Exploring Primary Teachers' Professional Learning Network (PLN) Activities for Value as Professional Development in Science Education

by Ruth Fentie

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Certificate of Authorship

I, Ruth Fentie declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Arts and Social Sciences at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abstract

Effective, scalable teacher professional development is requisite to international governments' objectives of improved student learning outcomes and career uptake in science and STEM fields. In seeking an optimal balance between personally relevant and professionally potent development, primary teachers are among those using Professional Learning Networks (PLNs). This multi-mixed methods study, includes quantitative and qualitative data collection, focused on investigating international primary teachers' PLN activities, for contributing value as professional development in science education. Data analysed and integrated came from an online survey, interviews, participant artefacts, including a brief review of professional documents. Participants' perceptions, analysed through a socio-cultural theoretical lens, revealed key themes. Themes indicated participants' informal activities in multiple online contexts of their PLN contribute considerable value for developing professionally, although not exclusively in science education. Value ascertained from teachers' perceptions, used criteria for effective teacher professional development and a model for teacher professional knowledge. Primary teacher participants, regardless of science background, perceived that their PLN activities inspire, promote, support and affirm implementation of newer science and technology practices. Participants' selective online PLN construction, contingent interactions and reflective activities provide evidence of developing science pedagogical content knowledge (PCK). Participants shared ideas, resources, tools and ways to implement these, to science-topic and K-6 suitable specificity. In sharing professional knowledge such as science PCK, participants influenced their own and others' professional identity. Participants adapted general pedagogical knowledge for science; and participants refined their science content knowledge (SCK) (to a lesser extent); both with implications for student learning. While acknowledging study limitations, primary teachers' PLN use, has individual and collective value for professional development in science education. An implication for pre-service teachers and in- service teachers is that using a PLN inspires and supports opportunities to develop their science pedagogical knowledge and teaching skills through a career.

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Abbreviations and Definitions

AR Augmented Reality

Augmented reality describes a composite or enhanced representation of reality by using technology to augment the real world with sound and/or image and/or text or other digital content.

CoP Communities of Practice

Communities of practice are groups of people with shared interests learning more efficiently through their interactions together (Wenger, 1999). The shared domain of interest creates an identity and membership in being part of joint activities where practice involves shared, co-developed resources.

CoRL Co-Regulated Learning

Co-regulated Learning describes computer-supported collaborative learning, based on self-regulated learning theory. Co-regulated learning is where individual self-regulatory processes are supported temporarily within a group by its members, the technologies used or by aspects of the environmental context (Jarvela et al, 2016)

Generalist science primary teacher

A generalist science primary teacher teaches across all key learning areas within the K-6 school curriculum with no specialised science discipline knowledge qualifications (does not exclude primary teachers with more specialised work experience, qualifications and specialisms in other domains). Generalist science primary teachers tend to teach in a single classroom across a school year, except where classes are composite (for example, K/1 or 5/6).

Abbreviations and Definitions continued.

NIC **Networked Improvement Communities**

NICs are sharing networks, designed to execute solutions to complex, difficult problems requiring multi-step solutions. NICs allow for deeper group understanding between members allowing them to work smoothly as a system to solve complex or "wicked problems" (Gomez et al., 2016, p.11).

PCK **Pedagogical Content Knowledge**

PCK refers to teachers' professional knowledge and skill focused on knowledge of the subject content, their beliefs about teaching and learning, and knowledge of ways to implement content learning activities using their knowledge of their students (Shulman, 1986). This transformative knowledge practice distinguishes teachers from subject matter content experts (Loughran, 2013). PCK is a crucial part of teachers' background knowledge. Where background knowledge involves teachers' curriculum knowledge, including assessment and general pedagogical knowledge of teaching approaches. Managing learning opportunities and environments conducive to learning, teacher's identity and motivations are also part of this background (Gess-Newsome, 2015). PCK is distinctive from general pedagogical knowledge as it is content, even topic specific; actively emergent with practice; and is complex in detail.

PCK & S **Pedagogical Content Knowledge and Skill**

Pedagogical Content Knowledge and Skill or PCK & S is a term used to describe teachers' practice at the classroom level of implementation of skill in PCK, suited to a specific group of students, and which develops with teaching (Gess-Newsome, 2015).

PCK-ing

PCK-ing is a similar concept to PCK&S which focuses on the active process of teachers transforming their content knowledge. PCK-ing or PCKg is inclusive of the learning context, and researchers propose that it comprises four aspects including content knowledge of subject matter, student needs, the learning environment and pedagogical understanding (Cochran, De Ruiter and King, 1993; Van Driel et al, 1998).

Abbreviations and Definitions continued.

PDP Professional Development Program

Professional development programs are developed (duration and mode of delivery varies) as a means of improving quality teaching classroom practices which can affect student learning, often for purposes of accreditation and continued teacher professional development.

PLC Professional Learning Community

Professional Learning Communities in education are noticeable for their common features. The community's shared aim of focusing on the collaborative, as well as individual responsibility to increase reflective practice is a feature, as are the professional goals of inquiry and promoting student learning (Jones et al., 2013).

PLN Professional Learning Network

Professional Learning Networks (PLNs) are complex interactional systems in online spaces where people access and use the available collective technology-mediated tools, resources and other people to support professional learning and ongoing development for their own and others' benefit (Trust et al, 2016).

PST Pre-Service Teachers

Pre-service teachers are undergraduate teacher education students, pre-employment.

Primary science teacher

A primary science teacher is a teacher of science at the primary or elementary school K-6 level, who may be generalist or specialist educated.

Abbreviations and definitions continued

RCM Refined Consensus Model

The Refined Consensus Model refers to a newer version of the Consensus model of teachers' PCK and skills. This newer model resulted from a second PCK summit, feedback sessions at science teacher conferences and electronic discussion, collated by Carlson & Daehler (2019).

SCK, SMK, CK Subject Content Knowledge or Subject Matter Knowledge

Content Knowledge or CK is used by Shulman (1986) to describe teachers' professional knowledge involving subject matter or discipline knowledge, curricular knowledge and pedagogical content knowledge. SCK refers to the content (facts, accepted theories, terminologies) knowledge particular to a subject and can be topic specific within a subject. Furthermore CK can be epistemic or syntactic, for example describing the ways that science knowledge develops, and substantive (SMK) knowledge of science (historic, accepted), (Anderson & Clark, 2012).

SDL Self-Directed Learning

Self-directed learning is a term used in an adult learning theory by Knowles (1975) where learners self-direct a process to identify their own ongoing learning needs; actively plan and pursue those goals, using relevant strategies and sourcing materials. Self-directed learners then evaluate whether their goals are met and formulate next steps. The self-directed learner may or may not enlist the help of others.

SNA Social Network Analysis

Social Network Analysis means conceptualising and analyzing social network relationships in structural-relational terms, emanating from social psychology and anthropology, and is facilitated in recent years by computer software. Patterns of dynamic relations are explored with global (big picture) and local measures (units at more individual level) using statistical methods to identify interaction characteristics like distribution, connections as ties and nodes, direction, and visualizing these flows of relationships such as reciprocity on maps or graphs (Carrington & Scott, 2014; Knoke & Yang, 2008).

Abbreviations and definitions continued

Science specialist primary teacher

A science specialist primary teacher is one who may have an other than primary education qualification, such as high school teacher with specialised domain knowledge in science, and also teaches primary or elementary K-6 school students; or teaches science exclusively; or a primary teacher with extra qualifications in the specialised knowledge domain of science (Appleton, 2007).

SRL Self-Regulated Learning

Self-regulated learning or SRL refers to the self-management of the learning process: identifying goals, employing self-control and self-monitoring towards goals and a self-reflective phase (Pintrich, 2000). This self-regulation involves motivational factors of affect, personal agency, self-belief and self-efficacy.

SSRL Socially-Shared Regulation of Learning

Socially-shared regulation of learning (SSRL) involves the collective efforts of group members to have productive group work processes. Through their group learning activities, they motivate and regulate group cognitive and affective experiences and behaviour (Jarvela et al., 2016).

STEM Science, Technology, Engineering & Mathematics

The acronym STEM was coined to lift the profile of each of these subject areas in educational contexts. STEM also refers to integration of these subject areas with their specific content knowledge as well as interdisciplinary activities (English, 2016).

TPD Teacher Professional Development

Teacher professional development to be considered effective needs to be based on professional learning that has structure and is associated with teachers changing their practice and improved learning outcomes for students, according to Darling-Hammond et al. (2017). TPD is usually associated with formally provided programs.

Abbreviations and definitions continued

TPKB Teacher Professional Knowledge Base

Teacher professional knowledge base is a general professional knowledge with several components. It is based on research and a shared understanding of effective teaching practice. TPKB also consists of topic specific professional knowledge (Gess-Newsome, 2015).

TSPK Topic Specific Professional Knowledge

Topic specific professional knowledge refers to content knowledge specific to science topics such as forces, living things etc., includes pedagogy and is specific to a student development level (Gess-Newsome, 2015).

Chapter 1 **Introduction**

Personally meaningful and professionally valuable teacher development requires a balance of needs and goals that has increasingly led to teachers seeking self-directed learning options (Rensfeldt et al., 2018; Trust, 2013). This study explores the value of primary teachers using self-initiated and self-directed professional learning in online networks to meet effective professional development goals. A significant reason for the shift towards self-directed learning, is to complement or even replace more formal, possibly agenda driven, provided professional development programs (PDPs) which teachers have perceived as lacking in personal relevance, therefore limiting professional value (Kennedy, 2016; Roth, 2014; Webster-Wright, 2009).

Further impetus for this study arises from other reported limitations to effective teacher professional development. Historically limitations have included successfully offering TPD experiences with sustained duration (Opfer & Pedder, 2011); support during implementation; and at scale, with convenient, low cost access (Luft & Hewson, 2014). The nature and extent of value from primary science teachers' online, informal, networked learning for offering affordable, anytime TPD is explored in this study. A recent study by Unger (2019) highlighted a Twitter community as useful for K-8 school teachers in sharing their science knowledge to implement new curriculum standards in USA. Taking Unger's (2019) dissertation into account, this remains a significant, yet rapidly filling gap in the current literature.

There are differing interpretations and varying definitions of the PLN acronym from *personal* learning networks recognisable by theories of connectivism (Siemens, 2004), the open, social networked learning notion for students popularised from Couros' (2009) university distance teaching and learning work, to PLN meaning *professional* learning networks (Ivanova, 2009; Trust, 2012; Xerri, 2014). This study adopts the definition forwarded by Trust et al. (2018) for its complexity and accuracy in explaining the formation, and extent of networks that teachers use. "PLNs consist of complex amalgams of people and organizations, face-to-face and digital spaces, and cognitive and technological tools that can support continuous learning and professional growth." (Trust et al., 2018, p. 137). For an extended discussion of defining a PLN, see 2.2.1.

PLN use offers convenience and personalisation of learning goals to meet professional needs (Greenhalgh et al., 2020; Tour, 2017) and has been found to support aspects of professional learning for other groups of educators, educational leaders and K-12 teachers (de Laat and Schreuers, 2013; Krutka et al., 2017; Oddone et al., 2019; Trust, 2012; Trust et al., 2018). Benefits and limitations of

PLN use are summarised in Chapter 2 (see 2.2.4).

Another issue, necessitating this study, was raised by researchers who noted that primary teachers, particularly those with a generalist background require professional development to improve their science content knowledge and pedagogical knowledge (Appleton, 2003; Harlen & Holroyd, 1997; Hartshorne, 2005; Huberman, 1985; Newton & Newton, 2001; Prinsley & Johnston, 2015). These historical research findings resonated with my ongoing professional development interests and the wider debate of current TPD practices, prompting this doctoral study. Educated as a generalist primary teacher over 30 years ago, and through a sporadic career path, it has been important for me to source ways to boost my science content knowledge as well as confidence in teaching science for two reasons. The first reason was to sustain my own professional development in an ongoing but not necessarily continuous way. The second reason, was to support my PST students' development needs, to confidently implement quality K-6 science and technology learning experiences. A colleague working at UTS introduced me to PLNs, sparking my interest as it built on my prior knowledge of educational technology.

Emerging research suggests online PLN contexts support science knowledge sharing and development of science teacher identity (Unger, 2019; Wall, 2015). There is collective interest in finding ways to improve student interest and longer-term engagement in science and STEM subjects and improving teaching practice is considered intrinsic to that solution (Office of the Chief Scientist, 2013; Prinsley & Johnston, 2015). The nature and extent of value and limits of PLN activities for primary school teachers' developing their science education knowledge and practice needs to be considered.

1.1 Background

Much research has reported the professional learning for teachers and PSTs through activities in singular online platforms like Facebook (Ranieri et al., 2012; Rensfeldt et al., 2018; Manca & Ranieri, 2016), Twitter (Carpenter & Krutka, 2014; Macia & Garcia, 2017; Reilly, 2017; Tucker, 2019), and Edmodo (Chandler & Redman, 2014; Reasoner, 2017) for offering expertise, collegial advice, sharing pedagogies and affective support. However, studies offering evidence as to the value of accessing multiple contexts rather than one platform (Duncan-Howell, 2010; Greenhalgh et al., 2020; Trust, 2012; Trust et al., 2017) are scarce.

Yet PLNs allow for multiple blended, disintermediated online contexts (Salmons, 2010). Contexts can be transient spaces such as affinity spaces (Gee, 2004), or more stable groups like professional learning communities (PLC's online) (Hume, 2016; Trust & Horrocks, 2018). Even purpose-built niche groups like network improvement communities (NIC's) designed for teacher groups' complex maths problem solving (Gomez et al., 2016), are accessible by online activities. All of these contexts have afforded professional learning possibilities for K-12 teachers.

The few constraints that research has identified to date, include querying the suitability for all participatory styles; attitudinal and personality types of educators (Oddone et al., 2019; Prestridge, 2017; Zhang et al., 2017). Sufficient depth and substantial content coverage to allow for reflection and professional development (Britt & Paulus, 2016; Kelly & Antonio, 2016; Rensfeldt et al., 2018) is debatable, with different studies reporting reflection as characteristic of teachers' (Krutka et al., 2017) and academics' PLN activities (Pataraia et al., 2016; Trust et al., 2017). Keeping personal and professional areas of networks separate to maintain privacy and identity (Owen et al., 2016) is also suggested as constraining teachers' willingness to use online, informal networks (such as social media platforms) professionally.

PLNs have been effective for other professional groups such as academics (Schuck et al., 2013; Trust et al., 2017). Academic networks are "characterized by reciprocity, good personal relationships, providing encouragement and prompting self- reflection" (Pataraia et al., 2016, p. 353) which these researchers credit with enhancing academic knowledge, skills and practice. There is research exploring if PLN activities are more or less advantageous at varying stages of career professional development (Kelly et al., 2016; Turvey, 2012; van Waes et al., 2016). The value varied for academics at different career stages according to VanWaes et al. (2016) and in quality ranging from swapping anecdotes to working together and more substantive discussion offering "immediate to reframing value" (p. 303). Experienced expert teachers were more capable of recognizing and leveraging higher value practice from their highly interdependent network interactions.

Similarly, benefits and constraints of using aspects of PLNs, such as social media platforms for learning by early career teachers (Mercieca & Kelly, 2018) and pre- service teachers (Kearney &

Maher, 2019; Luo et al., 2017; Mullins and Hicks, 2019; Nielsen et al., 2013), has been explored.

However, little is known about professional informal, self-sought learning online being sufficiently reflective, and transformative of science pedagogical content knowledge to meet criteria considered necessary for effective professional development (Darling- Hammond et al., 2017). It has been suggested in research that “the terms professional development and professional learning are often used interchangeably” (Faulkner et al, 2019, p. 270), but these authors maintain differences exist in content, intent and structure such as delivery and duration. Professional learning is defined

> as the formal or informal learning experiences undertaken by teachers and school leaders that improve their individual professional practice, and a school’s collective effectiveness, as measured by improved student learning, engagement with learning and well being (Australian Institute for Teaching and School Leadership (AITSL), 2012, p. 2).

Professional learning is implicit in the definition of a PLN which allows for self-directed activities of sourcing and using tools and resources to facilitate continuous, holistic, professional growth (Trust et al, 2018). Self-directed activities are not the only means of professional learning but are characteristic of PLN use explored further in this thesis.

Minimal research addresses the substance of online PLN interactions and their usefulness for professional development in primary science education (Chandler & Redman, 2013; Unger, 2019). Knowledge of assessment, curriculum, content and pedagogy interweave as teachers develop science pedagogical content knowledge (Gess-Newsome, 2015; Gess-Newsome et al., 2017; Loughran et al., 2008; Loughran et al., 2012; Van Driel et al., 2014) for effective primary science implementation and positive student learning outcomes. The nature and extent of PLN interactions for supporting these necessary aspects of science professional development requires exploration.

1.2 Research Problem

A recent research priority focuses on the broader sociocultural and political concern of students showing declined interest in learning science from high school onwards, resulting in a reduced science career uptake, particularly by females (Bokova, 2014; Marginson et al., 2013; National Research Council of the National Academies, 2014; Royal Society, 2010). The perceived needs, for science informed citizens, and STEM competent workers as important to future economic success (Office of the Chief Scientist, 2013), have resulted in calls for urgent consideration of science teacher professional development to avert the trend of low science participation (Prinsley & Johnston, 2015; Rowan et al., 2015). This necessity of a science-focused future workforce is amplified within the current COVID-19 pandemic where scientists network internationally experimenting for a vaccine.

However recent concerns have a strong historical precedent.

> The main issues identified in research over the decades are that elementary teachers tend to have limited science subject matter knowledge, limited science pedagogical content knowledge (PCK) (Shulman, 1986), and low confidence/self-efficacy in science and science teaching with the consequence that many avoid teaching science (Appleton, 2007, p. 497).

When the context was a shortage of adequately educated maths and science teachers for elementary and highschool in the United States, Malinson & Mallinson (1957) noted that elementary science teachers often had insufficient science studies background to teach required content knowledge while thinking they did have enough knowledge. In 1983, Whittaker, wrote of ways to improve primary teachers understanding of science as many are not science specialists and are likely to have limited experience of it, particularly physical sciences (p. 251). Kinder & Harland (1991), refer to Whittaker's work, and comment on the "sheer enormity of the problem involved in helping primary teachers to enhance their own levels of understanding in science, as well as to improve their performance in teaching it effectively" (p. 5). This issue has been ongoing and while not wanting to describe knowledge differences in deficit terms (Bradbury & Wilson, 2018; Loughran, 2014; Schibeci & Hickey, 2000), primary teachers are more usually educated as generalists, requiring professional development in knowledge of science content (SCK) (Hultén & Björkholm, 2016). However researchers have noted that "content alone will not necessarily lead to more effective teaching" (Schibeci & Hickey, 2000, p. 1168). Ways to teach primary science effectively or pedagogical content knowledge (PCK) are required (Appleton, 2007; Newton & Newton, 2001; Harlen, 1997; Nadelson et al., 2013; Rowan et al., 2015).

Traditional teacher professional development (TPD) methods have varied in program time and effects. Longer term studies have noted some successful outcomes, but with less effectiveness than expected (Aubusson et al., 2019; Sandholtz et al., 2016). Greater personalization of professional goals requires longer term support of newer teaching practices, beyond the provided program (Drits-Esser et al., 2016; Sjoer & Meirink, 2015; Smith, G., 2015). Kennedy (2016) suggests research needs to follow teachers for a year post provided PDP to ascertain if new practices are sustained for long term improvement. Recent research favours blended models of face-to-face and online professional development (Bakir et al., 2016; Mackey & Evans, 2011). However knowledge of accessible online provided professional development to support their learning may be a barrier, as a study by Watson & Watson (2014) found only 1/10 survey respondents (n=810 principals and primary teachers) knew of Australian Science Teachers' Association (ASTA)'s Scienceweb.

Professional learning mediated by technology, such as PLNs (Trust, 2012; Trust, 2013; Krutka et al., 2017) affords new possibilities of less didactic content delivery; mobility (Burden & Kearney, 2017); flexibility (Jones & Dexter, 2014), and self-determined choices (Beach, 2017; Prestridge, 2017; Tour, 2017) for in-service teachers' ongoing development (Duncan-Howell, 2010). The potential value of primary teachers' construction and use of PLNs as science TPD, requires exploration and provided the focus for this doctoral study.

The definition of teacher professional development (TPD) for this paper utilizes Darling-Hammond et al.'s, (2017) suggestion that effective TPD involves "structured professional learning that results in changes in teachers' practices and improvements in students' results" (p.v) with seven factors identified for the learning to be active, reflective, collaborative, content-focused, expert-supported, using effective models and of sustained duration (p.vi). These terms are based on the assumption that TPD is provided, structured and conducted by institutions and outside providers but this doctoral study seeks to find structure in self-initiated and self-regulated PLN activity and to determine whether structure promotes changes of teaching practice, as expected of effective TPD.

Self-efficacy and attitudes towards teaching science can be affected by perceived lack of self-confidence in teaching this subject (Mansfield & Woods-McConney, 2012) which has in turn, been found to affect student attitude (Denessen et al., 2015; Jones & Leagon, 2014). All primary teachers need to update and refine their practice so issues around effective professional development in science education do not solely prevail for the generalist teacher. Their success is contingent on intensive and extensive, ongoing, sustainable support in teaching science, but only if they are convinced of the value of doing so (Kinder & Harland, 1991). This thesis intends to make a contribution towards making that value more explicit.

The following researchers have noted that in building the complex characteristics of professional development, primary teachers require support. Characteristics include: their science inquiry identity (Carrier et al., 2017; Cripps Clark & Groves, 2012; Wall, 2015); ongoing development of SCK and all aspects of PCK (Gess-Newsome, 2015; Magnusson et al., 1998; Loughran et al., 2008; Shulman, 1998); sustained interest and motivation; scientific literacy and competency to strengthen practice and self-efficacy, perhaps with science specialist champions (Bradbury & Wilson, 2020; Campbell & Chittleborough, 2014; Roth, 2014). Support for professional growth could be possible through using PLNs to seek advice afforded by global expertise (Trust, 2013).

Other research alludes to further issues impeding success of Professional Development Programs (PDP) for science teachers. Issues of "Scalability"; "research findings reaching policy makers and providers"; "boundaries of context", "connectedness of development of PDP to stakeholders" and need for "high impact tailored PDP" are reported (Luft & Hewson, 2014, p. 906). The New South Wales Education Standards Authority (NESA) (2017) report stated that "Enablers and barriers to initiating professional development" from 12,000 surveyed teachers detailed that "The factors preventing further participation in PD activities were conflict with work schedules (23%), cost (19%), unavailable in accessible or nearby locations (14%), lack of support from a supervisor/principal/school (13%), no relevant PD (10%), and responsibilities outside of work (10%)" (p.7). Lesser concerns were relevance of PDP to teacher needs; suited to experience level; and matching with school goals. Yet PLN use could potentially mitigate some of these concerns, having shown some value already. There is a definite need for more personalized, relevant, sustainable professional development for primary teachers of science.

1.3 Purpose Statement

The purpose of this study is to explore the value that primary teachers' online PLN activity might contribute to their science teaching professional development. Construction selections by primary teachers when initiating PLNs online need to be understood for their purpose and contribution to aspects of science TPD. Teachers' ongoing PLN and detailed nature of interactions within PLNs, may offer insight into the value of these interactions as supporting ways primary teachers of science can develop professionally. Generalist primary teachers' PLN use could provide a scalable, sustainable solution to developing their science pedagogical knowledge, content knowledge and other aspects of professional development, for example development of identity as a science teacher, which research highlights as problematic. The extent and ways in which teachers of primary school science perceive they are developing professionally through their PLN activities will extend current understanding of value for their science professional knowledge and teaching skills.

1.4 Significance of the Study

Sustainable primary teacher science professional development which leverages the technological affordances of self-managed, multi-device and location accessible, anytime learning is a significant change in TPD approaches of the past (Duncan- Howell, 2010; Trust, 2012). PLN use may provide necessary spaces for valuable conceptual and practical transformative learning, as "there is still a significant gap in the literature regarding the value of PLNs and how they shape teaching and learning" (Trust et al., 2016, p. 17). This study offers a significant contribution to everyday practice for primary teachers of science as PLN use may support: development of their science professional knowledge; management of the sometimes necessary shifting orientations to science teaching; their development of their practice over the duration of a career.

The potential of PLN use as sustainable, scalable, TPD for in-service primary science teachers would be very appealing for its ubiquity and needs-based, anytime availability to a time constrained workforce. This has particular significance when face- to-face professional development in science is not always available as required by the individual's professional needs and even for the profession during the current COVID- 19 pandemic. The increased accessibility to ongoing professional development support in science is a benefit for primary teachers at all career stages whether requiring reassurance or support in the early stages or updating and shifting orientations with reflective practice, or looking for inspiration and alternatives.

Gaps in the literature exist around the value of online/offline reciprocal interactions; detail on quality of interactions; and connectedness of formal/informal professional development (Czerkawski, 2016; Kyndt et al., 2016) from qualitative studies. Defining informal learning has proven difficult with Kyndt et al. (2016) finding greater than 11,207 papers as part of their study reviewing 78 papers. For these researchers informal learning was teachers' everyday learning activities with nine categories such as "collaboration, experimenting and reflection" (p.1138). Whereas formal professional development is generally provided by an institution using an instructor with expertise and in collaboration with providers and teachers. These accredited programs of duration are aimed at improving student learning outcomes, with goals "prioritised by school leadership" (Department of Education, UK, 2016, p. 6). Boundaries are perhaps artificial and blurred when teachers' professional learning networks are on and offline (Kearney et al., 2016). Primary teachers' PLN use may reveal better understanding of the interplay of formal/informal learning for meaningful professional development in science education.

Research using data from Social Network Analysis (SNA), which predominantly maps more technical features of online networks, does not describe these complexities within teachers' experiences. PLN interactions in research to date are characterised by information retrieval, support and to a lesser extent content generation (Trust et al., 2016). Further, the concurrent holistic and specialist effects, of participation options in multiple online contexts of practice or inquiry, require detailed study to address this gap in understanding. Primary teachers can participate in various ways with a range of other teachers and specialists individually or within groups using informal online contexts which could affect their confidence and/or competence in teaching science.

There are suggestions of collective knowledge being pertinent to science education (Hume, 2016; Noble et al., 2016; Tobin & McRobbie, 1999 and teacher professional learning communities building and sharing collective knowledge in networks online (Oddone et al., 2019; Trust, 2012; Tsiotakis & Jimoyiannis, 2016). Therefore, investigating whether this is evident in primary teachers' PLN activity will add to current understanding.

Luft and Hewson (2014) consider four areas are needed for adequate PDP: support of science teachers enacting change, collaboration options, coherent program and a focus on content knowledge (p.893 in Lederman & Abell, 2014). Whilst Evens et al.'s (2015) systematic review of science teacher PDP research suggest "Reflection, PCK courses, contact with other teachers, and experiences in educational practice are typically part of effective interventions" (p.1). Other research and literature considers more personalised considerations including science teacher beliefs, identity and attitudinal change (Carrier et al., 2017; Mansfield & Woods-McConney, 2012).

Researchers have offered finer detail with a construct of PCK and its complex contributing aspects as important for understanding effective ongoing professional science teacher development (Carlson & Daehler, 2019; Gess-Newsome, 2015; Gess- Newsome et al., 2017; Loughran et al., 2012; Loughran, 2013). This thesis explores whether these important aspects of science teacher professional knowledge are represented in teachers' use of PLN informal contexts.

Online networked professional learning shows value as professional development for teachers (Tharrington, 2017; Trust, 2012; Trust et al., 2018; van Amersfoort et al., 2019). However, beyond supporting science teacher identity (Unger, 2019), the extent and details of the nature of this value for primary science teachers' development is unclear and requires further research. Furthermore it would be a significant contribution to understand whether teachers' professional science activities within PLNs can be considered effective, using the same TPD criteria usually reserved for formal, provided programs (Darling-Hammond et al., 2017).

A similar theme recurs in PLN research literature, of under-utilised development afforded by technology-mediated learning, perhaps because a detailed understanding of the extent of value is required, which is the intended focus of this study.

1.5 Research Questions

The Overarching Research Question

How do primary teachers' Professional Learning Network (PLN) activities contribute value for professional development in science education?

This focus is explored through each of the following research sub- questions.

Research Sub-Questions

RQ 1. What are the characteristics of primary teachers' initial PLN construction and ongoing PLN management for science teaching professional development?

RQ 2. What are the participatory relationships and details of primary teachers' PLN interactions about science education?

RQ3. What are primary teachers' perceptions of ways their online PLN activities contribute to their science teaching professional development?

1.6 Overview of Chapters

The next part of this thesis is Chapter 2: Literature Review, which discusses the theoretical positioning of this study and the literature supporting these choices. This study has an interpretivist philosophical premise (Greene, 2007; O'Donoghue, 2018; Scott, 2017) with socio-cultural (Vygotskian) perspectives. The choice of a philosophical basis is in keeping with honouring plurality of voices among teachers' varying perceptions of the world (Vygotsky, 1978; Wertsch, 1993). Interpretivism allows for the epistemological assumption of culturally imbued ways knowledge is developed.

Teachers are positioned as self-directed learners (Knowles, 1975) within a sociocultural context where science pedagogical knowledge is shared and co-constructed during their technology-mediated learning within their PLNs. Science teacher professional knowledge models (Magnusson et al,1999; Gess-Newsome, 2015; Carlson & Daehler, 2019) and effective teacher professional development criteria are detailed (Darling- Hammond et al, 2017). Related literature includes varying definitions of PLNs; situating this study in the current science and STEM education global prioritisation; exploring self-, co- and shared regulated learning as useful in describing teachers' PLN activities. Primary science pedagogy is discussed and the affordances and constraints of PLNs in research literature before proposing this study's framework. The study was designed to ascertain the nature and extent of value in primary teacher's PLN activities, for their professional development in science education.

