Phase 1 sites and only one of six teachers/teaching principals in Phase 2 sites. A possible explanation for this may lie in the career profile of the teachers participating at each of the two locations. The great majority of teachers in Phase 1 sites were early–career graduate teachers who needed to develop quickly the skills of resilience and perseverance as well as skills in giving and receiving feedback as part of learning the profession. A culture of needing to be resilient was constantly present during the early stages of their careers as they attempted to learn their trade in these challenging remote locations. They did demonstrate high degrees of resilience and a thirst for help on how to develop as professionals. At issue for these teachers was that their desire for feedback, and opportunities to network with colleagues in other schools both to give and to receive feedback on their teaching were not being met through either internal or external support mechanisms. In contrast, the career profile of Phase 2 teachers showed more experience with many more years of teaching experience in relatively stable teaching and learning environments, where it was more difficult for the data to show evidence of growth in these personal attributes for these teachers/teaching principals.

For *knowledge of one's personal orientation to teaching science* and *holistically scanning and fluidly moving between components,* relatively few participants (two and three teachers in Phases 1 and 2 respectively) showed growth in this PCK indicator. This study suggests the development this capacity takes time. The different career profiles for the teachers/teaching principals in each phase of the study, it is argued, is likely to be a factor in accounting for the differences in this indicator. We are not suggesting, however, that this skill is rigidly fixed to a teacher's particular career stage.

Discussion

From the analyses, it was clear that the Project (McKinnon, 2005, 2012) has strong potential for improving teachers' science PCK in the middle years of schooling in rural and remote areas together with the concomitant potential to help redress rural education disadvantage. The findings indicate that out of a total of 15 teachers/teaching principals, there was growth in PCK on six of the nine growth indicators for half or more of the participants.

The findings also show a concomitant possibility to help redress rural disadvantage. It appears that this potential derives from two sources. The first lies in the Project materials conforming to the design principles for educative curricula to simultaneously elicit teacher and student learning. The Project materials adhere to the principles developed by combining the works of Kind (2009b), Magnusson et al. (1999) and Shulman (1986b), as well as the design heuristics developed by Davis and Krajcik (2005). Furthermore, the Project materials follow the design principles for student curriculum developed by Bybee (2006) and Donovan and Bransford (2005). Both the teacher and student learning materials are extensive and of high quality. They offer high levels of support both in a face-to-face and in an ICT-mediated fashion. The second reason for the Project's potential lies in its well-conceived implementation plan, which is achieved by delivering an initial intense face-to-face professional development session followed by longer term IT-mediated support. The initial session is designed to provide an overview of the Project, model the use of the materials to teach students, and allow teachers to examine their science orientations so they may identify any alternative conceptions they may hold. In addition, the Teachers' Guide contains embedded professional learning to develop teachers' PCK including: advice on designing and modifying a number of instructional strategies to teach astronomy, astronomy content knowledge to support subject content knowledge development, explanation of students' alternative conceptions in astronomy, information on students' beliefs about astronomy, and advice on assessment practices. Other benefits of the materials are the Astronomy Diagnostic Test, which is an evaluation tool for measuring students' learning outcomes, and dissemination of all learning materials on a USB, DVD or by Dropbox that has extensive hyperlinks to guide the teachers through the Project.

The third research question addressed the implications for supporting teachers of science in the middle years of schooling in rural and remote areas to improve their PCK. This study identifies a number of implications. First, PCK development takes time, particularly in being able to holistically and fluidly move amongst the elements to continually assess and reassess the effectiveness of instructional strategies (e.g., Loughran et al., 2006). Visualising PCK improvement as occurring along a career continuum reinforces the view that it can be developed, improved and refined. Developing and improving the PCK of teachers of science in the middle years of schooling in rural and remote areas requires an integrative combination of educative curricula and professional learning in both short-term and long-term timeframes to develop both the quantity and quality of the nine PCK components. Secondly, given the criticality of science teachers to achieving the ideal picture for science education (Goodrum et al., 2000), this research indicates that the development of PCK cannot be left to chance. Rather, it requires a planned and systematic approach *for each teacher* supported by the employer. Further, teachers in the middle years of schooling in remote areas face a number of significant challenges to develop their science PCK, especially graduate and proficient teachers, who require both additional in–school and external support in addition to the educative curricula to meet these challenges. Finally, introducing educative curricula in Years F–4 in rural and remote schools provides an opportunity to improve early primary school teachers' science PCK.