This study's Multi-Mixed Methods Research approach (MMMR) (Salmons, 2015), design and the rationale for this selection are explained in Chapter 3: Methodology. International in-service teachers of primary school science were invited to participate in three phases of this sequential explanatory designed study. Phase 1 was an international online survey followed in Phase 2 with a smaller nested sample completing an online semi-structured interview. In the final phase, a subset of Phase 2 participants (plus one extra volunteer teacher) compiled an evaluation template, significant interaction excerpts, and took part in a follow up online tailored, semi- structured interview. National teaching standards professional documentation were reviewed less for triangulation and more for significance of participant teachers' value perceptions. Analysis utilised descriptive statistics for quantitative data using SPSS and Excel for broad understanding of the issues. Qualitative analysis was predominantly verbatim, constant comparison and structural coding, with several cycles for finer detail, using NVivo software tools. Findings were integrated and discussed with mixed method presentation (Bazeley, 2018; Greene, 2007). Chapter 3 provides full descriptions of the methodology, consideration for dependability and authenticity of the study, and justification of method selections as congruent to this studies' philosophical basis.

Chapter 4: Integrated findings result from interpretation and analysis of all phases of this study. This chapter details emergent themes which revealed participating teachers' perceptions of value of using PLNs for their professional development in science education. Key findings for this study detail considerable value for professional development in building primary science teachers' knowledge base. Comparison of results with literature, between study participants and study phases, are identified in this chapter. Similarities and disparate or unexpected findings are discussed further in chapter 5.

The significance of these primary teachers' perceptions of value are explored fully in Chapter 5: Discussion. Emergent themes from this study's research sub- questions included primary teachers' intentional construction of an online PLN for their affordances of multi- and within-platform contexts locally, internationally and with primary (K-6) specific content; managed with selective curation practices. Contingent, context specific participation in synchronous and asynchronous activities inspired, crystallised and supported their own and others' professional development in pedagogical knowledge, to a topic-specific level, content knowledge to a lesser extent, but not exclusively for science education. Some primary teachers held strong views that recognition of development from PLN activities by employers might increase value.

Participants reported PLN-mediated activities contributed value in science and other PCK development, with characteristically collaborative and cooperative socially shared and co-regulated professional learning (Vygotsky, 1978; Jarvela et al., 2016) which also boosted professional identity.

Chapter 6: Conclusions, implications and future directions for research details the benefits and value of primary teachers using their PLNs to support their reflective practice, leading to changes in science teaching practice. Implications for: primary teachers of science, regardless of specialist or generalist roles, at various stages of their careers (including pre-service), are discussed. Professional development opportunities which complemented, and yet were distinct from, more formally provided professional development were evident. Implications of this blend of TPD opportunities for providers of professional development, employers of primary teachers and useful learning for PSTs are considered. Further implications and conclusions drawn from this study, mindful of the study's limitations, as well as thoughts for future research directions can be found in Chapter 6.

Chapter 2 Literature Review

Chapter 2 explains the theoretical background and framework of this study with an interpretivist philosophy and pluralist methodology. The theoretical background also informs the methodology, see chapter 3; analysis and interpretation of findings in chapters 4 & 5 and conclusions offered in chapter 6.

Primary teachers' professional development involves learning that shapes their practice and student learning outcomes (Darling-Hammond et al., 2017). Teachers as adult learners progress towards more self-direction and know what they need to develop in order to set goals and work systematically to their attainment (Knowles et al., 2012). Furthermore adults' self-regulatory processes are refined with metacognitive guiding of ongoing self-directive learning and development (Zimmerman & Schunk, 2011). Piagetian Constructivist theory informs that the learner is responsible for their own internalised building of knowledge, often propelled by socio-cognitive conflict (Palincsar, 1998) and affected by developmental stages. Sociocultural learning, allows for interpersonal, collaborative, socially contextualised knowledge, but then internalised learning can lead to and promote development (Vygotsky, 1978). Vygotskian sociocultural theory helps to describe technology-mediated learning in this study, where teachers' access to internet technology (using computers or mobile devices) and use of tools mediates context and content of learning, with reciprocal effects on shaping cognition (Salomon et al., 1991). While learners self-initiate and direct their learning in informal online PLNs, there is also a collective presence of shared knowledge, co- and socially-shared regulation of their own and others' learning (Malmberg et al., 2017).

Science teacher professional development is complex with many effective teacher characteristics outlined in theory (Darling-Hammond et al., 2019; Shulman, 1998). Teacher professional knowledge has been detailed with significant contributions to models to explain the constituent parts and their interplay. Work by Magnusson et al. (1999) and many other researchers outlined by VanDriel et al. (1998) has led to summits and detailed academic exchanges online to form the "consensus model" of teachers' professional knowledge base inclusive of pedagogical knowledge, content knowledge, background knowledge to a topic specific level, personal pedagogical content knowledge and skills (Gess-Newsome, 2015), see 2.1.6. This model has undergone a most recent reconfiguration and is called the Refined Consensus Model (RCM) (Carlson & Daehler, 2019) although the authors contend it is not designed to replace earlier models.

Understanding teachers' professional development needs within this particular socio-historic-cultural context of global prioritising of science and STEM education is important. Competence and confidence in teaching primary science, and that teachers build a positive science teacher identity may be required of professional development processes. Traditional PDP methods have been found lacking and this study is predicated on finding alternatives for effective science TPD while addressing perceived gaps existing in the research literature.

2.1 Theoretical Background

This study begins with an interpretivist philosophical premise, and the assumptions that accompany it, where a society of individuals have multiple beliefs, representations and interpretations of reality (Greene, 2007; Scott, 2017). These interpretivist understandings of the world impact ways that knowledge within a society is understood to develop, and subsequent learning. These multiple realities, perceived and understood, need to be explored and interpreted in the context within which they are generated or co-constructed (Creswell, 2007).

2.1.1 An Interpretivist Philosophical Premise

An interpretivist view is that interpretation of human activity as meaningful must take into account the context of culture in which it was created. As O'Donogue (2018) explains, "the individual and society are inseparable; the relationship is a mutually interdependent one rather than a one-sided deterministic one" (p.16).

Furthermore, individuals within that society and culture through negotiated interactions make meaning which, because of their enculturation history, shape individual and societal interpretations of phenomena.

In accepting the idea of multiple possible realities, (dependent on the perceiver of that reality and their sociocultural, historically affected interpretations), there is not one absolute truth ontologically to be proved or disproved as might be required within a positivist paradigm (Scott, 2017). It is difficult to consider science knowledge as objective when facts rely upon human observation and theory building (Lincoln & Guba, 1994) both of which are subjective from the interpretivist viewpoint. Where deductive thinking and refutation are used in developing ever improved theories for a positivist, an interpretivist study requires abductive thinking, drawing out meaning from theory to data and revision of theory (Scott, 2017).

The interpretivist basis of multiple realities accounts for plurality of voices such as researcher's and research participants' perspectives which are documented with detailed and nuanced description in this study. Researcher reflexivity and participants' understandings are affected by their historic and present contexts. Ongoing interpretations by researcher and those researched continue to shape individual and collective knowledge as it is shared. Understanding the importance of multiple interpretations of phenomena throughout this study, for example the participants' expression during data collection, transcription and analysis of the data keeping context in mind, extends to a range of research audience or reader interpretations. These could represent what Wertsch (1993) credits to his predecessors' work, Bakhtin, Tulviste and Levy-Bruhl as "heterogeneity of voices" describing heterogeneity as "qualitatively different forms of thinking exist" (p.96) and where voice is never isolated from social context, "…voices always exist in a social milieu; there is no such thing as a voice that exists in total isolation from other voices" (Wertsch, 1993, pp. 51-52).

The lived experiences of primary teachers and their voices within the wider online professional contexts of their own self-regulated, needs-based learning are the central focus for this study. Geertz (1973) an interpretivist, recommends understanding science initially from its practitioners rather than from theories, findings or detractors. As Greene (2007) points out "because different contexts present different constellations of people, interactions, and events, what is meaningful to a given individual or group is, in important measure, context-specific rather than universal" (p.37). Although Tracy (2010) forwards an argument that more recent conservatism with funded projects in social sciences favours quantitative, statistically-based research for purposes of generalisability; researchers have increasingly used interpretive designs, over past predominance of experimental research designs, to better understand the complexities that interweave teaching and learning (Appleton, 2007). This interpretivist purpose of understanding, both the quality and detail of teachers' PLN interactions, and the meanings primary teachers attribute, in terms of value perceptions for their developing knowledge of science education, led to broad wording of the research questions in this study. Long term immersion and observation into the online culture of primary teachers' PLN usage is difficult due to teachers' multiple devices, numerous platforms and contexts, variable times of use and changing nature of internet spaces. So ethnomethodology has its limitations and challenges in the context of this holistic- emphasis, internet-mediated study (Hesse-Biber & Griffin, 2013) and teachers' own perceptions of value seem more pertinent to answering the research questions (see chapter 3 methodology).

Multiple interpretations require a plural and eclectic methodology in keeping with an interpretivist philosophy, therefore a multi-mixed methodology and dialectical stance (Greene, 2007) characterise this study. Meaning representations are filtered through the researcher's sociocultural lens (see chapter 3 for methodology, for researcher reflexivity, and as ethical issue of potential bias in section 3.3.1). Interpretivist studies rely less than positivist methods on triangulation to corroborate findings for a single truth, instead the focus of this study is on relevance in representing perceived realities of multiple participant teachers.

In making recommendations for interpretivist studies, Treagust, Won & Duit (2014) draw on Tracy's (2010) paper. Tracy tentatively offers eight guiding qualitative criteria while emphasising they are still context sensitive to a study and not meant to be restrictive of representation or "paradigm specific” (p.839). Summarised criteria are:

> a worthy, relevant, significant topic; rich data and appropriate theoretical construct; researcher’s reflexivity and transparency in value and biases; credible data through thick description and respondents’ validation; aesthetic representation of findings; significant contribution in theory and practice; ethical; and meaningful coherence of study (Treagust, Won & Duit, 2014, p. 9).

This study endeavours to accord with all of their suggested features to offer a robust interpretivist study.

2.1.2 Sociocultural (Vygotskian) Theory of Learning and Development

The main features of Vygotskian sociocultural theory such as the fluid reciprocity of social interaction, and recognition of cultural as well as individual situational contexts, offer advantages in understanding ways teachers’ online sharing can shape professional learning. Vygotsky, an eminent psychologist of the 1930’s, wrote of a theoretical connection between learning and development in children shaped by the Marxist Russian socio-political, historical context within which he and his contemporaries Luria and Leont’ev worked. Sociocultural theory has gained popularity since as it accounts for plurality, and varied layers of meaning in a construction process by, among and within learners promoting development. “Education in particular is concerned with the learning of people who are situated within multiple levels of organisational, social and cultural groups” (Schoen, 2014, p.16). This study takes a similarly holistic view.

Vygotsky’s activity theory of socially constructed learning (Vygotsky, 1978) emphasises human activity as purposeful with three main tenets which reveal the socialist subtext of charting individual progress, within a collective learning context of adults, teachers and other peers. Vygotsky’s three tenets for understanding human learning which have been popularised and reinterpreted since include: the significant role of genetic and ontogenetic development; individual higher cognitive processes (including individualised inner speech) were at some time derived from the social plane; and human activity whether at social or individual level is mediated by signs and symbols of the culture (Wertsch, 1993). These three tenets all have relevance for this study where primary teachers interact socially in online networks, using vernacular particular to education and multimodal representations typical of the online platform culture, to share and develop their own and others’ professional knowledge and skills.

Palincsar (1998) explains Vygotsky identified four linked aspects for analysis of human development. The first phylogenetic development is distinctly human activity in using psychological tools of signs, symbols and language, and voluntary attention (this last one Glassman (1994) attributes to Luria). The second cultural historical development refers to the role of repeated, sustained duration of cultural practices. The third ontogenetic refers to individual differences of age, personality, past individual successes, physical and mental capabilities. The last is "microgenetic" which refers to the interwoven nature of individual interpersonal actual interaction with the cultural environment (Palincsar, 1998, p. 354). Analysis of primary teachers' professional activity within PLNs with respect to their own situations, informal online contexts and broader school environment, individual and group interactions are fundamental to ascertaining and understanding of the complexities of teacher development in this study.

The higher cognitive functioning of humans occurs as a person actively engages and changes the situation in which the learning is occurring as a necessary part of their response in learning. This process of reciprocal effect is what Vygotsky described as "mediating" (Cole & Scribner in Vygotsky, 1978, p.14). For example, speech mediating problem solving (Vygotsky, 1978). Inner speech, observed as egocentric speech in children as transitional from external speech to internal, was considered important in learning as "language takes on an intrapersonal function in addition to its interpersonal use" (Vygotsky, 1978, p.27). Inner speech is also considered evidence of "self-directive function" (Zimmerman and Schunk, 2011, p.4). Glassman (1994) describes mediation as using existing cognitive structures and conceptual understanding to understand something new, giving the example of learning and understanding meaning and syntax of a new foreign language through abstracting everyday knowledge of the familiar language. Mediating could be people using symbolic relationships ranging from primitive examples like tying knots as an aid to memory or using external objects like fingers as a mediating tool for mathematical operations, to complex formulae and visual organisers (Kozulin, 2002). However "mediated learning" in Vygotskian terms differs from andragogical theorists' Knowles et al.'s (2012) definition "the shared control between the learner and an external authority (usually the instructor)" (p.176) which seems reductionist and represents issues of translation and repurposing concepts away from their original theoretical essence (Veresov, 2017).

Vygotsky's theory describes the prioritising of the learning context; with social interdependence and responsibility for shaping learning and development of self and others; mediated by humans' use of a cognitive toolkit of signs and symbols: a process of enculturation (Vygotsky, 1978; Wertsch, 1993). This study is based upon constructivist views of learning favouring the social constructivist perspective as more descriptive of teachers' personal and collaborative knowledge construction and development possible from technology-mediated learning within online PLNs.

Learning from a socially constructed perspective occurs through processes of collaborative social interaction and negotiation, "the appropriation of socially derived forms of knowledge that are not simply internalized over time but are also transformed in idiosyncratic ways in the appropriation process" (Palincsar, 1998, p.365). Emphasis on learning occurring first on a social plane, fits technology-mediated learning for teachers, within complex PLN contexts. The signs and symbols used by the online culture, and the presence of other individuals and their differing usage, offers other cognitive tools which further mediate learning. The human-built capabilities of technology offer further mediating and dialogicality of learning (see section 2.1.3).

Another useful aspect of Vygotskian learning and development theory with relevance for teacher professional development is the zone of proximal development (ZPD). Vygotsky according to one translation described ZPD as, "the distance between the actual developmental level as determined by independent problem-solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers" (1978, p. 86). In defining this zone, another proposition for translation is that human mediation by adults in determining the task and guiding children through the tasks, is a way to identify the child's current and possible next intellectual developmental level (Veresov, 2017). Veresov suggests a closer translation, is ZBR Zona Blizhayshego Razvitiya, "In the Russian original of 1935 we read: "what lies today in the zone of the proximal development, tomorrow will be at the level of actual development" [2, p. 42]." (p. 27). While in reference to children, the ZPD/ZBR has relevance for teachers progressively developing their professional skills, knowledge and understanding of teaching problems. Teachers may be able to use the mediating expert interactions possible within the culture of their PLN to self- or co-identify and regulate learning within their proximal zone and reach new understandings of practice through online activities with others.

A socioculturally informed constructivist framework seems to have most relevance for describing the decentralised teacher agency, autonomy and yet collaborative nature of online interactions within technology-supported PLNs. Primary science teacher online activity within their PLN is affected by broader socio-political contexts and individual contexts. In this study, attention is given to details of enablers and constraints of context to counter Scott's (2017) concern that a weakness of interpretive studies is to focus on agency at expense of structural constraints and enabling influences from life contexts. This study's focus on ascertaining if professional development is possible through teachers' interactions within multiple PLN contexts is in keeping with constructivist notions such as, "The environment, in particular the social milieu, can be used as an instrument in the progression of development" (Glassman, 1994, p. 203).

Vygotskian sociocultural theory also has implications for this study's mixed methodology. Cole and Scribner (1978) comment when introducing Vygotsky's work that,

> not only does every phenomenon have its history, but this history is characterised by changes both qualitative (changes in form and structure and basic characteristics) and quantitative. Vygotsky applied this line of reasoning to explain the transformation of elementary

psychological processes into complex ones (p. 7).

This reasoning permeates his experimental approach (p.14). A mixed quantitative and qualitative study design is consistent with understanding the nature and extent of learning and development changes of primary teachers through their PLN activity and sociocultural perspectives. Sociocultural theory accounts for differing views of realities among participants: in ways meaning is experientially and socially constructed; the prior knowledge participants bring to the research; and the ongoing social construction within this study.

2.1.3 Technology-mediated Professional Learning

Learning is mediated in the way people use technology and the internet's structure and differing environments or contexts to facilitate learners' interactions in terms of scale, content, quality, support (external and cognitive), learning design, platform algorithms, structuring learning, shaping cognition and metacognition. The technological environment offers another layer of mediating human interactions with constraints and enablers such as platforms shaping occurrences, continuity and availability of posing histories through sorting, blocking, directing, timeline curation algortihms (Rensfeldt et al., 2018). Hesse-Biber & Griffin (2013) point out that even the medium itself, multiple modes for representations, is impactful on interactions and learning. This is keeping in mind that it is learners' practices using and facilitated by these epistemic tools which allow for reflection and transformative changes in practices (Hakkarainen, 2009).

In detailing learners use of computers in mediating effects on education Salomon et al. (1991) raised a prescient point that whole school culture will change of necessity "from knowledge imparting to self-guided exploration and knowledge recreation" (p. 7). This is as true for teachers during professional development as for teaching their students. For teachers to fully leverage the valuable professional learning effects 'with' technology (during learning) and 'of' technology (residual effects of learning 'with') means change in activity. These effects on teachers' learning are not just due to technology but the amalgam of interacting effects with layers of influence from culture, role of the teacher, learning context and the purposeful goals of the activity. Technology-mediated learning is more complex than reducing cognitive load, enhancing, storing and accessing of information but affords distributed knowledge; making metacognitive thinking processes explicit; restructuring ways of thinking (Salomon et al., 1991), for example hypertext stacking and hotlinks which have altered forms of narrative structure and are prolific in online PLN platforms.

Hartshorne (2005) found integration of 'hypermedia' (term for online non-linear non-sequential display of information, graphics, etc) into professional development resulted in increases of science content knowledge almost equal to traditional PD settings. In a later study teachers' positive attitudes towards teaching science were found to be promoted with and through using technologies such as discussion board, lesson searches with a review feature, and teacher content resources (Hartshorne, 2008).

Further change has meant teachers' professional learning was affected as "the internet can be seen as altering 'traditional' (pre-internet) forms of teachers' work and ways of working" (Rensfeldt et al., 2018, p. 3).

The context of rapid rate technological advancements increase the difficulty for TPD providers meeting authentic current needs of teachers and "creates a need for greater flexibility in teacher PD" (Jones & Dexter, 2014, p.368). This study explores primary teachers' valued professional learning activity while acknowledging their online PLN consists of sometimes transient spaces, affinity and niche groups as well as more established contexts, comparable to communities of practice. "Networks are assembled in learning, and learning is shaped by networks. So the properties of networks are consequential with respect to learning, and are worth researching, even though they also change" (Carvalho et al., 2017, p. 1). Online networks like those afforded by PLNs allow for interactions beyond the scope of face-to-face networks and potentially more and varied expert exchanges from around the word (Trust, 2013). A strength of technology-mediated learning is the rate at which progress is embraced.

An advantage of internet-mediated research is in learners' more difficult to observe or less stated-processes being made explicit and visible (Hakkarainen, 2009). For example technology-mediated learning supports participation within communities of practice where learners can be peripheral (Lave & Wenger, 1991). Actively observing and stretches along an agentic continuum from vicarious learning to highly participatory learning (Myers & DeRue, 2017) with the mediating interactions of others impacting individual learner agency (Kozulin, 2002). Learning within networks can be incidental and serendipitous (Kop, 2012; Pataraia et al., 2015; Trust et al., 2017). Networked learning also provides intentional extensions of the physical workplace mediated by interactions with others.

Mobile learning affordances, possible within collaborative, personalized networks using mobile technologies (phones, tablets, laptops) is still being fully realized within educational realms, where teachers are developing technological knowledge, while teaching with, and using technology (Kearney et al., 2015; Schuck et al., 2017; vanWaes et al., 2016). Proficiency and level of comfort using technology could also pose barriers to PLN activity as effective TPD. Chandler & Redman (2013) describe a spectrum of possible experience among PSTs when using technology such as iPads and shared spaces like Edmodo to discuss primary science learning; and ways to teach it using these same technologies. PST's previous patterns of use were for social media sharing purposes rather than as generative professional teaching and learning tools.

Vygotsky describes human mediating activity through the use of signs and symbols, as well as use of the “psychological tool” (Vygotsky, 1978) sometimes referred to as a “cognitive tool” where signs and tools are an external means for mediating internal cognition (Veresov, 2017). Technological advances include “digital tool” with similar purpose, “With such examples on hand, it makes sense to call computer tools that offer an intellectual partnership cognitive tools (Pea, 1985) or technologies of the mind” (Salomon et al., 1991, p. 4). For example research suggests teachers use digital tools effectively within their PLN, bookmarking favourites allowing later transformation of information into knowledge which is an important professional development activity (Tour, 2017; Trust et al., 2017; Rensfeldt et al., 2018).

Primary science teachers extending their digital toolkit to include adapting resources and authoring versions suited to the contextual and individual needs of their learners is under-explored in existing research.

2.1.4 Self-directed Learning (SDL)

Self-directed learning assumes that adult learning differs from that of children (Rennie et al., 2019) while perhaps not in the way Knowles et al. (2012) express of children being “subject centred” and adults “life centred” (p. 66) as this ignores interest centred, problem-based and social realm as initiators of self-directed learning at any age. Knowles et al. (2012) contend that differences occur in the extent of adult’s prior and self-knowledge which enables them to identify what they need to know next or set their learning goal. Rennie et al. (2019) counter criticisms of Knowles’ SDL model, such as school students not being able to self-direct their learning, by asserting that problem-solving is achievable by school students. The main principles of SDL are “learner’s need to know, self-concept of the learner, prior knowledge of the learner, readiness to learn, orientation to learn and motivation to learn”: a ‘need to know’ and ‘motivation’ were later additions to the model (Knowles et al., 2012, pp. 60-62). Individual differences being another extension of the model.

SDL can be considered as “an incentive to learn plus an interest, leading to accessing resources; with systematic attention in their learning” (Bracey, 2010, p. 1601) with self-pacing and autonomy favoured by self-directed learners. While SDL and autonomy are linked, the latter is on a continuum and learners may make choices, for example meeting goals with more structured learning if unfamiliar with subject matter or on the other end of the continuum, feeling frustrated with this approach if conversant with content (Knowles et al., 2012).

Swanson (1996 in Knowles et al., 2012) defines one model of adult learning as “The process of adults gaining knowledge and expertise based on their personal goals” (p. 173). This model offers 4 phases, “need, create, implement and evaluate” (p. 173) which allow for lifelong learning and accommodate characteristics of teachers' online PLN activities and engagement. These characteristics are a good fit for describing teachers' continuous learning online. Tour's (2017) study, for example, found that teachers' in self-initiating use of their personal learning networks, "designed their own professional learning strategies and became independent learners" (p. 190). Self-directed learning has taken on greater importance with information technology, online communities and plentiful resources (Saks & Leijen, 2014).

> Technology presents bold new opportunities for providing adults with rich learning experiences in the andragogical tradition. First it directly caters to adults' desire to be self-directed in their learning…enables adults to access learning in a just-in-time, just-enough format under conditions of full learner control. In many ways it can provide adult learners with the complete self- directed learning experience (Knowles et al., 2012, p. 242).

The last two sentences contain debatable expressions such as "full learner control" and "complete self-directed experience" as this fails to acknowledge the potency of the social environment and participation of others within collective online culture to influence individual learning through co-regulated (Co-RL) and socially shared regulation (SSRL) learning experiences.

2.1.5 Self-, Co- and Socially-shared Regulation of Learning (SRL, CoRL and SSRL)

"Self-regulated learning and performance refers to the processes whereby learners personally activate and sustain cognition, affects and behaviors that are systematically oriented toward the attainment of personal goals." (Zimmerman & Schunk, 2011, p. 1)

Self-regulation like self-directed learning is an active, goal-related process of task setting, implementation, monitoring and reflection, where metacognition, internal (motivational) and external dimensions (social) of the learner are involved.

> SDL can encompass SRL, but the opposite does not hold. SRL seems more concerned with the subsequent steps in the learning process such as learning goals and strategies, while SDL clearly provides a crucial role for the learner at the outset of the learning task (Loyens et al., 2008, p. 418).

This is referring to the intentional goal setting, of what is to be learned, which distinguishes self-directed learning from self-regulated learning. Some researchers assert with SRL the learning task or goal may be set by someone other than the learner, like the teacher (Saks & Leijen, 2014; Loyens et al., 2008) (or an employer if referring to professional development). SDL is considered broader macro level overview of learning where SRL is micro level concerned with task execution although all SDL involves learners in self-regulatory processes (Saks & Leijen, 2014).

Other differences include that SDL and SRL have different historical theoretical origins (Saks& Leijen, 2014; Loyens et al., 2008), tend to be practiced in different learning contexts because of differing traditions. Teachers as life-long adult learners in work contexts with collegial and expert mentorship poses the need to consider both of these theories in tandem rather than suggesting theoretical traditions preclude one from the other when considering teachers PLN activities. Self-regulation in PLNs is manifest in teachers' help seeking behaviours and giving of advice in mentoring capacities within online postings and chats. "Contrary to conventional wisdom, self-regulation is not defined as an individualised form of learning because it also includes self-initiated forms of social learning, such as seeking help from peers, coaches and teachers" (Zimmerman & Schunk, 2011, p. 1) This is a well-documented characteristic of teachers interactions within PLNs, and Trust et al.'s (2017) paper on reflection and identity in PLN's offers a set of metacognitive prompts for teachers to utilise while engaging in their online PLN construction and activities to leverage their value for professional learning further.

According to Schunk and Zimmerman (1997) self- regulatory processes for academic purposes involve planning and management, cognitive strategies and using social resources to attain goals. Time management is a fundamental process for busy teachers and extends to time spent on self-initiated professional learning (Tour, 2017; Beach, 2017). These SRL processes have been prominent in research of teachers who use online networks for self-sought further professional learning (de Laat & Schreurs, 2017; Trust, 2012; Trust et al., 2017).

Self-regulated learning (SRL) within professional development may be a useful improvement from traditional provided program methods. Benefits are reported when SRL factors during science PCK professional development is actioned for elementary science teachers using reflective prompts and PCK teacher-designed rubrics to support planning, implementation and evaluation of inquiry-based lessons (Peters-Burton & Botov, 2017).

Additionally, regulated learning is social in that it is "influenced by environmental context, appropriated through participation or situated social activity systems" (Hadwin et al., 2011, p. 66). The mediating effects of others within that situated learning context affect regulation of learning which can result in co-regulation of self, or socially shared regulation in highly collaborative shared goal, process and collective activity. "Co-regulation is grounded in Vygotskian views of higher psychological processes being socially embedded or contextualised" (p. 73). Co- regulation is emergent during tasks when learners seek or are offered metacognitive style prompts, advice or encouragement and then individuals and cooperating others learn to better self-regulate from this transitional cooperation. These authors further suggest that all three regulatory learning types are present during shared activity tasks. (Malmberg et al., 2017). Complete definitions are:

> (a) self-regulated learning (SRL) in which group members take control of their own thinking, behavior, motivation, and emotion in the collaborative task, (b) co-regulated learning (CoRL) in which each other's engagement in self- regulatory processes within the task is transitionally supported by group members, technologies, or contextual features of the environment, and (c) socially shared regulation of learning (SSRL) in which group members work together to regulate their collective cognition, behavior, motivation and emotions together in a synchronized and productive manner (Järvelä and Hadwin 2013; Hadwin and Oshige, 2011;Hadwin et al, 2011) (Järvelä et al., 2016, p. 265).

Teachers were found to engage in multi-step, professional learning behaviours encompassing self-directed, self-regulated and co-regulated processes within online professional learning network social contexts such that Trust (2016) wrote of a new model for teacher learning in online networks. The processes involved identifying a goal; exploring knowledge through assess, test and curate shaped by the group's community context; adapting knowledge to fit teachers' school and classroom context; evaluating its efficacy in meeting goal and redefining new goals.

Primary teachers may further benefit from SRL sympathetic PLN environments, as research indicates that primary PSTs use of metacognitive skills increased in learning environments that allowed opportunities for SRL and modelling of these skills (Vrieling et al., 2012). There may also be implications for primary science teaching with shared knowledge on questions of practice. Further research is required about teachers' regulatory learning processes as they apply to working within large scale social contexts of their PLN and to a situation specific level of detail.

2.1.6 Effective Science Teacher Professional Development

Teachers require ongoing science professional development to adequately prepare students for this century's science and technological progress (Luft & Hewson, 2014). While there have been successful models of teacher professional development traditionally led programs by external providers, and more recently using blended contexts, there remain unresolved issues. These issues include policy directives as priority over personalisation for relevance and stage of development of the teacher; need for longer term programs and lack of post program support (Smith, G. 2015); cost effectiveness (Nochumson, 2020) and scalability of programs (Luft & Hewson, 2014); and convenient accessibility (Knowles et al., 2012; Trust et al., 2017) on a need-to-know personalised basis. There are also concerns related specifically to primary teachers' professional development in science.

Effective professional development should encourage primary teachers to meet curriculum requirements of classroom time spent on quality science learning rather than systemic avoidance or limited primary science teaching which have been reported in the past (Appleton, 2007; Harlen, 1997; Hartshorne, 2008; Roth, 2014). More recent research suggests consistent primary science teaching was supported in a major way by student enthusiasm for science, opportunities for integrating science with other areas and connections with other enthusiasts (Bradbury & Wilson, 2018), all with implications for effective TPD.

Programs for primary science teachers with success in promoting lasting changes in practice seem to require longer program structure. The STeLLA program of one year highly scaffolded teacher PD with collaborative video analysis of practice and three- week summer school was found to improve student learning (linked to teachers' science CK and teachers PCK of student thinking) and teachers retained their learning of content (Darling-Hammond et al., 2017). Project Smart, USA, involved 49 teachers in sustained PD with integrated Maths, Science, Reading and Technology implemented in their classrooms, and was found to "increase their science content knowledge, overcome their hesitancy to teach science, and use integrated science-based instruction as a way to support primary grade students' learning" (Miller et al., 2015, p. 318).

Research demonstrates the ongoing need for support, longer term than institutionally provided primary science PDPs allow, as necessary for practice-changing professional development and maintenance of the changes (Drits-Esser et al., 2016; Sjoer & Meirink, 2015; Smith, G., 2015). Even long-term studies of K-2 science TPD reported a decline for 2 years following the extended 3 year program (despite initial positive changes during the program), perhaps suggesting a need for other forms of ongoing support. However overall outcomes, of teacher science content knowledge, self-efficacy, teaching time and instructional practices, were better than pre-PDP (Sandholtz et al., 2016).

Blended contexts can refer to formal/informal and online/offline learning environments for teacher professional growth and define PLN spaces (Kearney et al., 2016). The advantage of blended contexts seems to be in terms of social support, collaborative learning with fluid responsiveness possible online, which allowed for "the substance of learner's thinking, their participation in disciplinary practices, and their suggestions for structuring the course" (Jaber et al., 2018, p.686). Influencing course structure exceeds traditional pre-set course science PDP as well as combining the face- to-face elements. Research also indicates blended TPD contexts support primary science teachers during time of implementing newly learned practices in their own classrooms although InterLACE is a more formal, purpose-built online platform (Jaber et al., 2018). Science TPD may be possible in less formally provided PLN contexts.

A substantial field of recent inquiry has been directed towards the role of Pedagogical Content Knowledge (PCK) in science teaching professional development. Unpacking science teacher expertise in practice to develop a framework of the critical elements of this elusive PCK construct has proven difficult (Gess-Newsome et al., 2017; Loughran et al., 2012; Magnusson et al., 1999; Shulman, 1987). Some of the elements of science PCK were proposed to be knowledge of science, orientations to science, knowledge of research on children's science understandings and misconceptions; knowledge of pedagogical strategies with approaches suited to specific science content, assessment and scientific literacy. "Effective teachers need to develop knowledge with respect to all of the aspects of pedagogical content knowledge, and with respect to all of the topics they teach" (Magnusson et al., 1999, p. 115). Teachers' need to develop their science professional knowledge base to be effective and improve their practice in the classroom.

Positive attitudes and feeling competent to teach science are required, and low confidence while associated with low content knowledge, is not the only contributing factor (Harlen & Holroyd, 1997). Even a small subskill development is associated with an improvement in self-efficacy towards teaching primary science (Mansfield & Woods-McConney, 2012) where "perceived self-efficacy refers to beliefs in one's capabilities to organize and execute the courses of action required to manage prospective situations. Efficacy beliefs influence how people think, feel, motivate themselves, and act" (Bandura, 1995, p. 2). Greater confidence and self-efficacy as a science teacher has also been found to impact more innovative, less textbook scripted science lessons and integration of science and technology into other subject areas (Corrigan & Taylor, 2004; DeLaat & Watters, 1995). Mintzes et al. (2013) found "a group of elementary school teachers with demonstrably low self-efficacy in science teaching grew substantially over a period of 3 years as a result of their participation in a PLC" (p. 1214) with biweekly meetings offline.

Primary science teachers need to be fluent in multiple representations of science knowledge (Smith, D., 1999; Tippet, 2016). Self-efficacy is affected by competence in this area according to research by Nichols et al. (2016) which showed improvements both in teachers learning and student understanding of varied representations with teachers feeling more competent in their interpretive ability after professional learning. Of relevance to this study where primary teachers are professionally learning within complex social contexts of their PLN is that "a host of factors, including personal, social, and situational ones, affect how efficacy-relevant experiences are interpreted" (Bandura, 1995, p. 5); and "efficacy beliefs play a vital role in the development of self-directed lifelong learners" (p. 18).

A reflective "teacher as learner" state of mind (Baird et al., 1993; Loughran, 2012) is required for professional development and a willingness to see the continuum of building more effective practice over a career. In training and in service teachers consider improvement as normal activity, intrinsic to professionalism, reflection in, on and for evolving practice (Bold, 2011) not merely required by professional standards associations but crucial to their own learning.

The criteria of effective professional teaching development (Darling-Hammond et al., 2017) pertinent to the analysis in this study are defined in reference to formally provided programs or "structured professional learning that results in changes in teacher practices and improvements in student learning outcomes" (p. v). The criteria are: "**content focused;** incorporates **active learning** utilizing adult learning theory; supports **collaboration,** typically in **job-embedded contexts;** uses **models and modeling** of effective practice; provides **coaching and expert support;** offers opportunities for **feedback and reflection;** and is of **sustained duration**" **(**p. 4., their bold font**).**

Content focus refers to discipline specific content (for example science) that is in the school context rather than generic or removed from this context and aligned with school priorities. Active learning involves teachers trying out new practices in classrooms. Mastery is one of the strongest ways to build beliefs in competency (Bandura, 1995). 'Supports collaboration' describes teachers sharing ideas or creating communities to support change. 'Uses models of effective practice' is about sharing best practice samples including lesson plans and student work. Bandura (1995) states, "People seek proficient models who possess the competencies to which they aspire" (p. 4) and PLN's would seem to offer these opportunities to build self-efficacy. 'Provides coaching and expert support' is expert advice directly related to a teacher's needs which teachers using PLNs have already reported in research (Trust, 2013). 'Offers feedback and reflection' is seen as asking and seeking feedback to allow teachers time to reflect on newly learned strategies and changed practices. Sustained duration refers to allowing learn, practice, implement, reflect (the range of self-directive and regulatory behaviour processes) for effective professional development.

The possibility that activities in informal PLN contexts could support any or all of these criteria and contribute to professional development for science education is integral to exploring the value perceived by primary teachers in this study.

When taking a more agentic approach towards professional learning and development rather than provided programs, learning seems less constrained. Using a PLN has been found to support teachers' transformative learning of professional knowledge and is valued by teachers as meaningful, relevant, just-in-time and important professional development (Carpenter & Krutka, 2014; Duncan-Howell, 2010, Visser et al., 2014; Xerri, 2014). In summary, professional development in science for primary teachers is so often reported as requiring improvement to be effective, and so it is important to investigate the potential of PLN use for this purpose.

Science teacher professional knowledge, PCK and skills. Teachers' science professional knowledge base and its constituent parts is largely influenced by the work of Shulman and those who have developed his notion of pedagogical content knowledge. Shulman (1986) envisaged teacher content knowledge as consisting of three categories: subject matter knowledge (SMK) which can be further delineated by substantive and syntactic knowledge (Schwab, 1978; Shulman 1986); curricular knowledge described as instructional materials and program design; and PCK, or specific and varied ways to teach the SMK. Knowledge of science refers to the substantive knowledge produced by science. "Knowledge about science refers to the nature of science (NOS): the principles and means by which scientific knowledge develops and becomes accepted (syntactic or epistemic knowledge)" (Anderson & Clark, 2012, abstract, p. 315). Generalist primary teachers' strength and depth of understanding in these areas would seem to be necessary for teachers where optimal student science outcomes are required.

Shulman further deconstructed PCK into three types of propositional knowledge, three types of case knowledge and strategic knowledge (Shulman, 1986). Interestingly these detailed layers of PCK have not had had the same impact of reproduction in science professional knowledge models and descriptions of PCK since. The model for PCK has greatly expanded in coverage of the complexity of teachers' intended and enacted practice; amplifiers like differentiated knowledge of their learners, teachers' beliefs about teaching and learning (of science and more generally), all within the contextual constraints and affordances of the learning environment and the broader socio-cultural context.

The construct of PCK has been developed and adapted further by researchers like Magnusson et al. (1999). These researchers contributed greater detail as to the specifics of PCK and shifting science curricular knowledge to be a subset of PCK; expansion of orientation to science as beliefs about nature of science, goals of science and science learning and teaching and scientific literacy (Friedrichsen et al., 2010). Inherent in the definition of PCK provided by Magnusson et al. (1999) is a professional development notion, "pedagogical content knowledge is the result of a transformation of knowledge of subject matter, pedagogy, and context, but that the resulting knowledge can spur development of the base knowledge domains in turn" (p. 96).

Teachers develop their PCK during classroom implementation refining it according to reflections on ways students interact with the content. An interesting explanation that connotes the enacting of PCK, was PCK-ing (PCKg), "a teacher's integrated understanding of four components of pedagogy, subject matter content, student characteristics, and the environmental context of learning" (Cochran et al., 1993, p. 266)" (VanDriel et al., 1998, p.677). While PCKg sounds dynamic, there is an inherent subtlety debated by researchers, as to whether PCK is constantly evolving, working knowledge, newly transformed through and during practice; or PCK is a more stable form of integrated knowledge of mixed parts, constructed as a result of experience (Loughran, 2013). Cochran et al (1993) stated that their notion of PCKg extended on original thinking of PCK which emphasised a Constructivist basis, with knowledge of students' learning needs, and the situated learning context.

There is a suggestion that PCK needs to be transformed through pedagogical situations where content is made more accessible/understandable for the learners. Additionally, PCK evolves with teaching of content SMK and how it is interpreted. This transformation happens for students and teachers alike (Loughran, 2013). Even in marking/assessing student work evaluative changes are being made by teachers that affect their later practice constituting professional development according to Falk (2011). The extent to which teachers become aware of different ways to make science content accessible for their students through their PLN activities and further use their PLNs to share these transformative within-classroom experiences needs to be ascertained. The evolution of PCK has been contentious in the past due to varied ways researchers "conceptualise and operationalise PCK differently" (Chan and Hume, 2019, p. 54). and their methodologies in exploring it which necessarily led to the consensus model although these authors assert more research around the consensus model is needed. Some of the later, more notable, shifts are towards notions of collective PCK (Falk, 2012; Hume, 2016) or cPCK which describes "what a group of teachers know" (Chan et al., 2019, p.259) and a re-prioritising of features that affect and are dependent "filters and amplifiers" on generative PCK (Gess-Newsome, 2017). This is in part attributed to the complex nature of teaching where other variables or characteristics are involved beyond pedagogical content knowledge (PCK) like affective, motivational and teacher identity factors which Shulman admits was an oversight in missing these from his original model (Shulman, 2015, in Berry et al. 2015, p. 9).

The model of teacher professional knowledge on which the analysis of this study rests for identifying teachers' perceptions of value in their PLN activities for aspects of science CK and PCK is known as the consensus model (See Figure 2 1).

Primary teachers in online contexts have been found to share knowledge of practice and gain advice from others (Nochumson, 2020; Trust, 2016; Trust et al., 2018; Unger, 2019). The precise nature of the professional knowledge shared beyond teaching tips from quick question and answers is unknown and is a feature of this study to ascertain value of primary teachers' interactions for developing professionally with regard to their science content knowledge.

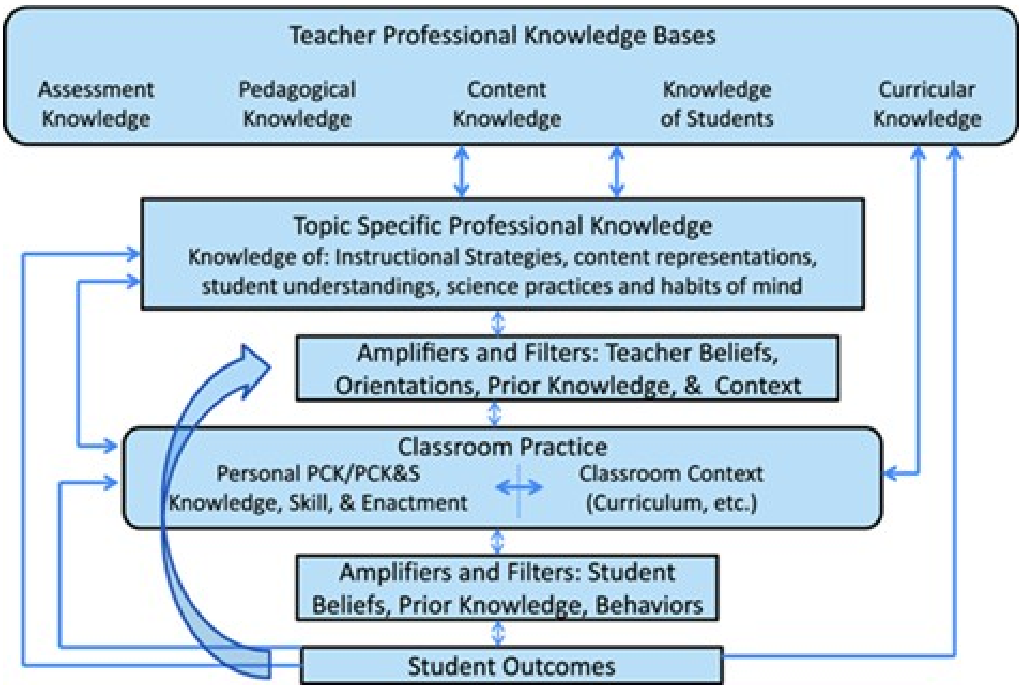


Figure 2.1

Model of teacher professional knowledge and skill including PCK and influences on classroom practice and student outcomes (Gess-Newsome, 2015, p.31)

This model is a result of numerous academics' and science educational researchers' contributions during summits to achieve a better understanding of the intricacies of a teacher's professional knowledge base generally, and it is useful in understanding teachers' professional knowledge as it relates more particularly to science (Chan & Hume, 2019; Gess-Newsome et al., 2017).

The model has layers of interactions in a hierarchical format of more general knowledge (TPKB) of assessment curriculum, science knowledge and student learning held my multiple teachers (and by the profession). This publicly held knowledge becomes more personal versions of science knowledge to a topic specific level (TSPK) where practices change according to a science topic's content and students' stage of development (Gess-Newsome, 2015). There is the added complexity to teachers' individual pedagogical content knowledge and skill set (PCK&S) of amplifying factors such as teachers' orientations to science, to teaching science, understanding of ways students learn science, the classroom context with influences also on students (who have their own backgrounds and prior knowledge) and their learning outcomes, all which reciprocally affect teacher's existing and developing professional knowledge base (Gess-Newsome, 2015). Science teaching orientations as "beliefs about the goals or purposes of science teaching, beliefs about the nature of science, and beliefs about science teaching and learning" (Friedrichsen et al., 2010, p. 373) were seen as more suitably described as amplifiers based on research subsequent to the Magnusson et al. model (1999) of PCK.

After conducting this study, a newer model the Refined Consensus Model (RCM) was proposed. This recent version incorporates a stronger view of realms of contextual influence from cultural to personal explaining levels of specificity of CK and PCK to topic and individual teacher levels and distinguishes between teachers personally held knowledge (pPCK) and enacted knowledge (ePCK) in classroom teaching (Carlson & Daehler, 2019). This study persists with the original model as boundaries of timing were necessary for the literature reviewed and teachers' enacted PCK as disparate to personal PCK was not the focus with no direct teacher practice evidence of science lessons collected but this is suggested as a worthwhile future research direction.

Professional science teacher identity. Research claims:

> it is not enough to address content knowledge, pedagogy and pedagogical content knowledge in teacher education, but that efforts also need to be made to influence prospective primary teachers' identities as scientific thinkers and their emotional commitment to their students' learning of science (Cripps Clark & Groves, 2012).

Research on professional identity for teachers as supported by online networked professional learning groups suggest interactions online are not only for immediate

help-seeking advice and pragmatic responses to questions. Detailed interactions reveal users positioning themselves as experts sharing knowledge on utilising the online group environment and other aspects of teaching practice in varied pedagogically effective ways (Krutka et al., 2016; Lundin et al., 2017; Wall, 2015). This positioning as expert within online threads is key to some teacher's professional identity development.

Blogging was thought to help secondary school teachers build professional identity as "reform practitioners" when needing support for introducing new inquiry based ways of learning and teaching in their classrooms (Luehmann & Tinelli, 2008). Wall's (2015) thesis stated that reflective comments made through blogging supported constructing primary science PSTs identity and knowledge of classroom practice for science learning. Blogging represents an example of successful technology mediated learning for developing a professional identity as a science teacher through PLN activities.

"Professional identity develops from science teachers' early personal experiences as students, with teacher role models, and through interactions with others who play a role in shaping teachers' views of themselves as teachers" (Jones & Leagon, 2014, p. 837). This is a perspective shared by Mansfield and Woods-McConney (2012) who maintain teacher training needs to take these historic aspects to professional science teacher identity formation into account.

Carrier et al. (2017) make the further point that professional identity is not only based on historic references but prospective future aspirations of professional identity for the kind of teacher an individual might want to be. This is a similar perspective to that put forward by Robson (2017) who proposed that projecting professional identity within online spaces is a dual construct with performance and constructive aspects shaped by ideal versions held by the teacher, their progressive reciprocal interactions affecting ongoing PD and ways they are perceived by others in these contexts. Gee (2004) asks "What if projective identities turn out to be a central form of learning for our "new times"?" (p. 303) This notion of projective identity is in reference to children imagining their virtual scientist classroom self as having real scientist capabilities and therefore perceiving a science career future for themselves. Similar scientific thinking identity issues could have import for less than confident or experienced primary teachers, not as future career scientists but as science teachers.

Beginning to teach, generalist primary teachers have been found to need time to reconcile conflicting past models of science teaching from their own schooling which may not have been strong with intentions to teach authentic lessons for students (Carrier et al., 2017). These researchers further recommend primary teachers learn "how to continuously reflect on their views of effective science teaching" (p. 1748). Krutka et al. (2016) propose the key elements of PLN experiences are "engaging, discovering, experimenting, reflecting and sharing" (p. 150) These are similar to the working scientifically skills outcomes documented in the NSW k-10 science syllabus (NESA) and if identified by teachers as mirroring their own emerging skill set could reinforce their identity and self-efficacy as better equipped for teaching primary science.

Science teacher identity, where primary teachers can visualize inquiry learning & teaching identity may also contribute to notions of self-efficacy (Carrier et al., 2017; Cripps Clark & Groves, 2012). Openness in sharing within online teacher communities, fostering an atmosphere of supportive collegiality can lead to a form of "collective teacher efficacy" (Vangrieken et al., 2017, p. 54) which would be beneficial for primary educators with low self-efficacy as primary science teachers.

Positive science teacher identity needs to be supported by PD (Bradbury & Wilson, 2020) and PLNs would seem to offer spaces and opportunities for necessary discourse to create a stronger identity as a primary science teacher.

2.2 Related literature

Teachers seek avenues beyond immediate local networks for solutions, to behavioural, curriculum and resource issues, for some, teacher beliefs of efficacy (Anderson , 2015; Stewart, 2015; Trust, 2013) and "to remain current in their field" (Maloney, 2015, p. 314). The following literature builds towards an argument for Professional learning networks (PLNs) to be further researched and seriously considered for their efficacy in contributing to discipline specific professional development as well as more general pedagogical knowledge in ways that improve upon traditional TPD mitigating some known limitations.

2.2.1 Professional Learning in Online Networks: defining PLNs

Collaboration and collegiality characterize professional online network interactions with virtual communities of practice providing rich professional development opportunities (Du Four & Reason, 2016; Ivanova, 2009). These complex interconnected cyberspaces have advantages and limitations for teachers who seek personalised yet collaborative professional learning.

Defining PLNs. There is an interesting morphology of PLN with little consensus as to the definition of PLN and even the acronym has multiple interpretations described variously in the literature as Personal or Professional Learning Networks. Ivanova (2009) used a different acronym entirely to describe professional learning networks (PfLN) in order to distinguish them from students' PLE personal learning environments. Blurry boundaries of social networks where students communicated, shared and learned to adapt resources, refine knowledge and skills meant passing through an intermediary step of setting up a PLN. "The transition from PLE to PfLN is an important step that supports students to become self-organised and lifelong learners" (p.v, line 5).

Tour (2017) uses PLN to define Personal Learning Network as "an informal learning network of teachers who communicate and collaborate online for professional purposes" (p. 180) which seems like an inherent contradiction in terms with personal and professional, unless personal refers to self-construction and personalized content selection. It could have other connotations which is confusing. Pataraia et al. (2016), Maloney's (2015) and Stewart's (2015) dissertations, and Gladney (2011) refer to Personal Learning Networks. This choice of definition is perhaps based on Couros' (2010) work, favouring a connectivist stance, as forwarded by Siemens (2004). Couros' students designed personalised learning networks using Web 2.0 tools as part of an open, connected and social learning university course. Students' use of PLNs was to promote longevity of group learning beyond the provided university course. This aim of benefitting from sustained learning beyond the provided program is shared by teachers regarding their professional development suggesting value of PLN use for teachers.

Stewart (2015) uses actor-network theory to advance his own definition built on earlier versions of personal learning environments dating from 2004 to describe "nodal associations will be viewed in terms of ideas, technologies, and online social interactions, which collectively will be referred to as a PLN." (p. 3) Manning's (2015) paper includes " A PLN consists of a collection of resources or nodes (people, content sources, etc.) that an individual accesses as needed for his or her learning" (p. 5) A list of the kinds of examples of people and technological connection possibilities follows. There are clear similarities in the use of "nodes" within their definitions which represent the technocentric priority to their versions, underlying a connectivist theoretical perspective.

Vaessen et al. (2014) state "informal" can refer to both learning and networks. These authors contrast mechanisms for informal and formal networked professional development such as knowledge construction across boundaries on demand, more autonomous, continuous informal learning versus knowledge transfer, supplied, bounded usually "under orders event". Then they suggest not making such contrasts but "emphasise the need to develop a hybrid form of learning where both formal and informal learning activities are recognised" (Vaessen et al., 2014, p. 57). This study prefers to consider primary teachers' use of informal networks but for intentional learning where definitions of informal learning may not allow for this deliberate agency (Tour, 2017).

Jones and Dexter (2014) comment that calling the PLN personal may be reasonable when the underlying assumption is "the starting point of connectivism is the individual" (Siemens, 2004, p. 4 para.9 online pdf). This definition they suggest has limited value from social constructivist perspective as the individual is prioritised and where context, as well as detailed quality of interactions within these spaces, is primarily important.

Nijland et al. (2018) offer definitions which distinguish between learning in social networks and learning networks. The latter "learning networks" is cited as "undertaking (a series of) learning activities by teachers in collaboration with colleagues, resulting in a change in cognition and/or behaviour at the individual and/or group level (Doppenberg et al., 2012, pp. 548–549)" (Nijland et al., 2018, p.3) and is not necessarily mediated by technology but predominantly face to face. It is not clear how useful this demarcation is in practical terms when there is seamless boundary crossing possible within a PLN between online and offline networks. Social connections blend with more professional ones and where the professional purpose may be achieved by communicating with the same personal contact, perhaps only made possible by technology use.

Trust's early definition was minimalist and modest in its claim and this version was adopted by

Visser et al. (2014) “A personal learning network (PLN) has been defined as a “system of interpersonal connections and resources” that can be used for informal learning, collaboration, and exchanging knowledge and ideas (Trust, 2012, p. 133)” (p. 396). The whole definition was actually where PLN was conceived as a “system of interpersonal connections and resources that support informal learning… There are two types of PLNs: information aggregation and social media connections” (Trust, 2012, p.133). However, this definition was problematic in that people’s PLNs contain both of these aggregation tools and social media and are not usually exclusively dedicated to either of these purposes.

The next iteration was, “A PLN is a collection of social media and Web 2.0 tools that facilitate the discovery of new information about a topic of interest. PLNs consist of two main types of tools: social media connections and information aggregation (Trust, 2012).” (Trust, 2013, p. 271). Yet PLNs are not just for purpose of discovery of new information about a topic of interest, their scope of inclusion of Professional Learning Communities (PLC), teacher communities of practice (COP), Communities of Inquiry (COI) and Networked Inquiry Communities (NIC) has necessitated a more encompassing definition. This version of the definition followed is professional learning networks are “uniquely personalized, complex systems of interactions consisting of people, resources, and digital tools that support ongoing learning and professional growth” (Trust et al., 2016, p. 35; Krutka et al., 2017, p. 151). While some research affirms reflective activity within PLNs (Krutka et al., 2017), some research has cast doubt on the reflective potential of interactions within PLNs (Kelly & Antonio, 2016).

Trust et al. (2017) further extend their qualification of PLN as inclusive of interactions within offline and online spaces where previous studies, based on singular apps like Twitter, potentially impose an artificial dichotomy that does not exist in reality. PLN activity is complex, characterised by multi-contextuality as Kearney et al.’s (2016) model depicts interactions between individuals and organisations, within and beyond school boundaries as the substance of what is in a PLN.

Figure 2.2

PLNs From A Teacher's Perspective. (From Kearney, Pressick-Kilborn & Hunter, 2016, p. 31). Used with permission.

This study has boundaries in focusing on teachers' voluntary self-initiated use of informal networks as a deliberate starting point, although PLNs afford access to formal, informal, on and offline contexts, and research indicates boundaries are not observed in practice (Czerkawski, 2016; Kearney et al., 2016; Vaessen et al., 2014). This study explored multiple spaces within informal online contexts, detailed and semantic content of interactions with consideration given to offline influences and practices consistent with current definitions of a Professional Learning Network (PLN).

The latest definition from dominant researchers is adopted for this study. "PLNs consist of complex amalgams of people and organizations, face-to-face and digital spaces, and cognitive and technological tools that can support continuous learning and professional growth." (Trust et al., 2018, p. 137). This version of the definition is favoured for its rich description and holistic encompassing of interactions possible at anytime within a teacher's Professional Learning Network (PLN).

Communities of practice, affinity spaces, niche groups. PLNs allow for multiple learning contexts provided within quite different spaces. Exploring expertise within local communities and those beyond the immediate locale to build and access a collective professional knowledge base has merit in theory and practice. Yet this notion that teachers will need to extend beyond their own school boundaries in order to learn and develop effectively is not a new concept, Huberman (1985) suggested, “My claim here is that teachers will reach outside the classroom for information and expertise that can explain and alleviate problems they confront in getting their work done satisfactorily.” (p. 252). Trust’s (2013) early work entitled “Beyond school walls” on online PLNs and their benefits described teachers’ outreach beyond school boundaries using a PLN to broaden the consultant arena of within-school expertise to learn from the experience of more expert, often international other contacts. These expert contacts can become part of the matrix within communities of practice.

A community of practice is described as:

> …a learning partnership among people who find it useful to learn from and with each other about a particular domain. They use each other’s experience of practice as a learning resource. And they join forces in making sense of and addressing challenges they face individually or collectively (Wenger et al., 2011, p. 2).

Professional Learning Communities have been frequently used and researched as ways to support and sustain primary science teacher professional development (DuFour & Reason, 2010; Jones et al., 2013; Mintzes et al., 2013), and with PLCs online (Schaverien et al., 2005; Zhang et al., 2017). Typically, these studies have a blended context of formal TPD element, short course even if only to instruct how PLC should work, with common goals explicated, then less formal online chat begins. Yet one of the more common findings is teacher discontent that their learning goals fail to meet up with the institutionally provided ones (Jones et al, 2013; Jones & Dexter, 2014; Kyndt et al., 2016).

Differentiation is required between communities of practice online and other group structures within a network. One example is a study on teachers using Edmodo Maths Subject Community, Trust (2016) describes typical communities of practice as having co-construction of knowledge, identity and artefacts whereas MSC was characterised by one-of interactions and short duration activity driven by professional need. This online community seems to share some features with an “affinity group” description as parts of a wider PLN can be so varied in purpose and structure.

Affinity groups (Gee, 2004) and affinity spaces (Gee, 2005), are characterised by more transitory affiliations or social semiotic spaces. In these PLN spaces, membership may not be required and communities are unable to be well-defined due to their transient and varied nature. Some examples are teachers online who form a group with likeminded views. The dangers of this limited affiliation though personalisation of a PLN has been suggested to result in echo chambers with no contrasting views to promote further professional growth which was identified among administrators' professional learning via Twitter (Cho, 2016; Trust et al., 2018). Unger (2019) states however, that primary maths and science teachers found being in a group with shared goals in an online professional development community empowering in forming an "affinity identity" (p. 5) based on that discipline specific support.

At their most specific, online groups for professional learning purposes can be considered "niche" due to their specialised membership and content which could be useful in boosting science content knowledge. Niche groups can be found to form within larger platforms where groups splinter or lead onto others, for example ever more specific Twitter group #s based on goals, interests, or content. Differentiation of teacher groups based on different grades of elementary teachers seems valuable as Drits-Esser et al. (2016) found same grade teacher collaboration had most influence on maintenance of primary science professional development changes in practice. An interesting counterpoint to this is from research by Ranieri et al. (2012) who found thematic groups less useful in practice for teachers actioning real world changes than generic groups on Facebook. Their suggestion was that thematic, specialised groups were already working on specialist projects and that generic groups inspired greater change. Reasoner's (2017) thesis found that disparate views promoted thinking and challenge existing teaching practices. A benefit of participating in online networks is sharing expertise but also learning views from those with different expertise (Trust, 2012; Trust & Horrocks, 2018). This seems to be the essence of niche groups which were found successful for teachers needing to solve high-powered maths problems collaboratively each week and Gomez et al. (2016) has called these purpose built NICs or "networked improvement communities" (p. 10). These execution networks are for the purposes of solving complex problems where community members share tools, methods and a collective goal rather than an individual one which is also consistent with features of socially-shared regulation of learning (SSRL).

Research on professional learning teacher communities whether formal, or member initiated, with fixed or emergent goals, means members have different perspectives that affect interactions and vary conditions for success. Factors for success tend to be dependent on group leadership, composition, trust and respect (Vangreiken et al., 2017). This doctoral study intends to explore if this perception is prevalent for primary science teachers where PLN use is less regulated or prescriptive as teachers self-select PLC's and COP's or other groups in which to participate as opposed to ones that are institutionally ascribed. Wenger et al. (2011) propose "Social learning is enhanced by a dynamic interplay of both community and network processes. Such interplay combines focus and fluidity as it braids individual and collective learning" (p. 13). Therefore it seems that there is potential professional learning value to be explored in primary teachers' multi-contextual PLNs.