The overwhelming benefit of educative curricula on teachers' science instruction was evident when the participants of this project commented very favourably on the quality and usefulness of the materials and requested similar educative curricula on a range of science topics from the researchers. $T11_{S8}$, for example, made the comment to the one of us that the "*standard had been set by the Project materials*" and wished for materials of a similar standard for all of the other *Australian Curriculum: Science F–10* topics she would teach over the next few years. While this was very positive feedback, it is also indicative of the time demands that teachers face in meeting the requirements of teaching. They are understandably *time poor* when it comes to finding time for activities such as developing their own curriculum materials, preferring instead to have someone else design the materials for them but to allow for the modification of them to fit their context. Education systems have the capacity to do this through their curriculum design functions usually located in Curriculum Directorates or Distance Education Learning Material Design Directorates, and need to be encouraged to provide educative curricula to support teachers.

In terms of developing teachers' science PCK, it was also evident that graduate teachers of science in remote areas require additional in–school support to meet these challenges. Ideally, this should come from more experienced teachers of science. Where these are not available, as was the case at remote Sites 1, 2 and 3, then support should come from school principals. Principals are able to provide additional in-school support by facilitating the establishment and nurturing of subject–specific and teacher and leader networks as occurred at the Phase 2 sites, where they jointly funded a Cluster Coordinator to help organise activities. Such a position provided organisational support for early career teachers who were coming to terms with behaviour management techniques as well as learning the subject-specific PCK. This was especially the case for the teachers in Phase 1 of this study who were beginning to develop their understanding of PCK needs across all KLAs, and not just in Science.

Conclusions

The results of this research indicate that the Project, with its educative curriculum design, has strong potential for improving teachers' science PCK in the middle years of schooling in isolated areas with the concomitant potential for redressing rural disadvantage. This educative curriculum achieves this by conforming to better practice design principles as well as having a well–conceived implementation plan. The study provides guidance to teachers and designers of professional learning experiences on areas of PCK to target when seeking to develop the attributes possessed by experienced teachers. Of particular note is perhaps the extent to which the educative curriculum helped teachers with no formal training in science to become more comfortable with teaching the content to their students. Teachers expressed the opinion that the materials had helped them feel more comfortable with, and confident about, teaching astronomy to their students. These aspects of educative curriculum with the embedded professional learning approach for teachers are worthy of further investigation in other science content areas for overcoming the "tyranny of distance" in Australia.

If science education in rural and remote settings in the middle years of schooling is to be effective then the development of science–teacher PCK is critical and cannot be left to chance. This requires an individualised, planned and systematic approach to PCK development *for each teacher,* supported by their employer. This research has also shown that educative curricula with embedded teacher professional learning should form part of a suite of professional support activities for teachers of science in rural and remote areas to assist their development of PCK. In addition to educative curricula, this study suggests that the suite of support should include other forms of external provision such as science consultants, cluster–schools support and face–to–face professional learning as well as in-school professional learning from the principal and experienced teachers.

Teachers in the middle years of schooling in rural and remote areas face many challenges to develop their science PCK to improve their students' learning outcomes. The moral imperative for improving science teaching and learning in rural and remote areas stems from the need to ensure that rural students (and teachers) do not experience another layer of disadvantage relative to their metropolitan peers by receiving a poorer science education or worse, no science education at all. If this disadvantage continues, it could potentially result in poorer scientific literacy skills for rural and remote students and a reduced ability to contribute to, and thrive in, the national and international knowledge economy.

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