2.2.2 Science and STEM Education Prioritised

The current economic and socio-political context has prioritised STEM education as a means to future prosperity, "Quality science education is a pillar for a more sustainable future" (Bokova, Nov 11, 2014) with many countries' responses varying in scope and scale. Bokova's statement for UNESCO encouraged science and STEM education with gender equity and the importance of traditional and indigenous knowledge central to her message. The reform agenda in Australia has led to initiatives being implemented locally, to meet the demand for scientifically literate citizens, competent in STEM fields. Educational research needs to ensure that change instigated by economic drivers has integrity and sustainability within the educational system and beneficial learning outcomes for students of all ages.

Issues exist of reported imbalances such as poor representation in sciences as a tertiary study choice. In Australia for example, "the number of commencing domestic PhD students in science and engineering in 2010 was below the 2004 level" (Marginson et al., 2013, p. 17), similarly low participation in high-school science subjects generally (Kennedy et al., 2014) or school age learners even visualising science careers for themselves, are issues not unique to Australia (Archer & DeWitt, 2015; van Tuijl & van der Mollen, 2016). DeWitt et al. (2013) found from 9000 primary school children 10-12 yr olds in UK "there were no gender differences in attitude towards school science" (p. 1053) but girls in their study did express weaker aspirations for future careers in science and "less positive self-concepts in science than boys." (p.1053) The need to address these imbalances is central to contemporary educational research and provides the broader context for this study.

Government initiatives to support uptake in science and STEM related career paths permeating the education system are international in scope (Office of the Chief Scientist, 2013; National Research Council of the National Academies, 2014). The power of engaged and networked communities of practice is recognised at a political level where the USA Department of Education and Office of Innovation 2026 STEM education vision report (2015) gives this discussion first priority. NESA Teaching Professional Development survey (NESA, 2017), the Future Needs section of the report specified that 90% of Australian teachers (n=7645) selected working collaboratively with others as relevant/highly relevant; 81% valued membership with professional networks or associations and 76% rated self-directed online learning similarly relevant. Yet teachers' continuing professional development is still predominantly considered to be in provided programs.

At a political level, PLN use requires internet access which is perceived by some as a democratising tool, not favoured by countries whose political frameworks do not support this. Disintermediation (Salmons, 2010) or the lack of gate keepers can be seen to influence intellectual activity whether it be an enabler (anyone can reach an expert opinion) and also constraint (anyone can provide an 'expert' opinion). It is also hegemonic in the predominant discourse of various organisations' dedicated sites and moderator's presence promoting specific agendas in sponsored chat forums (Robson, 2017). Concerns have been raised about the exploitative nature of the few for the many on some platforms with a risk of de-professionalism over time, although this is in the Swedish context of decentralised schooling and TPD since the 1990's where teachers seek online communities for professional development opportunities (Rensfeldt et al., 2018). Trust et al. (2016) suggest while diversity of opinion is one of the main affordances, there can also be filters applied, impacting that gain.

Gee (2004) in his work on "New literacies for new times" writing of the early 2000's described the devolved, decentralised and rapidly evolving notions of knowledge being distributed in new capitalistic times as distinct from the specialised academic knowledge handed down in old capitalistic times in schools. This democratising phenomenon of knowledge, expressed earlier by Salomon et al. (1991) (see section, 2.1.3), has rendered it less of a powerful commodity than the "ability to design new identities, affinity groups, and networks" (Gee, p. 284) that learners can access and contribute to this complex multimodal set of literacies afforded by internet technology.

Teacher professional development documentation from several countries make reference to professional online networks as necessary for practice but few employers credit time spent doing this "work" albeit out of school hours. Accreditation requirements are still predominantly based on formally provided registered programs although teachers are now permitted greater choice among these required options.

Teachers are expected to stay current in their field, extend discipline knowledge and utilise external support. Examples from professional documents are "update knowledge", "broaden knowledge" (AITSL, 2018 online pdf), from "knowing how and when to draw on advice and specialist support" (Department for Education, UK, 2011, 2013, p. 13) and "By reading professional journals…stay informed of policy initiatives that impact their profession" (National Board for Teaching Standards, USA, 2012, 2015, 2016, p. 54). Some of these activities PLNs are already considered to support well and content knowledge has been evident to a lesser extent (Britt & Paulus, 2016).

Scalability has been raised as an issue for effective widespread professional development for primary science teachers and yet research by Willet et al. (2017) shows,

> These interactions take place at a large scale: Over six months, Rosenberg, Greenhalgh, Koehler, Hamilton, and Akcaoglu (2016) captured 550,000 tweets—from 68,000 educators—using state educational hashtags (e.g., #miched, #wischat, #nyedchat, etc.). Research also shows that these educator interactions are largely teacher-driven, public, largely unmoderated, and thriving (p. 1823).

The affordances of online technologies is about dialogicality; multiple teacher interactions as within chat and forum spaces. More research around professional development is required to find the kinds of networks that primary teachers perceive as beneficial for developing their science educational knowledge and skills.

2.2.3 The Generalist and Specialist Primary Science Teacher Debate.

Primary pre-service and practicing teachers, typically with generalist or non- specialist science backgrounds, it is claimed, are perhaps not sufficiently well-equipped to make necessary changes for improved science and STEM pedagogies (Nadelson et al., 2013; Royal Society, 2010). Previous research has identified several issues with primary teachers' efficacy in science, lack of "preparedness" and "rigour" (Prinsley & Johnston, 2015, pp. 2-3) of primary teachers around subject matter knowledge (SMK) and/or effective ways to teach it, pedagogical content knowledge (PCK). Despite these apparent problems, recent research in Australia such as in the Primary School Science Teaching Survey Report (Watson & Watson, 2014) found 8/10 teachers (n=810 primary teachers, principals and personnel) were confident and interested in teaching science. In the Primary Connections Research Evaluation final report in Australia, "93% indicated that they enjoyed teaching the subject" (n=126 in-service primary teachers) (Aubusson et al., 2019, p. 110). These are promising findings for framing future teacher development initiatives. Although positive orientation may be due to teaching a "comfortable" form of science rather than conceptual depth required which Appleton (2007) suggests is an avoidant behaviour. Even among science teacher enthusiasts, similar constraints inducing negative emotions were lack of time, resources or not feeling confident in SCK content knowledge impacting ability to teach the way they desired (Bradbury & Wilson, 2020).

Research on SCK levels portrays a bleak picture for good student outcomes if teacher content knowledge is low, impacting quality of in class questioning, teacher mediated discussion and understanding in students (Harlen, 1997; Newton & Newton, 2001). In a professional development environment Zwiep & Benken (2013) explored maths and science teachers' perceptions and content knowledge. These researchers assert that conceptually strong teaching requires teachers "understand subject matter deeply and flexibly so they can help students create useful cognitive map, relate one idea to another, and address misconceptions; they need to see how ideas connect within a discipline and to everyday life", (p. 304). This raises several important points, substantial content knowledge and refined pedagogical content knowledge involving representations, knowledge of learner's potential obstacles to understandings such as naïve theories and misconceptions as crucial to effective science teaching. Ways to support career long refinement and extension of science professional knowledge among primary teachers regardless of their science background are essential to improving student learning outcomes in science.

Defining specialist and generalist primary teachers of science has been problematic with many theorists offering variations. This study adopts the definitions of science specialists as generalists who have studied a science to completion of higher school certificate level (Newton & Newton, 2000, p. 602) and “Those who take science exclusively also tend to be well qualified in science” (Appleton, 2007, p. 501) implied for those who teach science across multiple primary grades, acknowledging a possible limitation that this includes teachers of composite or mixed grade classes. Most participants in Phases 2 and 3 of this study had been recognised as team leaders in technology or STEM education within their school, on the basis of professional development in those fields or from showing an enthusiasm and progressiveness in their own teaching. This moving from a generalist teacher to providing more specialised support to other teachers in their school, does fit with newer definitions provided in AITSL primary specialisation guidelines (2019) “generalist primary teachers with a specialisation” (p. 3). However one U.K. participant clearly identified as “specialist teachers who fulfil specialist roles in schools” (AITSL, 2019, p. 3) and only taught science across multiple primary grades and classrooms.

Historically research has depicted generalists as lacking in scope and depth of science content knowledge (Appleton, 2007; Corrigan & Taylor, 2004; Kind, 2009). Even with sciences it seems some domains are better understood than others. “In general, teachers entering, as well as those in, the profession of science teaching were less well trained in the physical sciences than in the biological sciences.” (Mallinson and Mallinson, 1957, p. 367). Yet similar issues remain current, “Australian Year 4 students scored significantly higher than the overall science score in life science, but were weaker in physical science and, to a lesser degree, Earth science.” (Thomson et al., 2017, p. xix). Perhaps this suggests similarities with historical findings. Primary science teachers have been found to hold similar misconceptions to their students (Harlen & Holroyd, 1997). The need for specific content and pedagogical content knowledge development is required at scale. Science teacher professional knowledge includes their substantive and syntactic content knowledge (CK) as well as discipline specific suitable and sufficiently varied ways to teach that academic content (PCK) in science. Science education quality in early and primary school years could be instrumental in changing low student learning outcomes (Nilsson & Elm, 2017; Prinsley & Johnston, 2015; Royal Society, 2010).

Traditional methods of professional development seem to have not had sufficient effect when 35 years yields comparable limited results, prompting calls for effective primary science TPD. Responses included an initiative to “train 200 primary school teachers as maths and science specialists in 100 of Victoria’s most disadvantaged government primary schools” (Victoria State Government, Australia, 2012). Specialist teachers were required to work in a variety of roles as model, mentor, relief teachers, supporting generalist teachers develop required characteristics and effectively teach science in primary classrooms dependent on each school’s culture. Research of program effects are emerging and initial findings are positive, with generalist teachers educated during professional development as specialists, who have promoted science engagement in schools, organized resources, mentored other less science competent teachers (Campbell & Chittleborough, 2014; Herbert et al., 2017) and participate in offline and online networking beyond the program. This suggests the value of using PLNs for primary science teachers in offering continuity beyond the provided program.

Resources, support and successful implementation of curriculum-based science activities in the classroom seem to affect confidence and perceptions of self-efficacy in science teaching for primary generalists (Harlen, 1997). Resource support for these aspects of science teaching practice have been implemented with "Primary Connections" in Australia where the Australian Academy of Science (AAS) in conjunction with Department of Education writers and teachers have compiled booklets and CDS, using trialled science lessons in a Constructivist format related to national science curriculum. Hackling (2008) reports on specialist consultants providing in-service activities to help effective interpretation and classroom implementation of these resources and most teachers (96 out of n=97) believed their science teaching knowledge, confidence and practice had improved as a result of this TPD (Hackling, 2008, p. 77). A later report finding that after Primary Connections TPD workshops 80% of sample (teachers, n=126, PSTs, n=171) were confident (and very confident categories combined) in using the program and its tools to improve student learning in science, which includes open learning online TPD content (Aubusson et al., 2014).

Despite suggestions that well-resourced programs and specialists are the means to these ends, research by Levy et al. (2016) suggest "well-funded programs were not always associated with strong student outcomes," (p. 20). Regardless of the expense of the program in terms of excellent science resources or even the specialised knowledge of the teacher, it is the individual teachers themselves who affect student interest in learning science (Levy et al., 2016). Similarly Alshamali & Daher (2016) found from a sample of 138 Palestinian upper grade primary science teachers that scientific reasoning in a problem-solving context was high for this group as a whole but significantly higher among female teachers and there was no significant difference according to specialization, experience or qualifications.

CoRes was a planning resource designed by Loughran et al. (2006; 2012) to demystify the detail of PCK specialist science teachers hold and to make these usually hidden aspects of PCK visible for generalist teachers and PSTs. This layout for content representation offers self-regulatory prompts for thinking about science PCK related to identifying the big ideas of a science topic. Teachers learn about and build their own PCK and substantive CK before teaching the topic with students. Bertram (2012) explains that primary teachers benefitted in developing their topic specific PCK from planning science lessons utilising CoRes. The role that primary teachers' PLN use could play in contributing to areas of developing science content teaching knowledge is a significant research question still requiring an answer.

2.2.4 Understanding Advantages for Teachers in Using PLNs

The main affordances offered by Reeves, Herrington & Oliver (2004) suggest:

> intensive engagement in the collaborative solution of authentic problems, the learning outcomes accomplished by these learners will be of the highest order, including improved problem-solving abilities, enhanced communication skills, continuing intellectual curiosity, and robust mental models of complex processes inherent to the performance contexts in which their new learning will be applied (p. 53).

Although limitations are identified by these authors, such as insufficiently "authentic" tasks defined at length (pp. 55-56), later research also suggests that the full extent of benefits is rarely realized in practice during online networked collaborative learning. An example is learning community is affected by the knowledge and skills of those within the community (Jones & Dexter, 2014). Research on technology integration as a learning tool for PSTs, teachers and learners points to an issue of slow implementation as pedagogies are not fully developed to support effective practice yet (Chandler & Redman, 2013; Nielsen et al., 2013; Schuck et al., 2017). Research also indicates that even after a year-long technology integration instruction for teaching science, this does not necessarily result in increased teachers' implementation of inquiry science (Pringle et al., 2015).

PLN use has been found to enable teachers almost anytime and anywhere to develop their careers through invitations to conference participation and employment opportunities (Maloney, 2015). Teachers voluntarily taking on their PLN activities as serious and intentional "productive work" furthers their value for developing professionally (Tour, 2017, p. 189). The need-to-know or just-in-time basis of this access to advice and information has obvious benefits within and beyond the classroom (Duncan-Howell, 2010; Jones & Dexter, 2014; Knowles et al., 2012; Kyndt et al., 2016). Maloney's (2015) suggestion that "connected teachers are more likely to facilitate connected learning experiences for their students" (p. 322), could have value for primary teachers' pedagogical development and student science learning. Knowles et al. (2012) recommend that while using the internet has benefits and challenges, it requires that "the learners have very well-developed self-directed learning skills…of learning how to learn" (p. 243). Primary teachers would seem well placed with their pedagogical understanding and educational background to leverage these self-directed online opportunities using their PLN.

This raises the question of suitability of PLN activities for all teachers. Meijs et al. (2016) developed an instrument of factors to determine how socially minded teachers are and if social learning suits all teachers. The factors they utilise to describe social learning mindedness were a factor for preference to social learning at all; learning form others/colleagues; collaboration and new approaches; autonomy; and attitude to disseminating knowledge. They found social learning as professional development does suit a majority of teachers who rated very highly seeking advice from colleagues and slightly less collaborative learning from others. Over 90% of participants scored neutral or above on liking to share or disseminate their knowledge which the researchers took to be a general disposition of teachers. Teachers wanted control over choice of topic and preferred when collaboration led to PD "of which social learning is one form" (p. 100).

In any teacher network there are highly qualified individuals, with varied expertise within the group, who are capable of sharing their competencies in problem solving and advancing their own professional development (Roseler & Dentzau, 2013). These authors make a strong argument against traditional provided approaches of professional development because the implicit message is that teachers require outside expert help where potentially within their own communities there may be sufficient collective expertise to solve them. While age of the teacher also seems to impact on formal and informal teacher professional development activities where "participation in formally organized learning activities declines with age (Kyndt & Baert, 2013; Richter et al., 2011)" (Kyndt et al., 2016, p. 1112). Career long professional development is required and experienced teachers necessarily have expertise to share within a PLN.

PLNs support professional development activity for other groups of teachers such as ICT teachers who appreciate-different views could challenge their thinking with newer teaching ideas. "For example, secondary teachers noted that they didn't have a great deal in common with their primary colleagues, but nonetheless several noted that they were inspired to try new pedagogical approaches after reading posts from primary teachers" (Mackey & Evans, 2011, p. 11). The extent to which teachers feel positively towards engaging with various activities using PLNs will necessarily impact on their patterns and frequency of participation in these contexts. Clusters of social media "enthusiasts, engagers, sceptics" with a subset of "impartials" and "intellectual rejectors" who vary in their appreciation of value for themselves personally, professionally and for their students were identified by Owen et al. (2016). This has implications for primary teachers who may not all be enthusiastic about online PLN use for professional purposes.

Varying participation patterns add to the flexibility of learning for the many. Prestridge's (2017) research addresses ICT teachers' usage patterns and mapped a model of opposing continua. These continua explore social reasoning with self which extends to other, and interactivity reasoning ranging from take to contribute. The result is a typology such as a self-seeking contributor who may gain rather more than surface learning experienced by an information consumer. Amplifier motivational aspects such as curiosity and competitiveness versus complacency influenced participation. In other research, "Participation in learning networks is aimed at sharing knowledge and expertise as individuals personally see fit. Networked learning, in our view, is aimed at promoting professional autonomy, self- directedness and independent decision-making." (Vaessen et al., 2014, p. 58).

A constraint of PLN use has been identified as maintaining public and private domains separate. Concerns around keeping professional identities separate from online persona for recreation/social purposes and safety for students meant not all teachers were equally convinced of its advantages for their professional learning and teaching (Owen et al., 2016).

Another query regarding PLNs use for teachers' professional learning and development is whether all of teachers' PLN spaces may not be similarly conducive to reflective practice. A study about participation in large, open Facebook groups where "A significant finding is that the teachers in the groups studied did not typically engage in modelling of teaching practice, reflection on practice or feedback about practice" (Kelly & Antonio, 2016, p. 146), perhaps due to perceptions of its open, less than safe nature as compared to a more stable CoP or PLC. However Krutka et al. (2017) suggest ways to increase reflection through intentional PLN activities, identifying emergent learning goals, whether these are effectively met and ways to progress.

Conflicting perspectives on quality of PLN interactions are found in recent research. Disappointed by the limited quality of professional interactions on a Swedish Facebook group Rensfeldt et al. (2018) suggest teachers should move beyond superficial postings of "likes" to more critical and collective practice norms of open reflection and debate. In establishing arguments towards their professional development value, Tucker (2019) has found evidence of teachers reflecting on deliberately sought professional readings within Twitter PLN activities. Even major proponents of PLNs for professional learning still query the quality of content, "Although there were certainly examples in our data of more profound forms of collaboration, the depth and quality of PLN collaborations remains unclear" (Trust et al., 2016, p. 29).

Concern for quality is for sufficient depth and scope of CK in PLN discussion spaces with low prevalence of CK noted by several researchers to date (Britt & Paulus, 2016; Rensfeldt et al., 2018; Unger, 2019). Little evidence of content knowledge, PK or PCK was found in the first year of Unger's analysis of primary science teachers' use of Twitter in supporting their reform-based science teaching. Conclusions were that these spaces offered sustained and relevant professional development of science teacher identity (Unger, 2019).

However one of the major affordances is the ubiquity of access to multiple contexts (Trust et al., 2016) which users and platform providers have constructed to support different purposes and requirements in professional learning among adult teachers. Quality of content and holistic benefits for primary science teacher TPD represents a gap in the current research literature.

2.2.5 Ascertaining value of Professional Learning Networks for primary science teacher professional development

This doctoral study attempts to ascertain the value of PLN use as professional development in science for primary teachers as there is a well-established need for of detailed pedagogical content knowledge, science content knowledge, professional identity and self-efficacy among generalist primary teachers of science. PLNs offer a research context which is important for its potential value-adding to professional development of teachers and so influencing science education learning outcomes. In these ways, the "value" of PLN use for aspects of science teaching development could boost primary teachers' "effectiveness" and "preparedness" (Rowan et al., 2015).

The aim of sustainable, scalable professional development that has value contributing to primary science teacher rich content knowledge, reflective pedagogy and practical efficacy for improved student interest and outcomes in science is important.

However it needs to be perceived as relevant and efficient for primary teachers of science in current times to be of value. Advantages of PLN use is that "in a fast changing world, the power of network links to unfamiliar people and organisations is crucial" (Gee, 2004, p. 286) in its role to allow new learning and Nochumson (2020) states that 94% of elementary teachers (n=107) reported changes in their classrooms subsequent to new ideas learned online through Twitter and three quarters of interviewees (n=19) reported changes in their teaching practice.

Teachers' use of multiple contexts within platforms and across platforms for professional learning activity, are the reason that Wenger et al.'s (2011) value creation model of online communities of practice while useful, does not describe the whole picture. These values, immediate, potential, applied, realised, reframing have been found within networked teacher groups between schools to contribute effectively to the primary teachers' revisualising ways of learning (van Amersfoort et al., 2019). Other groups of educators have found "immediate value through interaction and potential value as knowledge capital" (Wenger et al., 2011, p. 4) which can lead to "applied, realised and reframing value" cycles (pp. 20-21) as Tharrington's (2017) thesis found for pre-service world language teachers, and even aspirational value among academics (van Waes et al., 2016). It is reasonable to question if online communities of practice built during PLN activities may offer primary science teachers similar professional development value of depth. However, many network groups are more transient and a teacher's development is personal even among collaborative learning and co-regulated groups.

The potential for extensive and arguably intensive learning across multiple blended contexts is what makes PLNs so appealing to consider for their contribution to teacher professional development. Value could arise from transient interactions, purposeful yet immediate, occurring across multiple platforms or groups. Often these weaker connections are typical of online learning environments where knowledge is intensive (personally held expertise) and extensive (shared and distributed), dispersed and situated (in practice), tacit and often difficult to verbalise explicitly (Gee, 2004, pp. 284-285). More studies seem to assert professional learning and growth than professional development. “Unfortunately, this continuous process of workplace learning, where people customarily exchange knowledge with others in their networks, is hardly ever recognised as professional development.” (Vaessen et al., 2014, p. 57)

Value known about PLNs so far is that PLN use promotes adaptive expertise in teachers (Trust, 2012) where teachers employ metacognitive strategies to reflect on their thinking and take action to improve their practice. This seems to be a similar concept to strategic knowledge when teachers explore options to resolve new problems of practice (Shulman, 1986) and is very comparable to reflective practice recommended of science teachers by Loughran et al. (2008).

PLN use has been found to have value as responsive, flexible, fluid informal professional development (Prestridge, 2017) without offering a framework for professional development. Unger (2019) found evidence in a Twitter group of maths and science teachers sharing pedagogical knowledge and content knowledge but stronger for group “affinity identity” (p.67) as science teachers with shared goals.

Primary science teachers were sharing information, valuable work, resources, student activities, science related topic opinions, and professional contacts in generating that shared science teacher identity. A nested approach was required to ascertain the value in this study, as the value can be perceived at various levels and for different purposes. Evidence from other PLN studies to date establish teachers’ social and cognitive presence during interactions in online spaces as consistent with communities of inquiry which have learning value (Garrison et al., 2010). Willet et al. (2017) use several frameworks to analyse Twitter interactions within educators PLN’s including affinity groups, social knowledge capital and media circuits, so precedents exist for this multiple framework approach. As Tour (2017) mentions “little is known about a whole repertoire of teachers’ professional practices through PLNs” (p. 182). The multiplicity of use and types of interactions across differing online contexts mediating professional learning by teachers is a key focus of this study on primary teachers using PLNs for their professional growth as science educators.

Korthagen (2017) describes a model of PD 3.0 which is holistic, looking at personal, professional, cognitive and affective domains of a teacher as whole person with agency and “An inconvenient truth may be that effective professional development 3.0 is first of all value-based (Biesta, 2010), which means that it starts from what practitioners themselves value in their own work” (p. 400). Following practitioners’ valuing their own work as a priority, this study embraces teachers’ perceptions foremost. The nested framework for this study continues with comparisons made with existing literature of required professional development criteria in a formally provided program. TPD is professional learning that promotes changes in teacher practice and student learning outcomes (Darling-Hammond et al., 2017). Further this study utilises the Gess-Newsome (2015) model of science teacher professional knowledge for the detail of primary teachers' PLN activities in contributing to aspects of effective professional development for science education (see Figure 2.3).

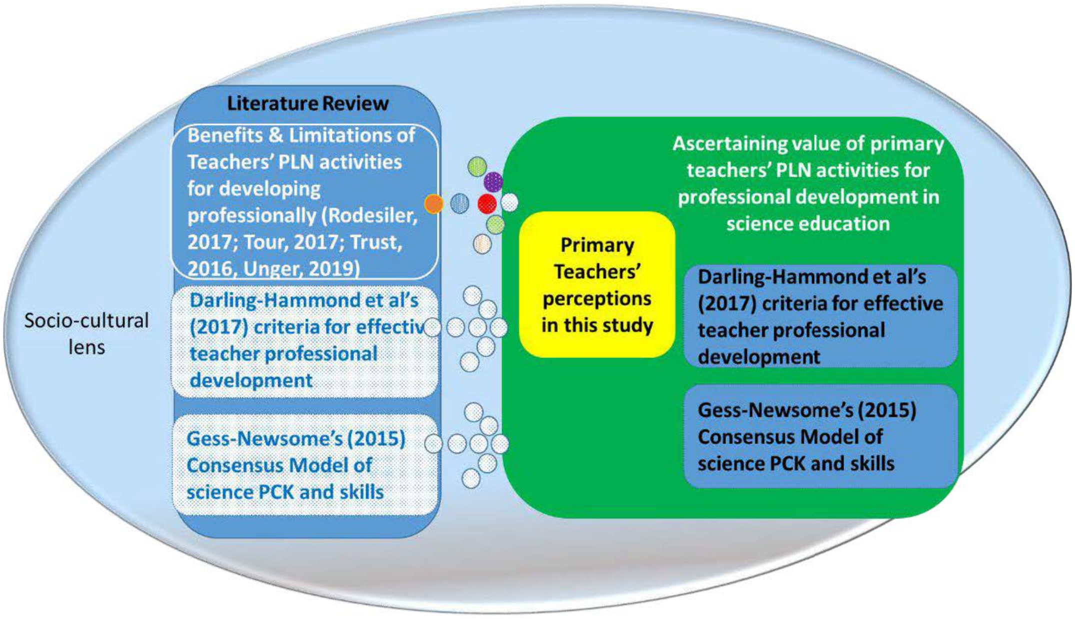


Figure 2.3

Proposed Framework for Ascertaining Value of Primary Teachers' PLN Activities for Their Science Education Focused Professional Development

2.3 Summary

An interpretivist study with mixed methodology allows for a robust investigation that leads to an in-depth understanding of primary teachers' perceptions of their PLN activities. This theoretical framework supports ascertaining the extent and nature of the value evident for teachers' professional activities in informal, PLN online contexts as ways of developing professionally in K-6 science education.

Previous research and theoretical literature suggest that PLN activities within communities of practice (Lave & Wenger, 1991; Trust and Horrocks, 2018) and informal contexts online (de Laat & Schreurs, 2013) have value for teacher professional learning. Others maintain meaningful teacher professional development is achievable through online networked professional learning activities (Hartshorne 2008; Tour, 2017). Part of the appeal in using PLNs for teachers as adult learners, is the self- direction of their own goal-driven processes to improve knowledge and practice (Knowles et al., 2012). Cooperative and collaborative co-regulation and socially shared regulation possibilities of sharing and shaping learning amongst the varied expertise of others are potential benefits (Hadwin et al., 2011).

Areas of this holistic study's focus in attending to possible value for primary teachers' activities within informal contexts (blurred boundaries acknowledged) of their online PLN, arises from literature featuring effective TPD criteria (Darling-Hammond et al., 2017) for science teaching knowledge and skills (Gess-Newsome et al., 2015). As "overall network benefits/value for professional development from the standpoint of individuals" (Pataraia et al., 2015, p. 337) offers a gap in the literature. The potential for "collective efficacy" (Bandura, p. 33) is a necessity within the current sociocultural context where effective teacher professional development in science and STEM education has been prioritised internationally for improving student outcomes and career uptake in these fields.

Further areas of interest for this study, based on a paucity of research literature, are: the value of technology-mediated learning in accessing multiple contexts rather than just one platform or group/space within a platform; value of PLN use for primary science teachers in particular who are typically generalist educated and may need more specialist science content knowledge (substantive and syntactic); value in using a PLN for developing science education knowledge and skills during implementation; value in meeting criteria deemed necessary for science teacher professional development when this term usually connotes provided programs by external sources; the value in scalable ways of individual teachers meeting professional goals within collectively resourced environments.

Finding answers to this study's research questions would be a significant contribution to understanding ways primary teachers of science develop their everyday practice. This study provides insights and detail for how contemporary primary teachers' PLN use supports their learning of dynamic science professional knowledge and refining their practice over the development of a career.

The methodology outlined for this study is in the next chapter. Chapter 3 details the way the research questions for this study will be explored using a Multi-Mixed Methods Approach (MMMR) (Salmons, 2015) to ascertain value for developing as a teacher of primary science through activities within informal PLN contexts.

Chapter 3 **Methodology**

This chapter describes the methodological choices made in the design of this research and justifies these decisions. The nature of content required from the research questions influenced the design criteria. The methodology adopted for this study fits well within the interpretivist paradigm and therefore provided methodological congruence (Richards & Morse, 2007; Creswell, 2007).

Chapter 3 outlines a multi-mixed method (MMMR) design and necessary considerations required for rigor in mixed methods studies, including multiple validities, researcher reflexivity, accuracy and legitimation. Ethical considerations specific to online research are presented. The sampling methods and participant backgrounds are outlined. Details of each phase for data collection and methods of iterative analyses are described. “Reflexive iteration is at the heart of visiting and revisiting the data and connecting them with emerging insights, progressively leading to refined focus and understandings.” (Srivastava & Hopwood, 2009, p. 77). Study limitations are also discussed before a summation of the methodology which scaffolded and allowed for the findings presented in Chapter 4.

3.1 Methodological Decisions

Several key reasons influenced the decision to explore the research questions for this study using a mixed methods, quantitative and qualitative, approach. The research questions involved three sub-questions exploring an overall research question which is worded as “how” to mean, “in what ways?” and “to what extent?”. Questions are formed in an attempt to describe teacher understandings of the phenomenon of professional development value through their PLN activities. The different aspects of teacher activity and perceptions of value indicated a mixed methods design would accommodate multiple perspectives and online contexts.

Overall research question

How do primary teachers’ Professional Learning Network (PLN) activities contribute value as professional development in science education?

Sub-question 1.

What are the characteristics of primary teachers’ initial PLN construction and ongoing PLN management for science teaching professional development?

Sub-question 2.

What are the participatory relationships and details of primary teachers' PLN interactions about science education?

Sub-question 3.

What are primary teachers' perceptions of ways their online PLN activities provide science teaching professional development?

Another reason for adopting a mixed method design is the range of data collection possible within these online multiple contexts, such as social media fora (e.g. Twitter, Facebook) and other sharing platforms (e.g. Google+, YouTube), aggregation and curation apps (e.g. Tweetdeck, Wakelet), yet data is also curtailed by their transience. Methodologies to explore phenomena of ways people share and co-construct knowledge and understandings have evolved from those accepted in the past, such as ethnography, morphing to 'virtual ethnography' exploring ethnography via and within the Internet (Hine, 1994); to 'online ethnography' (Markham, 2005) to account for studying connections and networking. 'Connective ethnography' was coined to allow for descriptive research around online/offline network interactions from both an individual (Leander & McKim, 2003) and practice orientation (Fields & Kafai, 2009). 'Affinity space ethnography' (Lammers et al., 2012) describes observations of transient participation and interactions within network spaces, but is derived from online gaming and linguistic studies, and involves critically engaging with popular culture rather than educational sites. The methodology of research studies using the internet pose special concerns. "These concerns include issues unique to this area of study, such as questions about the scope of cyberethnography, the validity of trace data relative to other approaches, and the analytical division between on- and offline interaction" (Hampton, 2017, p. 182).

This difficulty in tracking participants' multiple tool (websites, chat groups) and multi-device (computers, phones and tablets) use, is another reason for adopting a mixed method design. Multi-tool and platform use makes ethnography problematic for a holistic view of interactions, within these technologically afforded learning spaces, and "obtaining access to archives of comments made in conversation with other participants can present a methodological challenge" (Lammers et al., 2012, p. 54). This study's emphasis is on holistic as well as nuanced participant views of value, and findings of this nature are not consistent with more structurally focused methodologies like social network analysis (SNA). Hence for this science education study, with its scope and detail of the research questions, a mixed method approach was appropriate.

While the debate around differing ontologies and epistemologies within quantitative and qualitative methodologies continues among theorists and researchers, there is a growing research base, which defends mixed methods research and the strengths of each in a combined methodology.

Bazeley (2018) referred to mixed methods research as requiring "purposeful interdependence between the different sources, methods, or approaches used is the critical characteristic that distinguishes integrated mixed methods from a monomethod or even a multimethod approach to research" (p. 5). This kind of pluralism still meets its critics who feel the ontologies and epistemologies preclude the kind of paradigm that best fits a research project (Teddlie & Tashakkori, 2012).

This study on primary science teachers required a dialectic stance, using methods which account for socio-cultural environment influences and constructivist aspects of learning in these diverse online contexts. MMMR allows for the multiple teacher interactions and perspectives to be well-documented.

This interpretivist study was designed to represent varied perspectives in teachers' lived experiences with a multi, mixed method research (MMMR) approach (see section 4.1). To summarise, this approach was chosen for its suitability and flexibility to fully describe the ontological issues of plural contexts and detailed nature of meanings constructed within technology-mediated, socially constructed learning. Mixed methods involves multiple data sources, requiring approaches to analysis, with necessary integration, before conclusions are drawn. Salmons (2015) advocates the necessity for new domains of research such as online environments and multimodal communications within it to have research methodology that captures the diversity of expression - only feasible through mixed and multiple methods research.

This MMMR study involved 3 phases using an explanatory sequential design, across multi-modal, online contexts, to give in-depth, thick description of data. Where "extensive and careful description of the time, place, context and culture is known as thick description" (Mertens, 2019, p. 283), as explained by Gilbert Ryle-in Geertz (1973) to mean researcher thought and reflection on observations for culturally nuanced detail. For this study, providing sufficient detail was important so that others may make judgments about transferability or relevance of PLN value to their own situations.

The sample participants in Phases 1 and 2 were volunteers from the wider population of primary teachers, whether generalist or specialist-educated as teachers of science. An email invitation was sent to several teachers who expressed interest in response to an online message for more participants. A further one primary teacher was asked to participate in Phase 3 after an expression of interest at a conference. These teachers also had an online social media presence and identity for their own professional learning. Teachers' professional learning included pedagogical content knowledge (PCK). Aspects of both PCK and professional identity are tacit forms of knowledge which teachers often find difficult to articulate and researchers have acknowledged present access difficulties (Loughran et al., 2008; Robson, 2017). Yet "internet- mediated mixed methods research also allows for new research questions, especially with regard to revealing subjugated knowledge" (Hesse-Biber

& Griffin, 2013, p. 54). It was useful to study teachers' expression of meanings and value perceptions of these traditionally difficult to access aspects of TPD within observable PLN activity. The MMMR approach reflects the multimodal, mixed format reality that characterise personal, professional and social forms of communication (text, symbols and images) in online/offline contexts, in which this research was situated (Salmons, 2015).

There are varied ways to write findings in a mixed methods study, for example presenting each phase, or quantitative and qualitative separately, and integrating them in the discussion section. Bazeley (2018) recommends integration from the first presentation of findings and not waiting until the discussion, to show the necessary interplay in developing meaning. This study adopted the latter approach, where "…insights from both sets of data are best presented and discussed together" (Bazeley, 2018, p.89), as an integrated presentation of analysis of findings related to research sub-question topics and themes. Contradictions and comparisons between findings from both data types and theory are abductively explored in the discussion of themes.

This study's methods were descriptive and empirical in nature helping to build on existing themes in research literature and present new findings emergent from participant accounts of their realities. This moving from literature to data or vice versa is recognised as necessary within "an iterative, cyclical approach to research. MMR is characterized by the cycle of research, which includes both deductive and inductive logic in the same study or program of study" (Teddlie & Tashakkori, 2012, p. 781).

The extent of priority given to the quantitative and qualitative aspects of data collection and analyses was a purposeful decision. The mixing of qualitative and quantitative approaches also permitted validation and confirmation of findings through multiple sources of data collection and analysis. Hesse-Biber & Griffin (2013) suggest mixed methods approaches are less about improving validity or authenticity of findings and more about understanding the research problem more fully within complex environments. The quantitative data offer an overview and the qualitative data provide explanatory refinement and more in-depth perspectives from participants (Ivankova et al., 2006). Onwuegbuzie & Leech (2006) describe mixing of qualitative and quantitative methods for the purpose of "significance enhancement" (p. 479), maximizing researcher interpretations of data.

Another methodological decision for this study was the tri-level theoretical framework for analysis. Firstly, the findings were interpreted through a Vygotskian socio-cultural lens (1978) as this described the context for primary teachers' PLN activities. Next, findings were considered for the extent that the seven criteria describing the effective professional development model for teaching were met to contribute to an understanding of value (Darling-Hammond et al, 2017). The last level of specificity for interpreting findings was based on the science teaching theoretical perspective known as the 'consensus' model of professional knowledge in science (Gess-Newsome, 2015) for value as professional development in science education.

3.1.1 A Multiple Mixed Methods Research approach: The Study Design

This study involved multiple, mixed methods research (MMMR) using an explanatory sequential design (see Figure 3.1), where phase 1 quantitative data collection was analysed to inform Phase 2 qualitative sample selection (see section 3.4 for sampling methods) and data collection. Once analysed, data from both Phases 1 & 2 were integrated for interpretation where quantitative findings had foregrounded some qualitative findings and qualitative findings explained quantitative results. Phase 3 followed up sequentially and used qualitative data and represents the multiple (M) in MMMR methods. Mixed methods offer complementarity in this study for expanded understanding of themes in answering the contributing questions (Greene, 2007).

Qualitative analysis from Phase 3 was compared with all data from previous phases which consolidated and extended details of the perceived value of PLN use to identified aspects of primary teachers' science professional development. This mixed methods study can be characterised by (Quan + QUAL + QUAL). Dominant emphasis was on the qualitative aspects of the study (denoted by capital letters) integrated with quantitative (lower priority denoted by lowercase lettering) as the research sub-questions required nuanced detail of knowledge and understandings which could only be accessible this way.

The three phases addressed the main research question focus and relate closely to the contributing questions. Although no single phase was exclusively aligned to a sub-question, Phase 3 was most aligned with sub-question 3. Please see diagram in Figure 3.1 of research structure which includes data collection and analysis methods as recommended in Ivankova et al., (2006), modelled on examples in Wyse et al., (2017).

Phase 1. An international online questionnaire open to primary teachers of science was implemented as an initial step in this study. The survey instrument was designed and piloted on a small group of teachers and fellow students (n=7), items were amended based on feedback regarding wording and structure of questionnaire (see section 3.5 Phase 1 for development of instrument and Appendix B). Phase 1 quantitative results of the survey (n=49) offered an overview of primary teachers' of science PLN construction and practices which informed Phase 2 procedures, originally planned as focus groups. Too few participants (a below expected sample size from Phase 1) meant focus groups were not feasible so online interviews were selected for qualitative data collection as it required fewer, making this a more appropriate method.

Questions for Phases 2 and 3 were revised from original conceptual drafts and were created from emerging issues and required information from the previous phase. The phases progressed in depth and reduced in number of participants (by nested design and also through attrition).

Phase 2. An online interview was recorded with each voluntary participant who elected via email to continue to Phase 2 from the survey, (several invited solely via email) purposively sampled for their active PLN and interest in science (n=10). The online interview (unless requested as audio only) was via Zoom software and one interview was conducted by phone at request of participant. A portable digital recorder was used with participant agreement. This multimodal approach in Zoom also incorporated a typed chat line of prepared interview questions as a prompt for participants to look at during the interview, although some questions were emergent for clarity and follow up of participant responses. This chat line was used by the researcher to pace the semi-structured interview which was intended to take approximately 20 minutes (see Appendix D1 for interview schedule).

Phase 3. Participant artefact collection and short in-depth audio interviews (using Zoom technology) were conducted to understand the participant created artefacts, providing further details and legitimation of qualitative and quantitative data. For one participant in this phase (not same person as phone interview in previous phase) a phone interview was more convenient and conducted this way. The third phase involved a smaller number of primary school teachers of science (n=5), most of whom completed both earlier phases (n=4). One teacher joined the study just for this phase on a verbal expression of interest and email invitation. Artefacts were screenshots of their online interactions, self- selected by participants including images and text, for all but one participant who provided text excerpts only. These chat extracts were self-selected by participants for significance to their science education learning. Participants also used a provided template to produce an evaluation artefact for one significant interaction (see Appendix E for this template). Participant artefacts were then used as prompts or points of reference during a short 15 minute audio follow up semi-structured interview (see Appendix D2, with 2 questions out of 9 individualised based on their own evaluation templates.

This final phase had its key focus on answering contributing research question 3 to ascertain participants' perceptions of ways they are developing/have developed through PLN and its value.

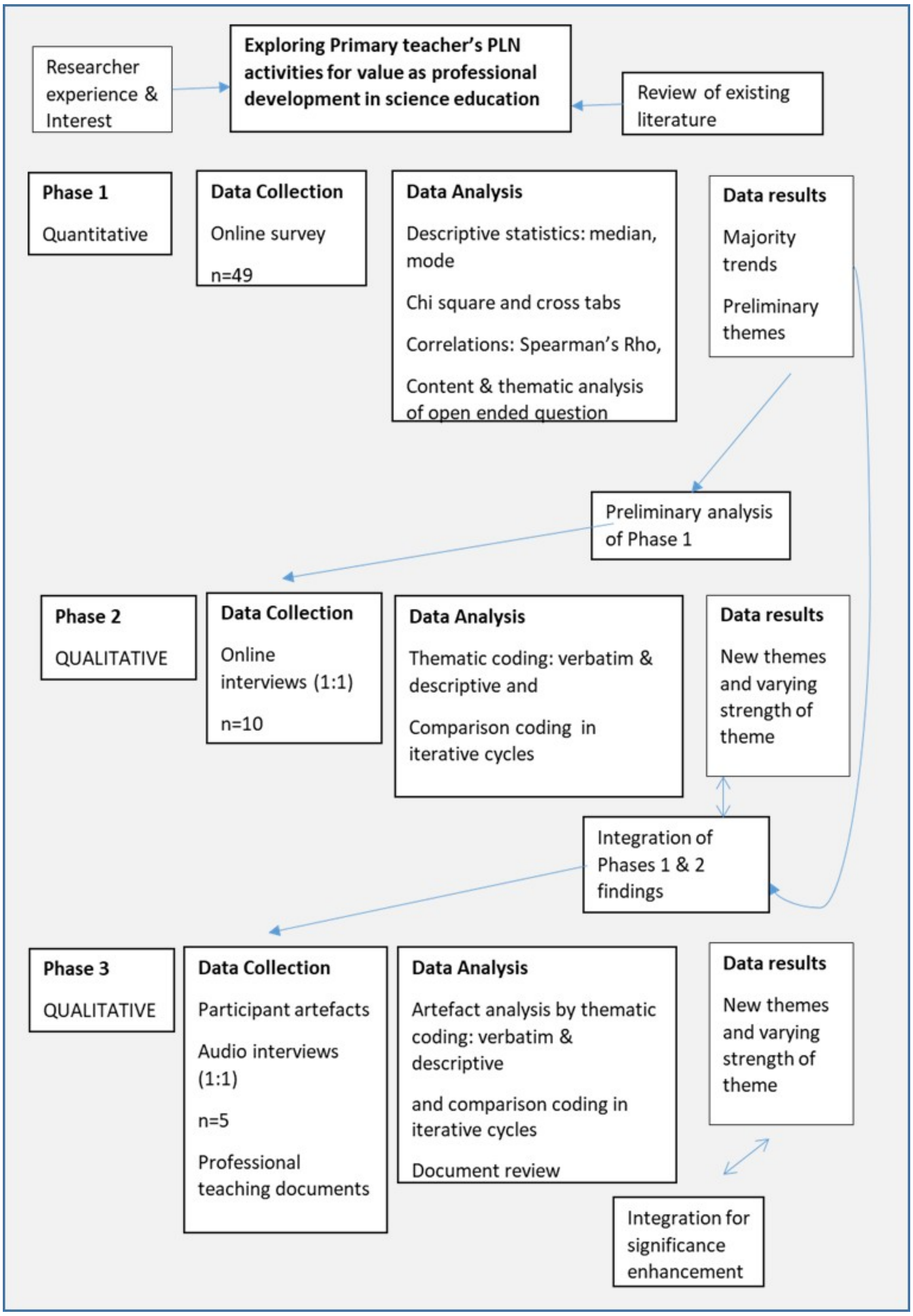


Figure 3.1

Exploring Primary Teachers' PLN Use: A MMMR Structure Overview of This Study

3.1.2 Overviewing Data Analysis Methods

Data analysis involved: quantitative descriptive statistics for Phase 1 and qualitative coding and analysis of open response items on questionnaire. Phase 2 interview recordings were analysed and coded for interpretation as were Phase 3 artefacts and interviews (see section 3.6 for data analysis techniques). Phase 1 quantitative results were integrated with Phase 2 qualitative findings for understanding and interpretation. Integration of the qualitative with the quantitative data aims to better explain teacher PLN use in terms of any surprising findings (Poth, 2019; Swaminathan & Mulvihill, 2018) and helped with development of pertinent more in-depth questions.

Phase 3 interview and artefact analysis were compared with earlier mixed methods findings to enhance the overall understanding of the meanings and contexts represented in the data. Although some chat excerpts included visual imagery these have been excluded from analysis as they require a complexity of semiotic and possibly iconographic analysis (van Leeuwen, 2011) beyond the scope and focus of the science pedagogical knowledge for this thesis.

Chat excerpts were qualitatively analysed. While the survey was considered to be the “quan” aspect in the “quan + QUAL” (Leech, 2012, p. 876) sequential mix of methods in this study, there was an open ended question which was analysed qualitatively and with quantitative word frequency visual representation using a word cloud for top 20 most frequently used words. See Figure 4.2 in Chapter 4: Integrated Findings.

The choice and prioritising of these different ways of viewing and analysing the qualitative and quantitative data collected, fits “multiple validities legitimation” (Burke Johnson, 2012, p. 753) criteria. Considerations included: minimising weakness of a singular methodology; the sequential choice of order, priority given, and justification of this paradigmatic mixing of quantitative and qualitative methods (Collins et al., 2012). Validities suited to quantitative measures were employed. Different validity considerations such as legitimation for qualitative methods was used.

3.1.3 Justification of Methods Chosen

Design Suitability. The survey in Phase 1 was chosen as an effective methodological tool for the broad perspective gathering possible as required by the overarching research question in what ways primary teachers' activities within PLN have value for their professional development in science education. Professional Learning Networks for teachers tend to be informal and self-initiated and self-directed, often in use beyond normal work hours, so it was considered that the best way to access this sample of busy primary teachers was when they were actually using the networks. The survey was available to primary teachers by contacting them through the online environments that they frequented already.

The online international survey was chosen for its international reach and to maximise the invitation take up to participate via numerous platforms teachers used. These platforms were selected as considered to be useful, based on preliminary short observation time dedicated to exploration and identification of primary science and technology dedicated sites and groups online.

In the designing of this MMMR research, the second phase was anticipated to be focus groups but the lack of participant response, to the survey's request for ongoing participation in the next phase, failed to produce sufficient numbers to conduct focus groups. The short online researcher-to-participant (1:1) online interview was decided to be the primary qualitative data collection method for Phase 2 instead.

"The qualitative interview is a key venue for exploring the ways in which subjects experience and understand their world. It provides a unique access to the lived world of subjects, who in their own words describe their activities, experiences and opinions" (Kvale, 2007, p. 9). In this study the researcher strove, particularly after the first interview, to minimise interruptions, unless for a specific purpose, for example, to reassure participants they were heard. The results were extended and comprehensive interviewee responses which had value in demonstrating participants' thoughts and opinions.

There are concerns and criticism of the value of interviews as data in terms that it may be individualistic, not accounting for a person within their social context while conversing, thus limiting credibility. Further issues are the intellectualising of responses which can make them seem 'arhetorical' (Kvale, 2007, p.140) and de-contextualised when they are recorded and reported. This researcher found that online interviews were very useful in this study and achieved the desired result, gaining responses of depth and complexity which allowed for nuanced and detailed answers to research questions.

In Phase 3, a deliberate selection process where participants' identified examples of their online interactions as significant to them developing professionally was useful in eliciting their perceptions of value of their PLN activities. Self-selection also mitigates some ethical research issues with copying online chat and researcher bias. The second interview in this third and final phase was to clarify any data missing from their own evaluation artefact of a single interaction (which was also subject to researcher analysis) and to establish if their selections were typical or unusual interactions in their content and why they were selected as significant.

Pictures (for example photos of student process and outcomes or snapshots from science teaching videos, labelled diagrams, and teachers' representations of conceptual models, slide shows, cartoon graphics, etc) and text were present on several selected chat excerpts. Some participants had conflicting perceptions as to the value of these for their professional learning (see 4.1.1). Two participants Jane and Angela, (see 3.4.1) remarked during earlier interviews that some visual representations detracted from value, where Archie said photos can be useful. Different forms of imagery, their relationships and purposes within the online contexts is complex and raises methodological issues for researching social media. These issues concern the need to analyse images in conjunction with text as suggested by Hand (2017) including "visual phenomena, means for circulation, visualising culture, contexts of new practices, diverse contexts for interpretation in terms of where they are situated in a post, visual modes of participation" (p. 217). This researcher acknowledges that it would constitute another thesis to explore visual contributions situated within social media posts for Barthes-style denotative and connotative effects of representation through semiotic analysis of these (van Leeuwen, 2011). Detailed attention is required and recommended as an interesting area for future researchers.

The Phase 3 follow up interview was to gain an in depth understanding beyond the Phase 1 & 2 information and to establish new ground. Preliminary analysis of Phases 1 & 2 revealed many findings in keeping with and extending upon literature, although little that was a novel contribution to the research literature. This method was also a strong contribution to the mixed multi-methods as it offered another layer of specificity of information and personalised level of teachers' perceptions of their own professional development and the value to them of using PLN activities for their professional learning about science education, building the sequential explanatory approach chosen.

Reference to national professional teacher standards documents in Phase 3 contributed to the triangulation of results, in their meaningful applicability to the participants' professional development. In Australia, for example, there are teacher accreditation requirements of a recognised standard which involve ongoing professional development, often by providers.

NESA, the NSW teaching authority, allow for up to 50 hours of Teacher Identified Professional Development (TIPD) within a 5 year period for full-time Proficient level teachers. This could include some time spent in online PLNs which seem to well suit details within AITSL professional standards 6.2, 6.3 and 7.4 (https://www.aitsl.edu.au/teach/standards) requiring broader community engagement and collegial networking. International equivalents of teacher professional standards from UK and USA (countries of majority of teacher participants) were also explored for language supporting PLN use as professional development. This was not document analysis as described by Altheide (1996) but a practical extension of the participant findings.

These 3 phases offered the ways to collect data addressing the research questions pertaining to initial then ongoing construction of online PLN, the nature, quality and extent of interactions. Design consistency further allowed for nuanced details and their relevance to professional development in science education through teacher perceptions of the value of their online PLN activities for their science teaching professional development.

The process for ensuring rigor in this mixed methods study began with aligning interpretivist philosophical assumptions with research phase methodological choices, and legitimation, in justifying decisions for mixing paradigms.

3.2 Rigor in Mixed Methods

3.2.1 Multiple Validities and Legitimation Considerations

There were some important considerations to "maintain the validity" (Harding, 2019, p. 114), reflexivity and accuracy of the research findings which are discussed below. In a MMR study these are referred to as multiple legitimation considerations which Collins et al (2012) attribute to Onwuegbuzie and Johnson (2006) and refers to "the process of applying evaluative criteria at multiple levels of the mixed research inquiry" (Collins et al., 2012, p. 851). Evaluative criteria describe rigor in the research, quality of design and transparency of verifiable findings.

The design of the survey questions was rigorous undergoing several iterations and redesigning in response to information being gathered. Please see the discussion of developing a survey instrument in section 3.5.1 for a description of this design process. The interviews were also implemented with thorough analysis subsequent to memo-ing, interviewer evaluations and multiple readings of verbatim transcripts, transcribed by the researcher for the added sensitivity to content within interviews before coding and detailed analysis. In these ways integrity of design suitability, consistency, and design fidelity were considered to ensure that all three phases fit together logically, data collection and analysis were robustly implemented, closely linked to research question responses (Collins et al., 2012; Teddlie & Tashakkori, 2009).

Commensurability. This refers to representation in a MMR with a mixed or multi-perspective world view. Commensurability for this study began with the inferences made by this researcher which were in line with the assumptions at the start of the research design to present plurality, provided there was not unanimous consensus in participant perceptions, which seemed a less likely assumption given the teachers represent a sample of the wider population. Sampling across all systems of teachers whether government or non-government schools was another means of ensuring plural perspectives. The survey and subsequent interviews were international in composition for further multi-viewed representation. Teachers were not selected on gender, SES background, ethnicity, school location which resulted in possibility of further diversity. See 3.4.1 for background of participants.

Political legitimation, honouring the "voice", values and differing positions of participants as stakeholders in the research was managed through the verbatim transcription. This included mentioning participants' own agenda despite not being within the scope of answering the research questions for this thesis. Keeping teachers' voice is extended by sharing the findings with the communities from which participants came and which may be useful for them in transforming practice.

Multiple validities, validity considerations from quantitative, qualitative and also mixed methods are considered to build higher quality inferences. In this study these included examining reflexivity. Keeping a continuous account of decisions made and justifications for these decisions through memos allowed for ascertaining validity of findings (Harding, 2019).

Reflexivity. Inside (emic)-outside (etic) legitimation type is the extent that a researcher represents insiders' and observers' views for clarity of description and explanation. For this study a more etic perspective and a less subjective positioning of the analysis is important, especially when the researcher has similarities to the sample, being educated as a primary teacher, working in science education. As Mertens (2019) remarked there needs to be "close involvement in the community of interest combined with sufficient distance from the phenomenon under study to record accurately observed actions" (p. 279). The etic-emic perspective is not absolute and binary. Preceding the research a short observation period of two weeks was conducted to inform selection of different well-frequented primary science teacher sites for later distribution of the survey.

Further online contact via postings unrelated to research but establishing a reciprocity of giving some information and answering questions or reposting articles by others and broader PLN engagement was required, throughout the first phase, and established a closer community contact, while recruiting participants. This engagement that could be considered more emic in quality was also extended through face-to-face discussion with prospective research participants by attending conferences and a TeachMeet. Furthermore credibility is also achieved through thorough documentation of all data collecting, analysis and interpretation as presented here.

A Wixsite (free) was generated post-release of the online survey to offer further legitimation to the study for participants and make researcher reflexivity clear. The website outlined the phases and purpose of the study in more detail than the social media advertisements used for inviting survey participants would allow. This was hyperlinked to the researcher's profile via a link provided on the social media platform Twitter. This also permitted another platform as avenue for recruiting participants with a direct hyperlink to the survey and email contact link to the researcher.

Accuracy and legitimation. There is always the need to check that participants' views and responses are represented as accurately as possible. Harding (2019) recommends that there are particular ways to achieve this beyond the verbatim transcript such as re-reading findings and transcripts for cross matching accuracy of themes, patterns and ideas documented at first during data collection and then subsequently analysed and reported. This was done not just through coding but after writing up the results for this document and conferences, to ensure accurate details represented participants' points of view.

There is the added accuracy required of considering alternative views or explanations for the findings collected besides those accounted for in this study. Harding (2019) cited eminent research writers as requiring consideration of alternate interpretations, hypothetically contradictory ones and the necessity to account for findings which do not fit the scope of analysis or interpretation of this study. Several themes that were emergent from the interviews were surprising and not directly relevant to answering this research question and yet have broader educational implications. Several participants expressed concern that undergraduate primary education students were not learning to use a PLN effectively as part of their tertiary studies. Participants repeatedly emphasised this was particularly important to professional development in supporting their ongoing learning and felt it would benefit new graduates' transition to the workplace. A further recurrent theme across participant responses was the lack of time to effectively implement a full science and technology-based curriculum into a typical primary school week, and the lack of this currently. Partially related to this was another emergent theme of concern by primary teachers around managing their workload and coping with expected workload.

It is important to mention a potential threat to accuracy of the online survey data is the use of an incentive which was a decision considered necessary to increase participation rates. Research has found that it may decrease the number of incomplete responses but does not affect the unit of non-responses (Callegaro et al., 2015, p. 150). However there is the concern that incentives can encourage respondents to be more eager to please, or, if allowed, respond more than once. The survey was lengthy and an invitation to ongoing participation may have helped discourage these multiple participation effects, but it is not possible to know the extent of this effect. The decision to offer an incentive was weighed with the consideration that survey fatigue is a reality as "Survey fatigue is not specific to online surveys, but a response to frequent requests to participate in survey research from a range of sources," (Roberts & Allen, 2015, p. 102) and an increased participation rate was an aim. The incentive was an online book voucher for a modest amount and was limited in number.

Accuracy of quantitative findings was also furthered by analysing the data in two different ways, once in SPSS and once in Microsoft Excel. Although the survey was designed by this researcher and piloted in LimeSurvey the international version was put into Qualtrics software by a third party technical assistant who was knowledgeable in this software.

Iterative rounds of differing level and types of qualitative analysis for strength of themes contributed to analytical rigor. Triangulation, while not strictly speaking worded as such within MMR studies, is another respected way to verify findings and involves the extent to which different methods of data collection can result in findings that are comparable and similar. In this study the quantitative survey, qualitative interviews and analysis of interactions allowed different avenues for comparison and contrasting of findings offering legitimation.

Authenticity and transferability of findings. All measures from sampling, data collection techniques and analysis have been carefully considered for their role in producing data of detail to satisfy research requirements of credibility (internal validity), dependability (reliability), confirmability (objectivity) and recognition of limitations to transferability (generalisability).

Participants provided their interpretations of their selected interactions, for screenshots and for qualifying references to online survey data results, in addition to the researcher's views and interpretations of data. This adds referential adequacy, offering some robustness to build trustworthiness through credibility (Lincoln & Guba, 1985) of the research. Further credibility was derived from questions being closely related to research objectives. Participants' attitudes towards PLN use could affect credibility of findings if only presenting positive cases. In this study, however, participants expressed some interesting counter case views on various issues relevant to and beyond the scope of this research. All interviewees were asked the same set of initial questions in Phase 2 interviews and some individually tailored questions were added to a standard set in Phase 3 interviews. This parity was for dependability and to counter interviewer bias, despite a semi-structured interview These questions were derived from previous literature and preliminary Phase 1 findings but no fixed apriori theory in keeping with interpretivist approaches. The researcher kept verbatim recordings and utilised these in analysis to ensure veracity of interpretations for internal validity (credibility) and confirmability (objectivity).

Authenticity was the fairness of the research in representing plural possible interpretations of the multiple, perhaps dissident, participant voices gathered in data collection phases. "….trustworthiness and authenticity standards are of fundamental importance to interpretive research…" (Taylor, 2014 p. 44). Priority was given to documenting and citing examples of participants' comments based on relevance to themes regardless of positive or negative perspectives given.

The reflective Phase 3 completion of an evaluation template by participants was an opportunity for educational authenticity (Taylor, 2014). The researcher asked primary teachers of science to consider aspects of their pedagogy using the template increasing awareness of others' science professional practice and evaluating their own development. Tactical authenticity (Taylor, 2014) was the extent to which primary teachers felt empowered to make changes as they developed professionally. The researcher noted any evidence of their shifting perceptions about developments in science teaching and learning practices attributed to their PLN use. Shifting pedagogical knowledge became an emergent theme.

The number of participants in Phases 2 &3 of this research project while they were anticipated to be small, were even less than expected and may preclude/inhibit the ability to make generalisations much beyond the scope of the study. The select nature of the sampled population, that is, primary teachers of science with active PLNs, limits the transferability of findings to within and only minimally across this section of the teaching profession. This research perhaps has most specific relevance to practice within Australia although international participants expressed some comparable and alternate perspectives. It is possible that findings could have applicability in other contexts and this transferability maybe evident through thick qualitative description presented (Creswell, 2007; Shenton, 2004).

The trustworthiness, authenticity and transferability of findings as described have all been considered and articulated to maintain quality standards for this interpretive study.

3.3 Ethical Considerations

3.3.1 Role of the Researcher: Issue of Potential Bias

The researcher, educated as a primary school teacher has also worked in teacher education for many years. Bias may result from some self-referential invested interest of the researcher in finding solutions to the research problem of ongoing quality support for in-service teachers of primary science but colleagues were not participants. Some discussion as to researcher reflexivity on the etic-emic continuum was already mentioned in the rigor of methods section of this document.

While in this study participants were asked to self-select and generate data, the researcher was also an instrument of the research in terms of inherent biases such as age, gender and socio-economic status, education, appearance and choices influencing the research process. Researcher bias is possible within face-to-face data collection procedures and to a lesser extent in nature of the questions on a written questionnaire and the wording of interview questions. Participants were asked to select snapshots of online interactions and offer their interpretations of these and their value which places the researcher as "outsider" to some extent. Researcher's interpretations of participant responses were presented to participants for clarification at times. Alternative perceptions were sometimes offered by participant, which gave greater neutrality and plural representation. The researcher piloted survey questions and made necessary amendments.

The researcher used follow up interview questions if there was ambiguity of meaning, or if researcher needed confirmation of participants' responses. The semi- structured planned question format allowed for themes of interest and salient issues arising from participants' to be responsively followed.

During interviews, the researcher's role was intended to be one of mediator, prompting discussion with minimal intervention but still demonstrating interest and attention (Salmons, 2010). Some teachers' responses required encouragement to keep flow of discussion and neutrality of these comments was quite difficult to consistently achieve, at least for this student researcher. Question content was provided in a chat line within Zoom software for participants to refer to in answering their questions. This chat line was an objective way without researcher's voice required for repetition and served as prompts for timing of response to next question rather than interrupting participants. This texted chat line of questions was not possible for phone interviews (two in Phase 2 and one in Phase 3 for participant's chosen convenience) so parts of questions were repeated as required.

The researcher's interpretations of participant selected interactions from phase 3 were also open to researcher bias, so to minimise this effect participants could comment on researcher views during the interview, correcting or extending answers based on researcher's understanding or misunderstanding, if evident. Interviewees seemed comfortable enough with the researcher to do this in several instances. Answering the final interview question "is there anything else you would like to add or know or would like researcher to know about this topic/study…?" gave another opportunity to minimise a purely researcher bias in interpretation of the topic. While participants selected their online interactions for analysis which counters researcher-based forms of bias had the researcher selected them, it was necessary for the researcher to reduce some participant selections. For analysis more manageable sized excerpts were needed, in the instances where hyperlinks to archived one hour conversations were provided, so some bias is acknowledged in this meta-selection process. Selection of reduced artefacts was based on science content in keeping with the research questions and focus.

As interviewer, the researcher audio-taped interviews and transcribed verbatim to minimise researcher bias. This collection method reduced researcher bias over other techniques such as note-taking during interviews.

Researcher subjectivities and priorities affected all aspects of this research from details of questions formulated, methodological choices and especially coding during analysis. The researcher's level of participation and personal involvement affected the research process despite awareness and using minimisation strategies (Saldana, 2009, p. 7).

3.3.2 Approvals, Participant Information & Consent, Data storage & Management

The researcher sought and was granted ethical approval formally from the university HREC before any data were gathered (number ETH18-2569). Participants were informed of their ability to withdraw from the study at any time and ensured of confidentiality and anonymity (if requested) via written participant informed consent forms. Several participants did decline to continue to the third phase. These forms also outlined scope and purpose of the research study and expectations for their co-operation and high autonomy in selecting data to share with researcher and required their agreement via written signature. This was a low risk project, where data was stored securely using a national research database cloud facility AARnet to counter a procedural ethical concern with any online information being vulnerable to hacking. Safe storage and data management was an important consideration with the University of Technology's research Cloudstor facility also used as a repository where confidentiality could be maintained and information de-identified where possible. A third data storage option of USB was used as backup.

Online invitations, on various professional science and primary teaching sites, resulted in voluntary participants passing the invitation on to other potentially interested participants. This snowballing, also known as chain or referral sampling is a sampling technique (Crouse & Lowe, 2018) where the first contacted participants make referrals to their contacts which extends the size of the sample. An experimental concern was not knowing the extent to which participants' awareness of data being collected, impacts their normal behaviours within PLNs and biases data. This was a concern as the majority of data collection techniques and tools revolved around participant self-reported measures. The researcher was cognisant of the time burden that being involved in this project will contribute to the participating teachers' work, particularly early career teachers. Participants will be provided with a summary of results (NHMRC, 2007 in UTS HREC) in the fairest and clearest terms possible.

3.3.3 Online Data Collection and Publication

The nature of the initial online questionnaire involved some ethical considerations beyond offline questionnaires such as providing participants with an information page and consent check box "to indicate consent before accessing the survey" (Roberts & Allen, 2015, p. 98). This sample of willing teacher participants also created an initial bias as not-interested parties would not volunteer and a screening question at the start asking for participants to meet eligibility criteria of having an active online PLN and being a primary teacher of science would have excluded those who were not active online.

Data collection involved online material indirectly in Phase 2 through participant responses and directly in Phase 3 through artefacts of interactions. The researcher de-identified and carefully quoted to minimise likelihood of identifying participants or people with whom they interacted. For this reason, certain people's names and hashtags as well as particular details of the individual's occupational responsibilities are removed from descriptions of participants and their quoted responses. All participants were provided with a pseudonym anonymity. In an effort to maintain confidentiality, the researcher has not included all of participants' achievements and personal references to other educators. There is enough detail of the research data such that exclusion of personal details has not compromised contextualising the data for readers. A further consideration was "Unique tracking links in online surveys also undermine anonymity through providing a link between survey responses and the email address of the survey respondent" (Roberts & Allen, 2015, p. 101). However, in this study only participants willing to go through to the second phase from the survey voluntarily provided their email addresses.

There were further ethical issues around consent for online groups because taking snapshots of conversations may impact on voluntary informed permission from all contributors to the discussion thread, could not be obtained (Kelly & Antonio, 2016). For this study that was not a possibility or requirement as only signed consenting participants' responses and parts of the online conversations were utilised. This related also to publishing any results, as it required and limited quoted conversation to ones from participants themselves as no approval was possible from their co-contributors of online interactions (Young in te Riele &Brooks, 2013). The researcher was aware that "published anonymised verbatim quotes may be traced to the discussion forum archives from which they originated, where they are likely to be linked to an individual's identity (discussion group posts might be permanently archived)." (British Psychological Society, 2013, p. 10). Any online social media direct quotations used in this study were provided by participants and did not contain any sensitive personal information that could be a privacy issue.

Participants were invited by the researcher to send an email address if continuing through Phases 2 and 3 of the study. These contact details were kept for any correspondence and stored safely and while anonymity was not possible, these email addresses could not be aligned to Phase 1 anonymous online survey responses. Public versus private information available on publicly visible online sites raised ethical issues of ownership of information which had further implications for publishing data gathered and presenting this data at conferences. The appropriate level of anonymity was agreed by participants signing the information and ethical consent forms, where these purposes were made clear in advance of any results publication.

Some ethical anomalies arose during the study. While the researcher offered confidentiality as detailed on the information and consent form, it was interesting to note that several participants chose to publicise their own involvement in the research via social media channels. The researcher, as a result of being known to be interested in the field by participants and then wider online groups, was requested through tagging to join online synchronous chats, which posed an ethical dilemma of following participants or not. One participant requested and received responses to his Phase 2 interview transcript in order to build resources for his own postgraduate research degree.

3.4 The Participants and Sampling Methods

This sample of participants came from the international population of primary teachers of science, generalist classroom teachers or specialist science teachers. Teachers were asked to self-identify as generalist or specialist in demographic survey item 6, based on their role in teaching primary science to single classroom (generalist) or across one, or multiple primary, or primary and secondary school grades (specialist). Participants had an online PLN, had to be a fairly active user (more than once a week) and an interest in science education by nature of the fact that they were purely voluntary participants. Participants could be any age, stage of teaching career, from any country but needed to be primary teachers, even if they also had other school or university employment. This study did not include pre-service teachers.

Sampling began by being purposively large and international, utilising snowballing, a common technique for within networks. This technique was to gain the heterogeneity of practice, as Bryman (2016) noted the value of purposive sampling over probability sampling, is to include a wide range of individuals, activities and the multiple perspectives of participants. The researcher invited participants to be part of the research via advertisements with professional science teaching organisations, magazines, online and offline professional science teaching networks. Snowballing started with prominent users in the online space and then moving on from their immediate contact lists. Sufficient sample size for quantitative study was required, although it is acknowledged a normal distribution is not strictly feasible when using a purposively selected sample. There is a concern that "Nonprobability samples, including convenience sampling, are prone to selection bias and have no theory to support statistical inference" (Hampton, 2017, p. 101). This did limit the quantitative analysis possible from the Phase 1 questionnaire and the number of participants achieved was low which limited non-parametric descriptive statistical analyses. Some statistical testing was not possible where cell counts were less than 5 due to the small number of participants in subgroups and across Likert style items with multiple categories.

Another issue with using this snowballing sampling technique was that referrals may be limiting, if teachers are isolated, "thus excluding a subset of the population. This technique also introduces the potential for a lack of confidentiality across participants." (Crouse & Lowe, 2018, p. 3 online document). This was true for this study as some Phase 1 participants announced online when they had completed the survey, posing an ethical issue of confidentiality, but a bonus in promoting survey participation to inspire others. The researcher targeted several platforms for their large numbers of users, science education focus, references to them in literature and practice as being popular with teachers. The sample for Phase 1 was drawn from these active PLN users.

It was originally thought that the research would involve sequential theoretical sampling where categories for participant selection for Phases 2 & 3 were contingent on the data gathered and analysed from the previous phase. This "nested sampling" (Mertens, 2019, p. 355) approach was where participants for Phase 2 were a subset of Phase 1 participants (please refer to figure 3.2). However, the research reality was a convenience sample based on participants' willingness to keep going with the study and their availability. There was also a need to recruit participants via social media more directly, which is closer to an "intensity sampling" (Mertens, 2019, p. 348) method, where individuals who might be considered as rich cases representing active online PLN users for developing professionally in science, are required. Prominent PLN users in education were kind enough to put out a "call out" for more participants on behalf of the researcher to complete the Phase 2 online video interview. Email follow up invitations secured more Phase 2 participants who were purposively sampled and asked to complete the survey prior to their interviews.

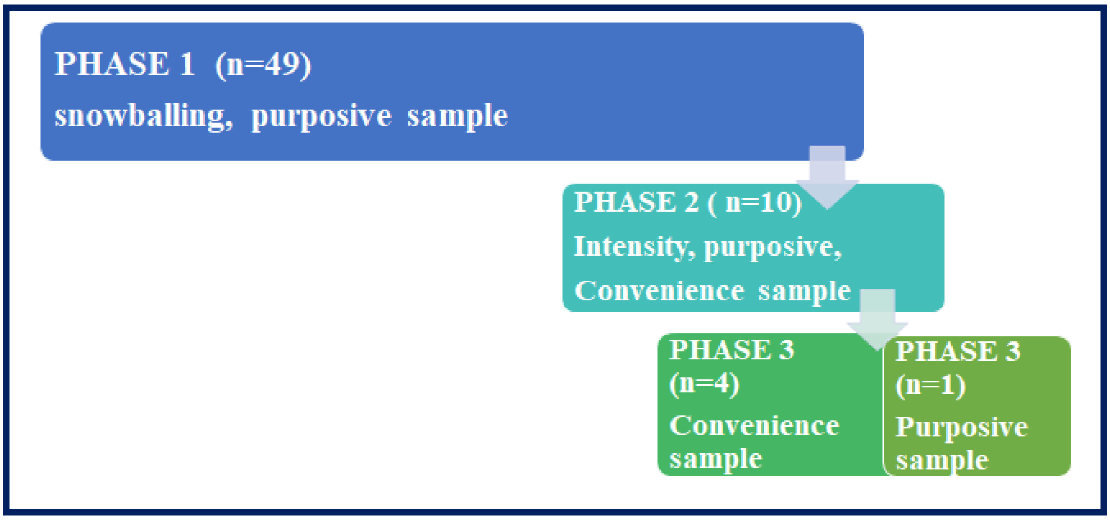


Figure 3.2

Nested sequential sample of participants over 3 phases

The third phase involved a further nested sample of a smaller willing and available group of participants from Stage 2 continuing on for collecting significant online interactions, evaluating one and then a short interview. This sample was a purposive subset from Phase 2 sample (n= 4 primary teachers of science), for convenience and for relevance to emergent theoretical categories based on initial analysis and integration of data from previous 2 phases. A new fifth participant joined just for this final phase of the study. This teacher, invited via social media to join the study following our introduction at another educational research project, was the only Phase 3 participant to be interviewed once.

3.4.1 Background of the participants.

Phase 1 participants. The screening question at the start of the Phase 1 international survey was to establish the participants were all primary school teachers who also taught the subject of science and had an active PLN. Of the participants who responded to the online survey (n=49), the majority (57%) were teachers in Australia, the remaining 43% were international respondents. (see Table 3.1 for detail).

In terms of primary science teaching experience, most of the participants were midcareer (62% in 5-10yrs and 10-20 year categories combined), although early career teachers and teachers with over 20 years of experience were also represented in this sample.

Thirty-three teachers were female and 16 were male. Eighteen percent of participants had a science degree at Bachelor level, 40% of whom had a postgraduate qualification across arts, education, special education, theology, educational leadership and business administration and 45% of whom had studied science to secondary school level with 55% studying science to tertiary level.

Sixty-nine percent were teachers of science for a single classroom of primary aged school students. 31% were primary teachers of science across one grade in primary school and includes those who taught science across primary and secondary school.

Table 3.1

Participant demographics for Phase 1 of this study

Demographic		Frequency (n= */49)	Percent
Gender	Female	33	67 %
	Male	16	32 %
Countries	Australia	28	57 %
	UK	13	26%
	USA	3	6 %
	Albania	1	2 %
	NZ	1	2 %
	Nepal	1	2 %
	Serbia	1	2 %
	Sri Lanka	1	2 %
Stage of career or years spent teaching primary students	0-5 years	10	20.4 %
	5-10 years	17	34.7 %
	10-20 years	14	28.6 %
	20+ years	8	16.3 %
Teacher of K-6 science	Generalist	34	69.4 %
	Specialist	15	30.6 %
Role in teaching primary science	In one K-6 class	34	69 %
	Across several K-6 classes	11	22.4 %
	Across K-6 and secondary classes	4	8.2%
Higher degree	Graduate teaching	49	100 %
	Bachelor level science degree	9	18 %
	Post graduate	20	40 %
Level of science education	Secondary	22	44.9 %
	Tertiary	27	55.1%

Phase 2 participants. Interview participants were eight primary teachers from Australia and two from UK. Some were recruited via Phase 1 as intended and others via a more direct shout out on “Twitter” to encourage more voluntary participants, nine of whom also completed Phase 1 survey and are included in that data prior to being interviewed.

“Specialists” in this study refers to teachers who taught primary science in across one or more grades of primary and secondary school, as participants answered in survey question six. However, each of the Phase 2 interviewees had specialisms of another kind either with extra administration, school leadership roles (lead teacher, deputy principal), technology specialists, or STEM education specialists as well as science and professional development for staff and one was also social media director for the school. None of the participants real names, or places of work are provided, these are pseudonyms to maintain their confidentiality, seen in Table 3.2 as per university HREC ethics participation consent agreement. Some participants tutored pre-service teachers at university in addition to their primary school teaching. For one teacher, Molly, this was a recent transition away from primary school teaching with a view to retirement from school teaching. Some of the teachers interviewed (Archie, Bob, Clark, Natasha, Ruby) mentioned they were also studying higher degrees at university. All participants in Phase 2 exceeded their responsibilities of a generalist primary school teacher and most were STEM and ICT enthusiasts and some led their schools in these learning areas. Teachers were working in a variety of school systems, government and non-government primary schools locally and internationally.

Their responses will need to be considered through this perspective as classroom teachers with extraordinary special interests and roles.

Phase 3 participants. This was a purposive nested sample from Phase 2 with the exception of one participant who volunteered after hearing about the need for more participants while attending a meeting about a different research project. This offer was followed up via social media direct messaging to recruit this participant whose name has been replaced with pseudonym Eloise for this study. Phase 2 and 3 participants are listed in Table 3.1 (* denotes participants who completed all three phases).

Table 3.2

List of Phase 2 & 3 Participants

Phase 2 Participant	Phase 3 Participant	Background of Participant
Angela		Primary teacher learning, technology specialist, NSW, Australia
Archie		Primary teacher, social media and learning enrichment co-ordinator, London, UK
Bob	*	Learning with technology specialist primary teacher, leadership role, NSW, Australia
Charles		Learning with technology specialist primary teacher, NSW, Australia
Clark	*	Primary teacher, STEM specialist, university tutor, NSW, Australia
Jane		Primary teacher, teacher professional development provider, NSW, Australia
Jess		Specialist primary science teacher for schools, teacher professional development provider, UK
Molly	*	Specialist primary science teacher, university tutor in science education, Western Australia
Natasha		Primary teacher, leadership role, NSW, Australia
Ruby	*	Primary teacher, STEM and learning with technology specialist, leadership role, Western Australia
	Eloise	Primary teacher, STEM enthusiast, NSW, Australia

Participants were sent the required paperwork, an information and ethics consent form as per university and HREC requirements (see Appendix A) which they all signed and returned prior to interviews (a second interview for Phase 3 participants). Information of this final phase of the study regarding participant involvement in producing artefacts was sent, and Bob, Clark, Ruby and Molly voluntarily remained for this phase. It was decided to keep the participants local to Australia for the ethical reason that copied excerpts of social media conversations are not permissible in England (where two of the Phase 2 participants were from).

3.5 Data collection methods

3.5.1 Phase 1: International Online Survey

This international online survey elicited responses from participants using closed questions and some demographic items and open-ended question items. The researcher collected these data after an initial pilot study to ensure usefulness of questionnaire instrument in terms of validity and reliability. Participants indicated a willingness to be involved in the study, a strong interest in science education as well as an *active* PLN (defined as more than once a week on more than 1 platform) then completed the survey.

The landing page of the invitation for the survey, included a hyperlinked document of ethics study information and consent, which was deemed given if participant had read this document and proceeded with taking the survey. This ethics form used a university provided template that the researcher modified with specific details for this project. The form met all of the criteria recommended by (Dillman et al, 2014; Callegaro et al. 2015) which requires that invitations should offer basic information of the study, legitimacy, instructions and incentives or motivation. Anonymity was assured for survey respondents. The survey was designed, piloted on a small number of people, amended then distributed across multiple platforms by the researcher for an extended time frame of three and a half months in total.

Development of a Survey Tool. This survey tool went through many drafts in consultation with graduate research staff and supervisor, 2 small pilot phases (one of questions only in offline format and one in an online format), before the final version went to international distribution, for completion by voluntary participants, in a variety of online platforms.

Numerous initial drafts addressed question types, styles, varying length, detail and order of questions, before being piloted. Questions were formulated from: initial observations of relevant online educational spaces, comments made in conversations by colleagues, students and practising teachers, but predominantly questions were predicated upon literature in this field. Literature included: PLN education research, PLN research with specific social media and where possible with a science or primary school focus; online and blended approaches to TPD, general TPD and science focused TPD as well as primary science TPD. Content for the survey items, taken from research-based literature, related to elements of TPD such as developing primary science teaching professional knowledge, inclusive of content knowledge, more specifically pedagogical content knowledge (PCK) and subject matter knowledge (SMK). Further literature indicated the value of PLN use to date, with other teaching and pre-service teaching groups. Item content was formulated in consideration of past findings, including contradictory PLN findings in order that evidence gathered from this study might offer comparison or contrast. The items were structured to ensure some aspect of all 3 research sub-questions were addressed and gaps in the literature were explored. Items were then clustered into a logical progression reflecting PLN initial construction and development, then behaviours and characteristics of interactions, and finally value as self-directed professional development.

Amendments made to survey after initial off-line pilot.

Content Validity. One colleague suggested adding extra platforms based on knowledge of what teachers tend to use from practice and conversations. The provision of-more choices of likely teacher PLN activity on the survey increased content validity. There was also a need to delete a question that appeared repetitive in content. One 'contrary-worded' item designed to discourage agreement prone respondents was removed as it was not considered to be helpful. This version of the survey was 45 items long with a double matrix question layout around platforms and their specific uses.

Another version of the survey was drafted with 35 items, reduced demographic items, and as clear and unambiguous wording as could be managed while remaining grammatically correct. The number of open-ended responses was now minimal to facilitate a more quantitative analysis. Later qualitative phases allowed for further exploration. The items were clustered into a user-based chronology of initial construction and continued use of PLNs; put into groups, based on similar content, appearing as a section on a page. Items were also ordered in such a way as to not pre-empt what participants might want to include in the open- ended items.

For the Likert style items, some text was italicised to denote differences in content. If several consecutive items seemed to be worded similarly "My PLN activities…" then use of italics font emphasised the different content, making it easier for respondents to complete more quickly and effectively. Emphasising essential content in survey items is recommended in Guideline 9.8 by Dillman et al. (2014, p. 349). A critical question, the key open-ended question needed to be rephrased for clarity of meaning.

Face Validity. The software by which it would be accessed by participants meant that some of the items could be re-designed to allow for "piping" and simplify onerous listing items. A screening question was added to the front of the survey to ensure eligibility criteria of teacher of primary/elementary science only and the design was reviewed to ensure participants could access a hotlink, to a study participant information and ethical consent page, before proceeding.

This version of the survey was put into online software, LimeSurvey, and piloted with three primary teachers in Australia, and one in Bhutan 1 of ESL background, which was helpful, as this was intended to be an international study. Other pilot respondents were one university post graduate science student, 2 fellow students also teachers. Subsequent revisions were reworded for more universal understanding and removing "jargon" or more theoretical terminologies.

Amendments made to survey as a result of online pilot version. Pilot survey respondents were emailed a link to complete the questionnaire and invited to provide detailed feedback. The researcher asked pilot respondents to critique items if they were difficult to understand, or needed rewording or, meant something different in their country as recommended by Litwin (2003). When respondents thought there were any order of items or structural anomalies, required additions/deletions or changes, the researcher considered this advice.

A statement about the number of sections in the survey was removed to not overwhelm participants. The double matrix question of platforms and piping to purposes of PLN use was changed for ease of completion. The data lost from that decision was what purpose each specific platform might be most useful for but this was considered a necessary loss given more specific science TPD focus. The question of platform preferences could be followed up in greater detail during online chats in subsequent phases of the study.

One item was again reworded for specificity of actual links over platforms, as pilot data indicated confusion over this. So examples using specific hashtags for Twitter were requested. This enhanced the face and content validity.

Several items were amended to shorten the length of survey, such as removing the early category for number of years a science subject was studied as it is unlikely a teacher could progress in their education with only K-6 science level reached.

The word "focused" was added to the question regarding science association sites. This item actually, remains flawed to this researcher, as it combined science association sites with science teacher association sites but this was deliberate for reducing numbers of items in the survey and so "science-focused" became their descriptor. The intention of this item was to see if more 'formal' science education sites were accessed and for what purpose: content knowledge, or aspects of it such as PCK.

Clustering of some items were reviewed and some adjustment to sections made for internal reliability of conceptual content such as separate sections relating to science content or subject matter knowledge (SMK) and also PCK.

Fine detail revisions resulted in the participant landing page having reduced information and minimal repetition when linked to ethics participant information and consent sheet.

Design Features of Final Survey. The type of questions varies from multiple choice items presented in software as radio lists (10 items in total, includes 2 "yes/no" items), one matrix style question, open-ended responses (2 items in survey), semi-open, offering option of "other" after radio list (6 items) and also Likert type items (9 items) and a possible Likert scale. This variety was purposefully chosen. All items which are Likert-style have 5 point scale with a neutral middle. Some are agreement-based rating from Strongly Disagree through to Strongly Agree; others that are frequency oriented are also 5 point scale from Never to Always and importance rated from Not at all important to Very important. There is a discrepancy where one item has second point on scale of frequency of use as 'Not often' where two other items use 'Rarely'. This was an oversight in editing phase, also the clarity was questionable when "not often" seems very close in English meaning to "sometimes", which represented the third point on scale so preferred term was "rarely". However a benefit of making these scales with accompanying labels was to make responses easier for participants as "Stern found that the fully labelled condition resulted in less time to reply and fewer changes in responses…So it seems that participants clearly prefer labelled options." (Mertens, 2019, p. 204). Page breaks were at appropriate points for ease of completion whatever electronic device was used (e.g. laptop, tablet or phone).

Some branching logic was used on screening question and then to separate science-based PLN user questions from more general use questions.

To enable easier embedding of URL into messaging on social media postings a bit.ly shortening function was used. Please find the design and content features in Appendix B1.

The final version of the survey, used Qualtrics online survey software (as Qualtrics offered some extra layout advantages beyond the piloted version on Lime Survey).

Actual version of Qualtrics survey instrument. For a copy of the final, distributed version of the survey, see Appendix B2.

Validities of final survey.

Face Validity. This was an exploratory survey and so there was not one consistent scale but a variety of items developed to fit with exploring the multi- contextuality and multi-purposed nature of online activities teachers can engage with their PLN's multiple platforms.

Content validity. The content was largely taken from literature and a few items were considered to be covering novel findings in terms of their detail and specificity to this sample of primary science teachers' potential professional development. It was an oversight not to include an item on informal science learning centres and museums, but it was hoped this might be covered by excursion/incursion question item. However the survey was already long and adding another item was not really an option.

Discriminant validity and reliability

An item referring to science and science teacher associations that was thought to relate to both content (SMK) and PCK was not placed in the correct area as was discovered with the preliminary analysis of the first campaign of distribution. It lacked discriminant validity but after consideration it was left in for clarification with a wider number. Had the pilot numbers been larger this would have been picked up earlier as having a better reliability or not, indicating if the item should be moved from content knowledge section and perhaps placed with pedagogical knowledge. Internal homogeneity as described by Fink (2003) was considered to be acceptable. There were consistent responses and clear understanding of the open-ended responses once the wording was revised and this was evident on comparison of pilot and actual survey responses.

Convergent validity

As this was not a survey designed for one scale or set of factors within a scaled instrument such as self-efficacy, there were few calculations made of associations. "Convergent validity evidence can be provided in terms of a measures correlation with other measures with strong validity arguments that assess theoretically related constructs" (Brussow, 2018, p. 388). Some correlations between what is known to be related in literature such as low confidence in teaching science and low content knowledge were explored.

Survey Distribution. The campaign to distribute the survey was a concentrated effort initially to post the advertisement, in primary science teacher relevant online spaces, using multiple platforms. Mainly Twitter and Facebook groups as well as Edmodo were targeted. Numerous emails to some author/researchers with work in this field and academics' contact lists from conferences related to science education were used. Some colleagues were supportive in retweeting the posts and circulating to wider networks as was the researcher's university. One colleague designed an attractive and purposeful graphic to draw attention to this study in social media spaces where instant appeal is important. The hope was for a snowballing effect of teachers across different countries to participate and retweet the advertisement and complete the survey.

Other advertisements were designed by the researcher using free Canva software. Please see Figure 3.3 for examples of these advertisements (more in Appendix C1).

Figure 3.3

Samples of online advertisements for survey recruitment

Advertisement placement was co-ordinated with world clock times for before and after school times to enhance visibility of the study for working teachers.

Platforms were selected for primary education and science education focus and large numbers of followers. Despite being public Facebook groups, there was often a ‘permission to join’ via a moderator question and answer feature to be approved first. Platforms were also chosen for global representation where possible (Twitter handles, names and email recipients are omitted for confidentiality requirements). Twitter spaces were selected with similar criteria and then extended to incorporate hashtags provided by others. Edmodo public groups offered that were relevant related to professional development, elementary school, science and primary school grades were used. Emails requesting assistance from academics to use their relevant networks returned a mix of agreements & rejections. The researcher constructed a website, using WIX software (also suggested by a colleague), featuring a description of the research and providing a live hotlink to the survey which was linked to the researcher’s Twitter account. This enabled a more permanent version of the survey to be accessed during the time it was open.

The original list of connections for distribution expanded with responses and retweets across the differing platforms. Numerous “likes” did not translate into many participants responding to the invitation to keep going into second phase of research. By day 9 the posting had received 3,548 views on 2 Twitter networks where it had been initially posted. The survey advertisement and link postings were still visible on most of the Facebook groups, several of which had a SPAM rule against posting more than once a week. One Facebook group rejected the posting as irrelevant to their relief teacher group, the administrator for that site expressed in a direct message, that the planning and assessment items were not relevant to their “one-hour notice” to teach.

Report of progress on 19/02/2019 showed 16 completes, 2 in progress and 38

attempts for the survey. A third participant replied via email expressing interest in follow up conversation around the survey. This had progressed on 1/03/2019 to 50 attempts, 21 completes, 9 in progress with varying stages of completion (63%, 59%, 7%, 4%, 7%, 59%, 7%, 59%, 7%) and by 24/03/2019, 29 completions. On 6/05/2019 progress report was in all: 125, with 80 finished, 44 completes, 45 unfinished. The campaign of the survey extended to an open timing of 3 and 1/2 months. The final results on 6th June, 2019 was in all: 136, with 49 completions with data cleaning. This gave an overall completed response rate of 36%. This low completed response rate may be due to table style items and open-ended questions being awkward to complete on smart phones, as some researchers report. "Callegaro (2010) noted that breakoff rates for surveys taken on smartphones were 2-3 times higher than for those taken on desktop/ notebook computers." (Callegaro et al. 2015, p. 197). This was also a consideration for not doing seven point scaled survey items as layout on a phone could be problematic and even five point scales may have discouraged completion.

Preliminary analysis of the survey campaign informed the revision of Phase 2 interview questions, initially intended to be focus groups but there were insufficient responses in Phase 1 for that to be possible, necessitating this minor change. This is consistent with advice that the researcher should not only have non-response plans and report on implementations of distributing the survey, but also "fieldwork interventions, eventual changes of plans, etc" (Callegaro et al, 2015, p. 161). So online (1:1) interviews using video conference software were proposed with Zoom for Phase 2.

3.5.2 Phase 2: Online Interviews

Direct requests via Twitter and email were also few in responses. Facebook was also used to circulate an interview invitation. The researcher's website was updated with information to encourage participants to a second phase to sign up via email for a short interview. Email invitations with accompanying Phase 2 participant information and consent forms were sent out for permission to be signed by participants, as required by HREC and university ethics and returned with some participant specified availability for date & time of interview (See Appendix A for participant ethics information and consent form). On receipt of those signed papers, the researcher organised a date & time of mutual convenience for interview. Interview questions were designed to answer all research questions, but particularly sub-question 2, related to the nature and detailed content of interactions in depth, and were reviewed after conducting interview 1.

Participants had the choice of mode for their interview in terms of online or face-to face where applicable (only more local participants, not international) and choice of whether video or audio recording. Zoom software was utilised for recordings. A back up form of recording using a portable voice recorder was also used. The researcher found an audio recording preferable, as sitting very close to the computer to add chat line for the questions gave a distorted view of the researcher's face, which may have not been conducive to relaxed chat for interviewees. Questions were presented on Zoom screen via "Chat" function of software which was intended as thought prompts for interviewees during Zoom interviews and interviewees commented on the usefulness of this multi-modal approach to questioning protocol for helping them to consider and formulate their answers. The Zoom software itself was remarkably reliable with only some small audio/volume glitches on UK interviews. Two interviews were conducted by phone on request of participants.

An interview summary was created for the first interview. This did not seem useful once a more detailed knowledge of each interview was built through reviewing, multiple readings of transcripts and coding was begun to attempt to answer research questions. This decision to omit summaries was made as there were only a small number of interviews while this researcher acknowledges there would be benefit to summarising a larger number of participants' interviews to facilitate analysis.

Interviews were transcribed verbatim by hand by the researcher for all interviews. Memos, interviewer evaluation and queries arising from interviews were documented for further consideration by the researcher and if changes were needed to explore content more fully.

Feedback was sought from the first interviewee regarding interview structure and technique. Useful feedback included more wait time and maintaining the use of written questions as a chat line which were found to be helpful. These suggestions were noted for further interviews. From interview nine onwards the participant responses were indicating saturation as there were no new themes occurring, and similarities in responses to previous interviewees while confirmatory were not adding much detail. Time taken for the ten Phase 2 interviews ranged from 18:37 to 50 minutes with an average time per interview of 34.4 minutes.

Three participants were given a book voucher at the end of this phase (no draw was required, as had been advertised in Phase 1 survey for an incentive to complete the survey).

Design of Phase 2 Interview Schedule. The interview was semi-structured with a set of 14 questions that addressed research questions but were too open and time consuming to be included in the Phase 1 survey. A couple of questions were added based on surprising findings from the survey responses, such as the item on participation as moderator. This emergent question inclusion with consecutive phases is suited to a sequential explanatory MMR where there is interpretive integration at every phase of the research process (Poth, 2018) and each phase informs the content of the next phase of the study as needed.

The interview set of 14 questions could be reduced dependent on participants' previous completion of the survey. Questions were also emergent from participant responses during interviews to follow lines of inquiry that built towards research question content; or to resolve and add clarity to any ambiguities of understanding for participants and also researcher. Also for the purposes of richer, thick data in terms of interesting comments, interviewees were encouraged to elaborate on responses which sometimes compensated for poor sound quality.

Participants asked questions of the researcher either for clarification or out of interest in the content, which also represented an interesting manifestation of what Kvale (2007) calls the "power asymmetry in qualitative research interviews" (p. 14).

The flow and order of the interview questions was amended for all interviews beyond the first interview, after which some changes were made to help with a more natural unfolding of the discussion (see Appendix D1 for interview questions). Time taken for the first interview went beyond that intended. Each subsequent interview had the same questions and order for parity. The improved flow was considered advantageous as the time required for interviews reduced, although the first interviewee was generous with extended responses and expressed no real issue with time taken.

3.5.3 Phase 3: Participant Artefacts and Follow-Up Interview

Participants (n=4), selected from the Phase 2 sample based on their willingness to contribute to this last phase, were sent and asked to sign an ethics information and consent form relevant to this 3rd phase of the study. This phase required participants to collect three interactions, from their online PLN activities which were of significance to their own professional learning online highlighting their professional development (in science). Not all participants returned three examples, some exceeding this and one providing just two significant interaction excerpts.

Interactions could be chat history online conversation excerpts from any platform and indeed multiple platforms, if more than one was used by participants.

Collection technique was open to most convenient choice by participants. Techniques suggested by researcher included copy and pasting from chats, screen videoing relevant conversation excerpts or static screen shots. So a text based format was needed for analysis. These were emailed back to the researcher using image files, word documents including those with participant chosen hyperlinks provided, to flag interactions significant to them as professional development. Others in conversations were redacted as required to maintain confidentiality of non-participants as required in ethics guidelines (UTS HREC, 2014; British Psychological Society, 2013).

Participant artefact: Evaluation Template. An evaluation template was sent for participants to create an artefact describing the professional development value perceived to be attributable to just one of the three conversation/interactions selected.

Participants sent artefacts to the researcher. The template (see Appendix E) provided a meaningful structure for reflective comments and details about the nature, context and content of their self-prioritised significant interaction selection for its value to them professionally. The structure allowed for some parity of response type and yet also allowed for comparisons to be made across participants and for coding of themes from earlier phases in the study or new themes to be more easily identified.

While the template provided to participants was inspired by Wenger et al.'s (2011) community of practice value creation model, it is not the same in structure and content. This is in part because many platforms and interactive spaces/groups within these contexts, may not qualify as goal oriented communities of practice, as many PLN groups have less structure. PLN activities can involve communities of practice but also offer looser and more fluid connections in less formal spaces with transient participation (Trust et al., 2018). There was also the more pragmatic reason of not wishing to overburden participants who are busy primary teachers, with time consuming, complex matrices which had much preliminary work charting within the community of practice and was not the focus of this study. Similar information about teachers' perceptions of value could be elicited in the follow-up interview; using evaluation templates and selected online conversation excerpts as aides de memoire; which in Vygotskian terms "plays an auxiliary role in psychological activity" (Vygotsky, 1978, p. 53). The template used in Phase 3 of the study asked teachers to reflect and account for their selected interactions contributing to any or all of the following: development professionally but at a personal or affective level; professional development generally as a teacher; and professional development as a primary teacher of science, with several category of response suggestions as prompts.

Some changes were required in that not all participants submitted their template and excerpts well in advance of the interview. Two of the five teachers submitted them minutes before which made them only a talking point rather than a memory aid as no significant time had elapsed. The evaluation template did however provide a useful personalised yet formatted content focus for all participants' Phase 3 semi-structured interviews in addition to the structured and tailored question schedule.

Design of Phase 3 Interview Schedule. Questions were semi-structured, open- ended and the first 2 were specifically tailored to each individual based on preliminary analysis of their template content. The one participant who was new to the study at this final phase had an entirely tailored set of questions which included some content from Phase 2 interview schedule and also Phase 3 for better context and to see if themes were recurrent. Questions were based on a need to gain greater understanding of the extent and nature of value teachers perceived from their activities within online PLNs. This included exploring more detailed examples and a broader view of perceptions of the value of PLN use for teachers and employers. Since online PLNs are often informal in nature, it was important to find out the extent to which teachers' use of PLNs are goal driven, for example school priorities and/or teachers' own professional learning goals.

Follow up interviews allowed teachers to express reasons for their selected choices of significant interactions as these were not immediately apparent just from looking at the chat excerpts. The extracts required some re-contextualisation and even translating from the "in- group" abbreviated dialogue of short online interactions. The depth of meaning within these interactions could have been overlooked or missed if reliant purely on researcher interpretation. So the interview was very useful for clarifying the teachers' templates and interaction selections with the participants themselves and understanding the responses.

Questions were anticipated to take 15 minutes to complete this final follow- up interview (see Appendix D2) but participants talking about their artefacts exceeded this time frame. The response time for these Phase 3 interviews ranged from 18:37 minutes to 25 minutes with an average of 23 minutes.

3.6 Data Analysis Methods

3.6.1 Phase 1: International Online Survey

Quantitative methods of analysing each survey item were required since there were multiple item types utilised in the survey design. SPSS software and Excel were utilised for analysis. The reliability was calculated for items. Categorical or nominal variables such as gender and science taught across grades were explored using two way chi square tests; and cross tabs for stage of career and participation role with Likert style items. Purposive sampling meant normal distributions could not be assumed and piloting indicated non-normal distribution with high agreement levels on Likert items. For analysis, Likert type items were considered ordinal items and non-parametric tests were used as it is "unlikely that participants perceive the distances between all of the points along the Likert scale to be equal (e.g., the difference between strongly disagree and disagree is the same as that between neutral and agree), particularly when there are only five response options" (Gracyalny, 2018, p. 1558). Descriptive statistics analysis such as median, mode and frequencies were used and distributions compared.

Some correlations were made where two ordinal variables were explored for associations using Spearman's rho for these items to ascertain if there were relationships of statistical levels of significance at an 0.05 error tolerance for primary teachers' perceptions of value, purposes and ways of interacting within their PLNs for their science professional development.

Some data visualisation techniques such as graphing multiple responses for comparison between groups of agree and strongly agree aggregated responses and different stages of teaching experience were also made to highlight variations that were apparent. An open-ended survey item regarding teachers' perception of ways they were developing professionally through PLN use was analysed both qualitatively for prevailing themes which contributed to thematic structure for later analysis of verbatim themes in Phase 2 interview analysis. The same question was analysed quantitatively. Frequency of words was visualised in a word cloud of the top 20 most frequently recurring words. Thirty teachers answered this open-ended question. Content analysis of word frequency from this open-ended survey item was an example of "quantitizing" the qualitative data (Sammons & Davis, 2017, p. 499) to indicate possible themes.

Piped questions resulted in analysis of several items reflecting smaller sample size of n=38. "Hidden" items for boosting completion rates in making the survey shorter did not seem to affect completion time as had been anticipated.

Mean completion time for survey was 14.8 minutes and prior to reducing number of items and 16.9 minutes afterwards.

3.6.2 Phase 2: Online Interview

Online interviews were qualitatively analysed. It was important that transcription of the interviews was full and this was completed verbatim by hand by the researcher without engaging the use of software except for the recording methods, as there were only a small number of participants and online critique of transcription software was conflicting in recommendations as to its accuracy under all conditions.

As Kvale (2007) states,

> With the heterogeneity of contexts, the issues of translations come into the foreground, such as from oral interviews to written texts, and from private interview conversations to public conversations…Knowledge is interrelational, interwoven in webs of networks…The qualitative interview is a construction site of knowledge (p. 21).

With this knowledge construction comes challenges with decisions regarding coding to be made. Coding of in vivo themes and some from theory was implemented. Other data and recurrent themes not related to research questions were also charted and yielded some surprising findings and concerns or educational issues which are beyond the scope of these research questions. A decision was made to remove the "ums" from the transcripts as there were only few instances that this added to content in terms of designating thinking time and more often broke the meaning of statements once in written format (Roulston, 2013, p. 301). This highlights one of the methodological challenges in maintaining integrity of tone, structure and participant's meaning when transcribing interview data to written formats.

First cycle coding. After transcribing the recorded interviews, some verbatim themes were identified in manual analysis from chunks of interview text. These were both emergent from verbatim in vivo sections of interview transcripts and also based on some a priori theoretical themes from the literature. Themes directly related to research question content around current known findings for benefits and limitations of initiation and ongoing construction of professional PLNs, and teachers' perceptions of the value of their interactions. Value pertained to the nature and extent of the content and quality of their within (online) and beyond (offline) PLN interactions and their perceptions of ways they were developing professionally through use of their PLNs. These themes became the starting point for a second reading and iterative analysis process using coding software NVivo. The result of this process also led to compiling a document identifying the surprising, observed findings and consideration of what may be missing as well as those expected or consistent with literature, recommended in Swaminathan & Mulvihill (2018).

Thematic analysis of interviews required an inductive process of expanding codes (represented as parent and child nodes within NVivo) themes that were emergent from Phase 1 open ended question data. These codes were generated using a mixture of coding techniques. Simultaneous coding was used as many teacher comments had multiple concepts packed into a statement necessitating overlap and multiple codes within a statement. Structural coding (Macqueen et al., 1998), which involved larger chunks of text, related to a research question and used explicit wording of question structure and content, such as "PLN construction", and "participation" was also useful.

Second cycle coding. From the expanded coding, these nodes were then axially coded by clustering nodes that were thematically linked. This process Saldana (2009) describes as "codifying" (p. 8) into more aggregated, condensed hierarchical structure of parent nodes and overarching themes through the inductive process described.

Codifying was also when this pattern finding set of categorised codes was applied to other sources of data such as Phase 3 interviews. The researcher then compiled a document of stronger to weaker themes using Excel.

In addition, comparative analysis was used for the broader perspective of contextual features evident in the interview data through a process "which involves comparing and contrasting data collected from different respondents until no more new themes or issues arise" (Harding, 2019, p. 104). This also allowed for considering relationships within comparisons and contrasts, and between different participant's interviews and the Phase 1 survey which are aims of thematic analysis (Gibson & Brown 2009; Harding, 2019). While constant comparative analysis is typical of grounded theory, it also has value in an MMR approach to explore the differences and similarities between participants' responses within the interviews. An example is participants' different purposes and ways of using and building a PLN. This process served to highlight similarities and differences between individual participants, contradictions and repetition within participants' Phase 1 and 2 interviews and dissonance between Phase 1 and 2 interpretation of findings. This analysis allowed for comparison between qualitative and quantitative data for purposes of integration, highlighting major consistent and recurrent themes as well as nuanced and disparate themes.

Content analysis "where the researcher works systematically through each transcript, looking to see how often certain factors (which are recorded by codes arise)" (Harding, 2019, p. 104). This can result in almost a quantitative style of reporting from the qualitative data as the frequency of main ideas or words re-current in interviews can be counted as they appear in individual interviews and across the set of interviews. This was done using Excel to see strength of themes after NVivo "coding by interview question" which represented a second and third cycle of coding to visualise key themes. The cyclic, imperfect nature of coding and recoding allows for filtering as repeated attention "focuses the salient features of the qualitative data record for generating categories, themes, and concepts, grasping meaning, and/or building theory" (Saldana, 2009, p. 8). NVivo summary by node and source reports were used and queries run for tree diagrams for association of nodes and similarity of coding between cases. This informed further query runs of nodes to explore commonality as well as personalisation (differences) of PLN construction for individual teachers.

This study therefore utilised what Kvale (2007) refers to as a "bricolage" (p. 115) of various differing analytical strategies in order to understand the fullest meaning and perspectives of multiple participants from this qualitative interview data.

3.6.3 Phase 3: Participant Artefacts and Follow Up Interview

Phase 3 interviews were transcribed (verbatim by hand), with memoing and evaluation of interviews from perspective of the researcher completed. Interviews were analysed qualitatively using similar iterative cycles as for Phase 2 interviews, thematic, comparison and content coding considerations were explored using NVivo software (please refer back to Phase 2 for more detail).

Evaluation templates and online chat excerpts contained text and images from some participants and where text information was present these were coded to existing or new nodes. Artefact analysis was through deconstruction in terms of four layers of meaning in their information function, presentation of content, representation and interpretational analysis within their online, informal educational, context (Plowright, 2011). Some content analysis across artefacts was conducted. Images as part of artefacts were only mentioned in terms of what they contributed to aspects of professional development as well as existing themes from earlier phases as full analysis was not feasible in the scope of this thesis.

National Primary Teacher Professional Standards documents from the countries of the majority of participants were reviewed then compared. Documents were read for direct text relating to professional development using online professional learning networks, or where this could theoretically fit with themes through thematic and comparison analysis. This was in response to Phase 1 survey items and Phase 2 interviews which indicated most teachers do not log their informal online professional development hours and teacher perceptions that employers tend not to recognise PLN activities as professional development.

3.7 Limitations

This study presents several limitations which need to be acknowledged, some of which were anticipated before the study began.

The effect of bias when participants will be more acutely aware of their PLN interactions as a result of being researched which may influence data collection. Known as the Hawthorne effect this heightened awareness resulting in changes of behaviour or practice has been recognized in research (Lee, 2000, p. 5).

There is a limitation of data gathered from a changing population within online environments being non-representative for any length of time beyond data collection (Hesse-Biber & Griffin, 2013). This constraint is compounded by the small number of participants purposively sampled reducing representativeness and only those sufficiently interested in science education are likely to volunteer to participate. There was a disappointing lack of international representation despite advertising widely (see section 3.5.1 Survey Distribution for full details of procedures).

The resulting purposive sample meant enthusiastic PLN users would only have replied to participation invitations and were also altruistic to give up time for research.

Only those teachers on the platforms where advertisements were posted or those within email networks would have received invitations to participate. Further the respondents seemed to be quite specialised in their knowledge bases in science and STEM specialists representing quite an elite or niche group of primary teachers.

It was an interesting anomalous situation to note that social media quantitative analytics revealed a disparity between number of advertised study invitation views and number of participants. Data collecting via advertising on social media platforms such as Twitter, Facebook and Edmodo, even email, the number of postings and copies sent, the number of recorded views and likes for various invitations to participate whether for Phase 1 online survey or the Phase 2. interview bore no relationship to the paucity of responses. Views were in the hundreds and yet responses were less than 50 completed surveys and 10 participants for interviews largely recruited by follow up email.

There may have been other more pressing issues around teachers choosing to not use PLNs which were not available due to the sample who did use PLNs. Insufficient antithetical cases could be a limitation, although participants did respond to a question regarding limitations or constraints to themselves/others using PLN as professional development. This also relates to being unable to follow-up on non-respondents for further “anti-case” information that may be pertinent to the study due the online response format of survey and the anonymity provided. The sample was sufficient to produce a few anti-views on the survey and interviews on some aspects of PLN use which were documented in data analysis.

Semi-structured question format and time limitations curtail the extent of the discussion, cross-examination or clarification possible in immediate responses to interviewees' answers in real time.

The survey may have been too long and some unnecessary questions in the background section may have led to survey fatigue before the end which resulted in high number of incompletes. Also the Likert style questions are not very easy to do via mobile phone despite Qualtrics software converting presentation to be more user-friendly, it still could have been annoying for number of questions requiring that style of response. The five point scale on Likert style items was positively received in the pilot, where a seven point scale was not an option for mobile display reason. Within the actual survey structure there was piping, so that participants who did not have favourite science sites in their PLN were excluded from 2 further questions which reduced the sample number for the quantitative analyses of these items from n=49 to n=38 and only n=30 chose to answer the open response. Both of these conditions could limit generalisability.

Time elapsed between some participants doing the survey and then the first interview meant some re-familiarisation with overall content was required.

Phase 3 resulted in four participants doing the follow-up interview plus one new participant. This new participant could also represent a limitation in that they had not completed earlier phases and may not have been as knowledgeable of the research focus, although this was also seen as advantageous to theme exploration and data saturation.

A few minor audio issues with technology for online interviews would have had negligible impact on transcribing and interpreting data.

Limitations pertain to challenges in making accurate analyses of social media images in participant artefacts and chat excerpts. This is particularly true when these images can be liked, retweeted and tagged across various platforms and their context significantly altered in each scenario. It may have been a further limitation to choose not to analyse images which may have contributions to the value of professional development, such as offering models to emulate.

The reality of busy teachers' lives meant that the evaluation template in Phase 3, designed to be a reflective tool and memory aid, was more of an interview discussion point as two teachers only provided these minutes before their interview. This limited the possible tailoring of questions to individual participants but meant content was fresh in minds of participants to readily access and describe to the researcher.

3.8 Summary

Multi-mixed methods gave this study the structure to develop both a broad perspective and in-depth understanding of the many ways that primary teachers perceive PLN activities contribute value for their professional development in science education. Mixed methods are acknowledged as a relevant choice for interpretivist science education research. Mixed methods are purposeful and dynamic; reflective of multiple contexts primary teachers use for learning online, and consistent with assumptions in socio-cultural theories of learning, distributed collective knowledge and constructivist views of science education.

Quantitative and qualitative data were used in this sequential three-phased design. Mixed analyses of data provided realistic, comprehensive ways to answer the research sub-questions. The following chapters present a discussion of integrated findings while acknowledging limitations of this study. The researcher interpreted findings at the conclusion of Phase 2 organised under discussion headings of emergent, conceptual themes from quantitative survey data and qualitative interview data. Further qualitative thematic detail, from Phase 3 participant interviews and artefacts, enhanced theme significance. This last phase of findings was integrated with findings from previous phases to answer the research question. These findings of the value of primary teachers' PLN activities for their professional development in science education, are presented in Chapter 4 and discussed in Chapter 5.

Chapter 4 Integrated Findings

This chapter presents findings of the main research question addressing ways in which primary teachers' PLN activities have value for professional development in science education. Emergent themes are identified through qualitative and quantitative data analysis, to interpret participants' perceptions about initiating a PLN, ongoing construction, and their interactions in PLN contexts, for developing their knowledge of teaching science.

Qualitative analyses in this study include verbatim, thematic and some content analysis, to determine prevalence, and strength of occurrences in the data. Quantitative descriptive statistical analysis of Phase 1 survey data, when integrated with Phase 2 interview qualitative data, indicated major and nuanced themes and associations in the data. Where medians were similar for Likert style survey items, categories were combined to report and highlight differences (e.g. strongly agree and agree categories). Phase 3 qualitative data analyses provided detail, strength and further significance. Analyses involved data from all study sources (online survey, online interviews, participant artefacts and consultation of professional teaching standard documents) and are combined in presentation, and interpretation of findings, as suggested by mixed methods researchers (e.g. Bazeley, 2018; Greene, 2007).

This chapter contains sections with subheadings which include key themes evident in data sources to answer the research sub-questions.

RQ 1. What are the characteristics of primary teachers' initial PLN construction and ongoing PLN management for science teaching professional development?

RQ 2. What are the participatory relationships and details of primary teachers' PLN interactions about science education?

RQ3. What are primary teachers' perceptions of ways their online PLN activities contribute to their science teaching professional development?

Comparisons of this study's findings with literature and other research findings, are only highlighted here. Significance and implications of similar and disparate findings are discussed in the next chapter, Discussion (Chapter 5).

The chapter is organised by themes of participants' use and design of PLNs in this study highlight their purposes, features, and considerations for developing professionally including professional relationships and identity as primary teachers of science. (See methodology chapter, section 3.4 for demographics of these teachers and their pseudonyms to situate the findings).

The main purpose in building an online PLN that participants provided, was seeking professional learning, but not exclusively for science education. Primary teacher participants initiated advice seeking and sharing ‘useable’ professional knowledge of curriculum, content, topic specific, assessment and pedagogical knowledge. Activities connecting across multiple and blended contexts, another theme, was to share, according to some teachers, ‘best practice’, with ‘newness of ideas’ as a very strong theme in the study. Seeking and building science and technology PCK was a prevalent theme as teachers explored ways to effectively implement newer teaching ideas. Participants initiated construction of a PLN for the purpose of improving student interest which appeared as another theme.

Primary teacher participants were decisive about the construction of their PLNs utilising multiple platforms. Refining their use of multiple platforms fit for varied purposes was an identified theme. Attention to blended PLN contexts (offline and online), revealed a theme of PLN use as complementary to, yet distinct from, other forms of science teaching professional development.

Using their PLN for collegial advice and help from accessible, more expert ‘others’ were priorities. Several teachers (Molly, Bob, Ruby) reported building a specific group of expert professionals on whom they could rely for quick responses to advice-driven queries and affirmation. Teachers were mindful of maintaining a suitable professional identity, another theme, evident in their decision-making to participate with individuals within broader networks. These teachers’ participation was contingent on specific factors like content and potential controversy of interactions.

Key themes were general pedagogical knowledge, and science and technology specific PCK, evident in discussions around implementing science content. PCK to a topic specific level was apparent (numerous instances) to a concept level (less often). Another theme recurrent in the study was the realistic depictions of science PCK which teachers appreciated as possible to implement in their own classrooms. In contrast, substantive content or subject matter knowledge was a theme notable for the lack of un-elicited, mentions by participants.

While immediacy of advice and support was reported as an advantage of using PLNs, another theme emerged from teachers also mentioning convenience beyond work hours ~~and~~ with delayed usefulness. Teachers described their ability to reflect on latest science education research readings, resources and PCK accessed, for later use and for revisiting chat histories.

Further themes emerging from the study related to teachers’ time constraints that affected their PLN building, frequency of access, with positive and negative implications for their engagement activities. Selectivity rules, according to relevance, valid and reliable numbers of sources, influenced their PLN construction, relationship and identity building, ensuring time efficient, quality interactions between contacts. The need for improving curation strategies for effective PLN management was another theme.

The primary teacher participants in this study perceived that building and managing a PLN supported their professional learning within multiple online contexts, accessing local and international expert others' advice in enough detail to implement in their own teaching. This newer PCK contributed to perceived value for science education professional development such as developing, refining and refreshing their PCK, CK to a lesser extent, and adapting more general PK.

4.1 Primary Teachers' Purposes in Initiating PLN Construction

Primary teachers constructed a PLN suitable for initiating their inquiries and sharing practice within networks of professionals which allowed for a range of activities and interactions: being mentored; accessing information; building knowledge or offering help and receiving advice about primary education including science and technology. (See table in Appendix F for sample of coding key themes). This study identified ways that primary teachers initially became active in the online community. Survey responses (n=49) showed 69% began their PLNs for self- initiated learning purposes, 4% responded that a PLN was required by their job and also selected self-initiated learning as a reason (see Table 4.1). "Other" category reasons included professional advancement, concerns about spreading incorrect information (mainly about newer teachers' varied science curriculum interpretations) and interest in activities.

Table 4.1

Reasons Why Primary Teacher Respondents Initiated Building a PLN (Phase 1 survey responses, n=49)

Reason for initiating PLN	Frequency	Percent
3 self-initiated professional learning	34	69.4
1 job requirement	5	10.2
1 & 3 job requirement and self-initiated professional learning	4	8.2
3 & 4 self-initiated professional learning and other	2	4.1
4 other	2	4.1
1 & 2 job requirement and tertiary studies	1	2.0
2 & 3 tertiary level studies and self-initiated professional learning	1	2.0
Total	49	100

Figure 4.1 provides a graphic representation which emphasises the small proportion of teachers who initially constructed their online PLN as a result of their tertiary studies requirements. The survey sample demographic had representation from all stages of teaching career.

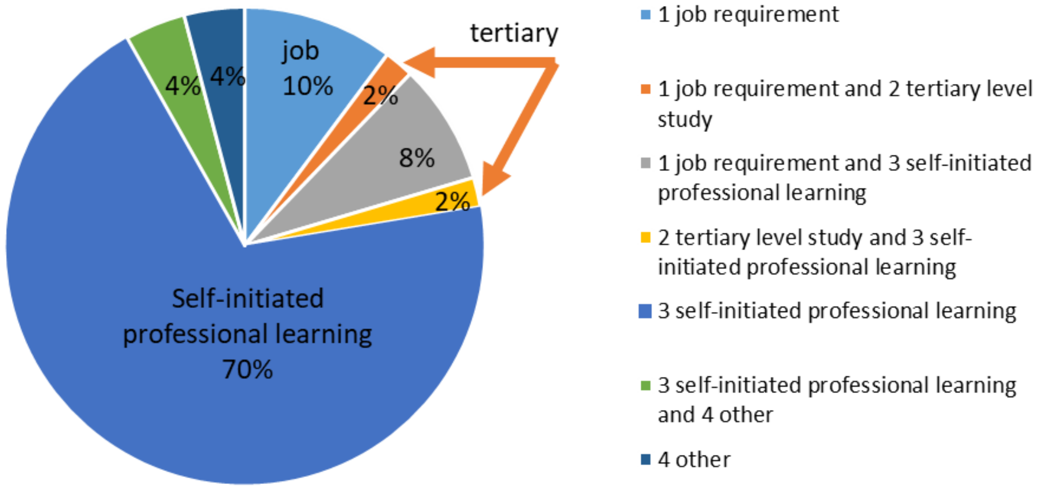


Figure 4.1

Reasons Primary Teacher Respondents Initially Constructed a PLN (Phase 1 survey, n=49)

Only 4% of survey respondents nominated tertiary studies. This group of teachers, represented in Figure 4.1 by orange arrows marked “2%”, were also in the category of 0-5yrs teaching experience. This finding does not correspond to all of the more recently graduated teachers initiating their PLN as part of tertiary studies as that would be 20% of sample (taught 0-5yrs). This could suggest that PLN use is more recent, but not yet widely included in primary teachers' tertiary studies.

Responses to the final question of 'anything else this researcher needed to consider about value of PLNs?' was pertinent. Three teachers advocated lessons or guidance in PLN construction as important to pre-service teacher's professional development. Eloise (Phase 3 participant) pointed out PLN activities were useful for a personalised approach as teachers are at all different levels of development with specific needs. However, surveyed primary teachers showed most importance, according to what they sought from their PLN, was almost unanimously 'new teaching ideas' (94% of teachers, n=49). Other ratings of what teachers sought from their PLNs are shown in Table 4.2. These findings were supported by open item responses from the Phase 1 anonymous survey and Phase 2 interviews.

Table 4.2

What Primary Teachers Were Seeking from Their PLNs (Combining Categories of Important and Very Important Phase 1 survey responses, n=49)

What were you seeking from your PLN?	Median	Percentage of Participants N=49 (Ratings of Important and Very important combined)	Sample quotations From Phase 1 open response survey item
New teaching ideas	5	93.9 %	"It helped me to gain new ideas of same subjects but in very different ways" (Participant 9)
Supportive professionals	4	87.8 %	"Help me with a range of activity ideas. Gives me confidence in my teaching" (Participant 19)
Improved content knowledge	4	85.7 %	"Ability to look up or research in greater depth new materials to try out" (Participant 10)
Expert advice	4	69.4 %	"Getting advice from more knowledgeable colleagues about how to program to meet new syllabus. Practical ideas for how to integrate digital technologies" (Participant 24).

The prevailing strong theme from the Phase 2 interviews differed from the order of importance in the Phase 1 survey as "expert advice" and "conversations with colleagues" in many forms were prioritised in Phase 2 indicating a slight difference in data between phases although themes were similar (Green, 2007) (see section 4.1.2).

4.1.1 Sharing New Ideas in Sufficient Detail for Implementation in the Primary Science Classroom.

Responses to the Phase 1 survey open ended question, asking participants how their PLN activities contributed to professional development as a teacher of science, gave some strong indications of prevalent themes that emerged across all phases of the study. Most frequently occurring responses from the NVivo analysis of this open survey item showed 26 counts of practice ("teaching" and "practice"), 17 references to ideas, seen as a most frequently occurring word in Figure 4.2 top 20 word cloud query. There were 8 references to new, also current and up-to-date; tools and expert advice each had 6 direct references. The next tier of recurrent terms were building network contacts, inspiration, participation, resources and materials, content knowledge, experts and student engagement all with 5 references from this one survey item.

Figure 4.2

Word Cloud of 20 Most Frequent Words, Generated in NVivo in Phase 1 Survey Open-ended Professional Development Item (n=30) Responses.

For the purposes of this study, it was important to unpack what new ideas were comprised of in terms of science content knowledge, or general pedagogical knowledge. The results of a word query search for "New" in NVivo revealed some of the numerous associations for new such as emergent practice, changing nature of science, new digital technologies strand, tools, companies, research, apps, materials and ways of teaching, (see Figure 4.3).

Figure 4.3

Integrated Results from Text Search 'Word Query' of "New" in NVivo for Phases 1 and 2 Data

It was clear new ideas incorporated advice, activities, examples, resources, ways of envisaging and implementing science and STEM teaching. Primary teachers in this study favoured takeaway new ideas, or practical, useable knowledge. 'Takeaway' ideas as 'useable' meant they had immediate, clear relevance or application for the classroom, as can be seen from one teacher's remark; "So it's the ones with clarity and focus I suppose and practical actionable suggestions." (Jess, Phase 2 interview)

For some teachers this would necessitate some repurposing to suit their own needs; sometimes adapting to suit their class cohorts; sometimes changing PK into PCK suited to science, or PCK from another key learning area such as literacy to PK for science. This adaptation or transformative process, a characteristic of PCK, is seen in Natasha's comment: "So I don't really take something exactly how it is but I take ideas from a variety of places and create what works for my class" (Natasha, Phase 2 interview). For others, advice was appreciated if directly useable, with sufficient details provided of required equipment. Teachers valued ways to implement activities with successful outcomes assured, as Angela found in teaching a unit on Properties of Materials for different purposes. Angela adapted a boat floating and sinking activity outlined in a renowned university academic/science education consultant's online postings.

> …and I thought that's great cost effective activity to do with kindies so we did it the following week. You are not (inaudible) by the knowledge but I suppose you could spend hours on Twitter or hours online but when you follow those high quality educators you do get new fresh ideas. (Angela, Phase 2 interview)

The primary teachers in this study chose to engage online with organisations, people and sources with actionable pedagogical content knowledge that was new to them.

Limitations to teachers developing professional knowledge, affected by the quality of their PLN mediated interactions, was a result of mostly insufficient details within the statements posted. At times, platform constraints, such as limited Twitter characters, influenced diminished context or detail for successful implementation of an investigation. Jess made this comment, "particularly on Twitter there's a character constraint so trying to explain things you can get the wrong tone or the wrong end of the stick, but people are usually pretty good at explaining what they're doing" (Jess, Phase 2 interview). Statements, descriptions or explanations online that lacked detail made it more difficult for a teacher to transpose an experiment for her/his own classroom context and student cohort.

> ...so you want short sharp, straight to the point, answers but you want them as detailed as possible so you know references to sites or to links or other resources are helpful that give you what you need I find are the best. (Jane, Phase 2 interview)

The challenge for teachers' online PLN activities is to provide succinct but sufficient information, despite platform constraints, so their advice can be utilised; or provide links, for interested teachers to pursue the idea further, for their own professional development purposes.

Teachers Valued Realistic Depictions of Science PCK. Primary teachers were aware of the potential limitations in shared information found through their PLNs, for example, what may work in a well-resourced glossy lab may not be applicable, or achievable in their own primary teaching context, without significant modifying of ideas and materials. Primary teachers were of the opinion that "lack of what doesn't work" discussions are considered important but were not often represented in PLN contexts. Other teachers in these PLN spaces online were appreciated for sharing their practice but seemed to showcase "perfect" classrooms and what worked in a super resourced "cool lab". This flawless version of reality was seen by study participants as problematic in two ways. Teachers valued relatable classroom scenarios; and understood that not all lessons work perfectly the first time. Reality was preferred rather than 'perfection'. There was concern this misrepresentation could have negative impact on teachers looking for professional knowledge, support and advice.

> It's about understanding the social context, I think some people love sharing the most polished, amazing thing they've done, a bit like those Instagram classrooms where they're perfect, it starts getting a false understanding of what reality is like…we're of sharing the most amazing polished things and we don't often see the mistakes. (Angela, Phase 2 interview)

Teachers built a PLN to find more representative examples of classroom science learning and teaching strategies as Natasha shared, "I find it really handy to get ideas from other teachers who are just teachers in regular classrooms and just sharing some of those experiments that people do in their classrooms…" (Natasha, Phase 2 interview). However in Phase 3 an interviewed teacher spoke of the benefits of being inspired herself and for students and other teachers, who can see showcased student learning online, in order to learn about creative presentation ideas. Eloise perceived:

> …wanting to showcase the students' learning and the effective use was sharing the creativity and using the technology in creative ways. But I suppose since then for me personally not for students has been a way of sharing our learning to others to help other teachers as well as learn

> from others… (Eloise, Phase 3 interview)

Eloise also commented that her initial showcasing of her students' learning in her PLN had transitioned to be more about collective sharing of innovative practice and new teaching ideas for implementing technology authentically.

The mixed media, multimodality possible in online spaces offered varied representations of science pedagogical information, practical advice and support that teachers are keen to find. Chats were often peppered with numerous images, video and still, photos and icons to enhance or showcase student learning to teachers or ways for teachers to extend their practice. Relevant readings (a mix of professional and academic articles and blogs) were linked in posts, and images were used by teachers in comparing their interpretations of pedagogical models such as design thinking and inquiry learning. One teacher, Archie, commented on the need for sufficient detail to implement modelled practices effectively with photos for explication,

> I see some people who are very focused in sharing their ideas, so they will put their ideas in a very specific way and that demonstration with a very comprehensive set of background instructions including resources and other information …they will talk through the steps that are required to use that equipment and show an example of outcomes. (Archie, Phase 2 interview)

In this study images were present in a few Phase 3 participants' artefacts. These images brought diversity, offering primary teachers another rich way of potentially understanding aspects of teaching meaningfully within these online contexts. However, full analysis of the impact of these images would require another thesis devoted to Barthian semiotics, and iconography as outlined in Van Leeuwen (2011), and is recommended as further study direction for future researchers.

4.1.2 Seeking CK and Building Science PCK with Valued Expert Advice.

Primary teachers perceived value in accessing advice and answers to questions of teaching practice from those they considered more expert than themselves. Links to contacts were assessed by teachers as valuable based on their varied definitions of expertise. Experts were considered by participants to be scientists, celebrity scientists, Science and STEM educators, Science and STEM industry professionals. A person with expertise was "experience backed", had "a wealth of experience" or a "raft of experience" behind them, and was "respected in the field" or "world renowned".

Teachers perceived access to these experts, through online PLNs, as democratising. Access to expertise, on a need-to-know basis, was perhaps not usually possible in such convenient and timely ways, another distinctive feature of PLN as professional development opportunities. Access to experts without need for "gatekeeper" obstacles and the weaker theme of inclusivity/exclusivity was evident in all phases of data.

Salmons (2010) refers to this accessibility as 'disintermediation' which also has implications for participatory roles and professional identity. (Refer to discussion of findings, sections 5.21 and 5.22) for more detail.

For Jane links to science experts were a clear priority:

> I think you've got your science experts so having the experts who can give you up to date information and insights is really important because otherwise it's hard to find those so I think that building that community, that network and resources is really important as a primary teacher. (Jane, Phase 2 interview)

Equally for Bob, here he explains unprecedented access to experts through his PLN with impact for his professional development,

> …almost crowd sourcing ideas, crowd sourcing current research being able to connect with researchers who are world renowned sort of thing and ask them questions; something that a classroom teacher face to face would probably not be able to do, but in my network I'm able to reach out to some of the people that we actually would read as educators in books, and ask them questions and they respond.
>
> (Bob, Phase 2 interview)

Accessing research was shared by other teachers and academics, as a feature of expert advice. The wider sample of surveyed teachers supported using their PLN for accessing latest science educational research findings. That 80% (n=49) of primary teachers used their PLN for this purpose was an interesting finding and distinct from more traditional professional development (see Figure 4.4).

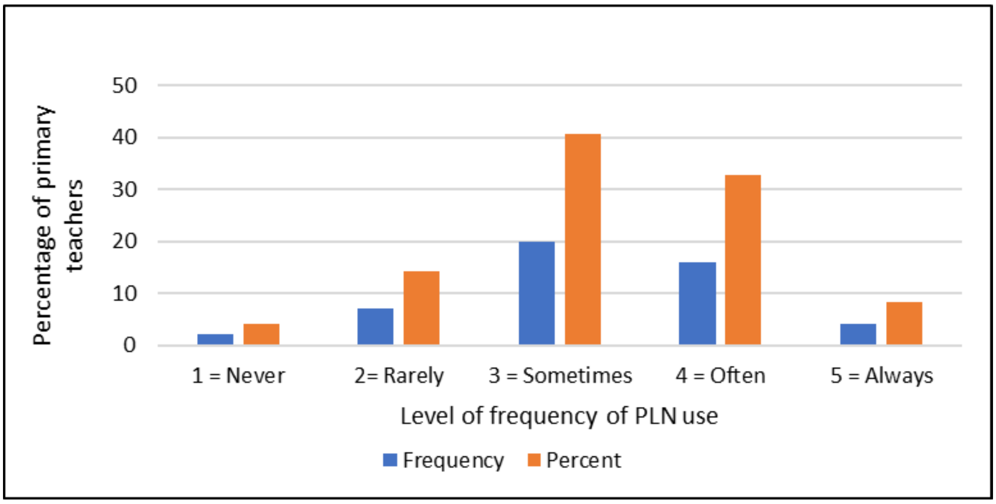


Figure 4.4

Participants' Rating of Frequency for Using Their PLN to Access Latest Science Educational Research Findings (Phase 1 Survey Responses, n=49)

Interview data revealed some teachers used their PLN to access the latest research as an opportunity to upskill, learn new theories, models of practice and develop professionally in a self-directed way and be part of a wider science education network.

> I follow the major universities, that's part of a broader fabric of work. At some of those universities I then follow those academics that might be attached to a particular faculty, particularly the education faculty, and they can be in all sorts of forms so they may be in science and science learning directly or indirectly. So I follow also a number of perhaps if you like theorists and other individuals who are making commentary on science learning. (Charles, Phase 2 interview)

Primary teachers' development of their science content knowledge (SCK or SMK) was rarely discussed in the interviews. This specialised group of teachers stated they were confident in their primary SMK, and searched Google or consulted the primary science curriculum, when feeling the need for content 'top ups'. Some participants from the survey were very science content focused as conveyed by Ruby's comment,

> If you're not covering content, I really don't know what you're doing in science……we obviously want kids to build all those other skills of critical thinking and collaborating and all those skills outside of content learning but I think it's important we still base our teaching on learning the content. (Ruby, Phase 2 interview)

An interesting finding emerged from 2 Likert style survey items about confidence in primary science content knowledge and using a PLN for seeking primary specific science content knowledge. It might have been reasonable to expect that teachers who self-reported feeling less confident in their own science content knowledge might use their PLN to more actively seek content knowledge. However this was not evident. While there was a correlation (depicted by straight line in the scatterplot in Figure 4.5 below) between primary teachers using PLN for content knowledge and earlier item of confidence in primary science content knowledge as seen in Figure 4.5 and Table 4.3, it was not to a level of significance. The result of Spearman's rho test, was a correlation coefficient ρ = 0.169, an asymptotic significance of p=0.245 (two-tailed), n=49.

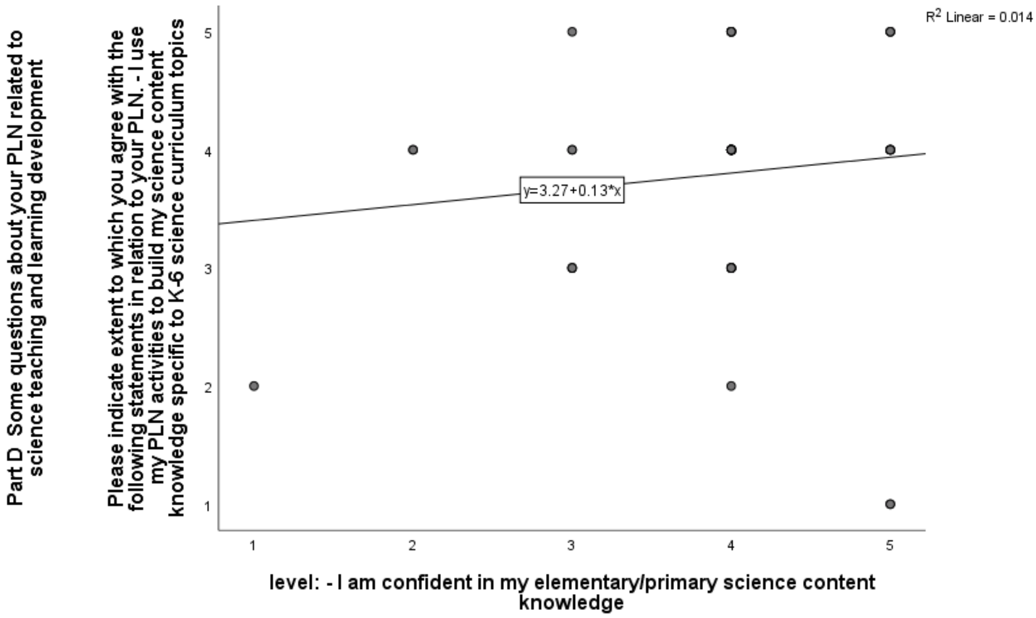


Figure 4.5

Scatterplot Indicating Very Weak (Non-Significant) Relationship Between Confidence in Primary Science Content Knowledge and Using PLN to Build Primary Science Content Knowledge

Table 4.3

Correlations of Survey Items Baseline Confidence in Science Content Knowledge, and Using PLN to Build Primary Science Content Knowledge

Spearman's rho test		I use my PLN activities to build my science content knowledge specific to K-6 science curriculum topics	I am confident in my elementary/primary science content knowledge
I use my PLN activities to build my science content knowledge specific to K-6 science curriculum topics	Correlation Coefficient	1.000	.169
	Sig. (2-tailed)	.	.245
	N	49	49
I am confident in my elementary/primary science content knowledge	Correlation Coefficient	.169	1.000
	Sig. (2-tailed)	.245	.
	N	49	49

Teachers were accessing science content knowledge in other ways, for example, using science and science teaching associations was mentioned in Phase 2 interviews, by two primary teachers from the UK, despite preferring to use their PLNs for developing their pedagogical knowledge. Jess expressed her perception of the benefits of more formal online contexts.

> In this country we have the Association for Science Education (the ASE) and so they have a presence in some of these PLNs as well either individuals or as an organisation and they can be hugely useful and certainly I would engage with those. It's both in terms of resources and content and lots of the pedagogy there as well, they're engaged in lots of research on teaching science so there's new things coming up, ways to present and what we gain from that.
>
> (Jess, Phase 2 interview)

Other participants said that some associations were not sufficiently accessible, often requiring paid membership. Intentional, extension of a PLN was perceived by Bob and Clark to be even more crucial to compensate for lack of access to primary specific science resources.

Responses to survey questions addressing both teachers using their PLNs to access experts for content knowledge and for using science associations, demonstrated 43% (Agree & Strongly Agree, n=49) of surveyed primary teachers agreed to using science and science teacher association sites to build content knowledge (see Table H1 in Appendix H) and also used their PLNs to ask scientist experts to share content knowledge. This percentage was low compared to other survey items. This may suggest misinterpretation of wording in the survey question or as mentioned in the methodology chapter, an issue of researcher's wording of the item. In fact from the interviews and open survey question, teachers' perceived development of their science PCK was a strong theme. Primary teachers seemed to value experts sharing their PCK within a PLN as well as content knowledge.

As can be seen from the teacher's perception below, having a more specialised science-based online PLN is a possible way to develop science content or pedagogical knowledge with the help of expert advice.

> …for example by intentionally connecting with scientists you've got the ability then to bring them into the classroom and have that connection if you just stick with your PLN as a generalist network then unfortunately you don't necessarily have those scientific links so it helps to develop those links both to industry as well as to other educators.
>
> (Bob, Phase 2 interview)

Throughout each phase of this study teachers accorded high value to expert advice, a noticeable feature emerging from the interview transcripts. There is a discrepancy between responses to the survey item addressing using a PLN to access science content knowledge from science content experts, and earlier item responses that suggested teachers were seeking content knowledge and expert advice, shown in the graph below (See Figure 4.6).

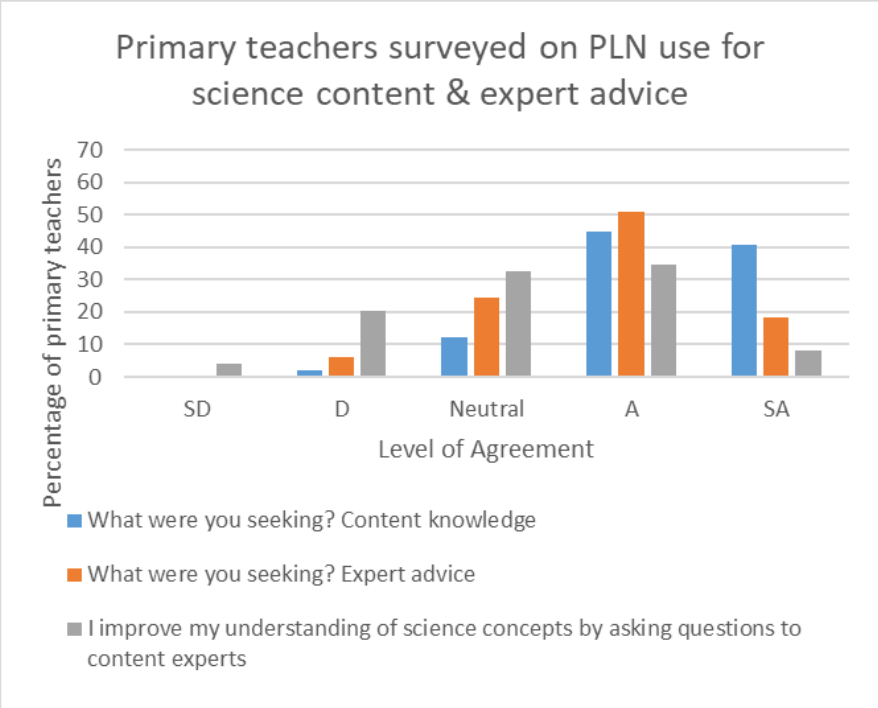


Figure 4.6

Contrast of Using PLN to Seek Content Knowledge and Expert Advice with Using PLNs to Improve Science Concept Knowledge by Asking Experts (Phase 1 Survey Data, n=49)

This discrepancy could perhaps be attributable to primary teachers using expert connections for PCK as well as, or in preference to science content and concepts, or that consulting experts to increase SMK is an under-utilised PLN activity, or primary teachers sought CK in ways other than PLN activities as Eloise described,

> I think it's mainly strategies. Content I sort of draw on other areas but more the different ways of approaching things or different ideas that um could enhance the students' understanding so it might be the process that I might be focusing on or it might be the product.
>
> (Eloise, Phase 3 interview 1)

Participants' reported using their PLN activities which refreshed and refined their epistemic CK, more than the substantive science content. Teachers who perceived the use of their PLN to be relevant to nature of science, did so on the basis of science being an evolving discipline in the world beyond the classroom. However only half (five out of ten primary teachers) considered a PLN to have particular (exclusive) suitability for science education, as the perception was there was also the need for technology focused teacher professional development and PLNs were useful across other disciplines. Teachers perceived PLN use confirmed scientific ways of knowing and thinking or as one teacher phrased it "science as a human endeavour", (often an emphasis in science curricula).

> Science is quite progressive, it's often filled with very enthusiastic individuals who are you know testing, and hypothesising and retesting and I think, the very nature of being online allows that to be further evidence to what's happening. (Charles Phase 2, interview)

> Science is, by virtue of its very being, a forward-looking discipline, rather than looking back at what has come before, so perhaps that makes it especially involved in online PLN at this time. That said, I think other areas are also using online PLN, but I am perhaps less aware of them.
>
> (Jess, Phase 2, offered this in a post interview email)

> …science is based on what is happening right now and so I feel like it gives me access to that whereas if you've got work and a program and basing your teaching on that it might not be up to date with the latest thing that's been happening in space ed. or exploration or things that are happening all around the world so it keeps me up to date if that makes sense.
>
> (Ruby, Phase 2 interview)

For some teachers, PLN use meant they perceived their professional development could keep pace with demands of science being progressive, relevant and future-focused. Testing new PCK and using multiple online contexts such as YouTube, Twitter and websites to support and share newer PCK implementation was described by Clark, similar to other projects globally. His example was an initiative to pilot small robotic drones as part of STEM education and relate their usefulness in remote and farming science applications with children exploring initial coding and capacities of drones to do work.

> We're getting the kids to actually code them in a 3 dimensional plane to actually do simple things in the classroom like navigate an obstacle course, but that's for the purpose of applying that science elsewhere in a real world situation and saying ok, "what can this drone lift?" "What can we do to it's engine power?" "What can we do within its capacity?" Then modify it. (Clark, Phase 3 interview 2)

Gaining advice and help through building online relationships with collegial support from science and STEM industry leaders and educators whether expert or other teachers was valued. Students seeing their science activity as authentically relevant is also important so teachers PCK that promotes this understanding is worthwhile.

Several participants reported similarities between the nature of science and the nature of PLN activities, in the way science progresses quickly amidst knowledgeable debate of shared experimental findings and theorising.

For Molly using a PLN not only strengthened her teaching to ensure the pupils in year 6 were meeting outcomes that would enable them to have a smooth transition to high school.

> And a lot of the questions are about planning investigations, collecting and analysing data and practical components that's probably the thing I probably got most which helped to drive what I'm teaching it also helps to validate that what I'm doing is right.
>
> (Molly, Phase 2 interview)

Discussions with high school teachers online were highlighting the details of the nature of science in terms of science processes that primary teachers need to know in some depth. PCK, the more effective ways to investigate, explore, problem solve or experiment and represent findings appropriately were important for teachers and students.

Several examples of expert co-teaching were mentioned where visiting experts were called on for their science content knowledge or their pedagogical knowledge to add to classroom learning, and also professional development for teachers later in face-to-face mode. All kinds of scientists are readily accessible via online platforms where they have a presence, and the technology for virtual meets has improved in recent years which Ruby appreciated as extending learning opportunities for herself and her students.

> The other thing that I really enjoy for Twitter is I put out a call for scientists who can come and visit so I've made a lot of connections that aren't educators but are scientists and then they've come and worked in the classroom with my students and I with the topic that we're doing at the time. So they all came through from me putting a call out on Twitter so when we were doing a particular topic or when we're looking at anything in particular or women scientists to inspire my girls that's another interaction that's been really useful for me.
>
> (Ruby, Phase 2 interview)

Another example was when a celebrity scientist via Skype assisted a teacher in planning and carrying out of a classroom inquiry project for students' self-selected questions. See section 4.2.3. Potent science learning may be possible when teachers can co-teach with experts, if only for a short time, to better inform their science classroom practice or PCK&S (Gess-Newsome, 2015) or as it is known in the refined consensus model (RCM) as enacted PCK (ePCK) (Carlson & Daehler, 2019).

> The interactions that I mostly have are 'what are leaders in the industry in terms of education doing?' but also leaders in the actual industry doing so 'what are people within science actually working on? That are people working in engineering technology and maths actually working in their daily business?' so then I can have an insight into what to teach children and what they need to be focusing on for their futures. (Clark, Phase 2 interview)

> I like the fact by making links to scientists whether or not they visit, sometimes I've just shown students things on Twitter so when we were doing space and the fact that there were

scientists/astronauts up in the space station who were tweeting, 'cos they're very active on Twitter up there, you know being able to show the kids that there's things happening right now in space and we can tweet at those people and they can respond is another exciting thing so it just helps them see the relevance of science as human endeavour I think.

(Ruby, Phase 2 interview)

Teachers developed PCK that prioritised authentic science learning experiences for their students' learning benefit, appreciate how "real scientists work" and strengthen understanding of the nature of science.

PLN-mediated expert collaboration and advice was also valued by participants; providing inspiration for primary suitable ways to explore science concepts. Experts mentored teachers for depth of required CK, and teaching that richer science knowledge in a way that is understandable and engaging for students. So teachers were developing their PCK at a topic specific level, as shown with this example addressing the science topic of forces,

I use it from a professional development perspective but also from a programming perspective. An example was we're doing stage 3 at the moment in science our focus is a unit in Forces and I wanted to get some really quality examples from the network of teachers I have so I put out the question who's got some really good resources around Rube Goldberg, forces, motion, things like that and sort of within 10 minutes I had at least 8-10 examples that I could tap into. I had Rube Goldberg account themselves reached out themselves and said we have a whole bunch of resources that's available on our website, specifically designed for educators. (Bob, Phase 2 interview)

From Bob's statement there were advantages to enrich his own understanding and teaching strategies for teaching the topic specific content of forces to optimise his primary school students' learning experiences as a direct result of his online PLN.

However an important part of a teacher's PCK in science is understanding primary students possible conceptual misunderstandings as a way to prepare activities that allow naïve conceptual beliefs to be challenged or alternatively to avoid activities that may unintentionally support formation of alternate (other than scientifically accepted) theories. It was therefore interesting that 67% primary teachers (n=49) were in agreement that they were availing themselves of this possibility in using their PLNs (see Figure 4.7). Only 6% of participants were in strong agreement about using their PLN for the purpose of learning more about students' misconceptions in science, yet no examples were provided.

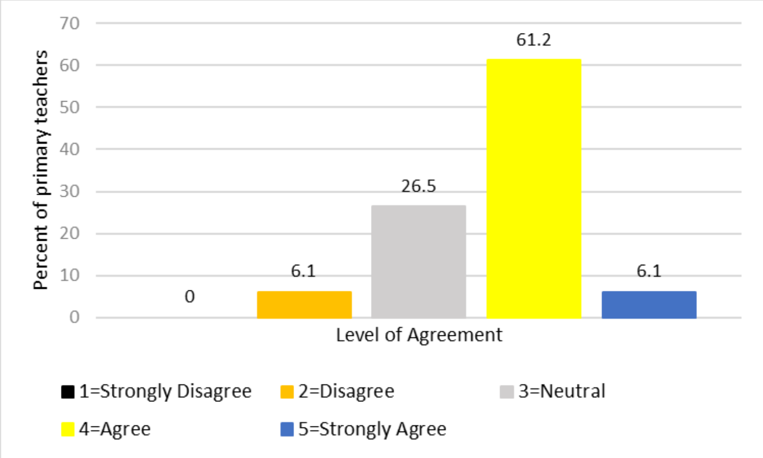


Figure 4.7

Teacher Respondents Surveyed (n=49), Agreement of Using their PLNs to Improve Understanding of Primary Student Misconceptions

Phase 3 artefacts indicated science substantive content knowledge (CK or SMK) was still a minimal part of online activities. Only one out of five participants selected a chat excerpt based on discussion of some science content knowledge. The topic under discussion was nomenclature of magnets. Despite initially being a posted query around terminologies relating to polarity of magnets, the discussion that followed became one of definition and explanation of magnetic versus electrical fields and reasons for the different names. While atypical of the interaction details provided to this researcher, there seems scope to boost these kinds of 'science content clarifying' discussions for primary teachers prior to or during teaching, as queries arise. This widening of substantive content knowledge is discussed in Chapter 5, and as an implication for improved primary science teaching and pre-service teacher education in Chapter 6.

4.1.3 Sourcing and Using New Tools for Newest Science PCK and Teaching.

Primary teachers, regardless of stage of career, were using their PLN activities to learn up-to-date ways of teaching primary science,

> I think I've been teaching for about 13 years now it's more that I'll be looking for new ideas, new ways of thinking that I might not have thought about before so I'm looking for something specific to further my own knowledge, my own skills to do things that I hadn't thought to do before. (Natasha, Phase 2 interview)

This comment from Natasha highlights the usefulness of a PLN for experienced teachers to improve their science PCK and these online spaces should not be perceived as just the domain of one demographic of teachers.

Evolving practice was evident as teachers learned to adapt, adopt and integrate digital tools and technologies, using information available on their PLN. Eloise was using her PLN to contribute to achieving a self-identified professional goal relevant to her teaching and group of students as she shared: “At the moment it’s because of the technology aspect in STEM. I’m looking at ways to meaningfully integrate technology for creative ideas for students to demonstrate their understanding of the science phenomena in a different way.” (Eloise, Phase 3 interview)

Clark provided a recent, meaningfully integrated-content example of primary science and technology online, where he used Twitter to share a kindergarten science lesson integrating coding using mini electronics kits with a unit on living things about plant needs, to “check the moisture levels of the soil to start plotting data on which plants they were planting were more successful. I then took video and photos of that and shared that” (Clark, Phase 3 interview 2). Other teachers then requested advice on how to implement the lesson in greater detail than possible within the Twitter posting. Following up from the online interaction Clark reported that he was able to share his science and technology PCK with teachers in face-to-face modes visiting their classrooms and providing professional development opportunities for them.

Sharing new technology integration practices in science (and STEM) lessons had a high priority for most primary science teachers in this study, as shown in Table 4.4. Participants reported that this focus was in response to newer emphases on digital technologies in science syllabi, and their school’s commitment to implementing more STEM based projects.

Table 4.4

Extent of Primary Teachers’ Agreement to Learning How to Implement New Learning Tools (e.g. Apps) in Science Lessons Through Their PLN Activities (Phase 1, Survey Item, n=49)

Level of agreement	Frequency	Percent
Strongly Disagree	0	0
Disagree	1	2
Neutral	9	18.4
Agree	23	46.9
Strongly Agree	16	32.7
Total	49	100

Some teachers were enthusiastic to be at the forefront of teaching science with technology and learned about it through their PLN,

> … 'hey there's this cool new piece of technology, looks like they're testing some equipment to try and actually get so you can control a piece of hardware with nothing but brainwaves'. Now that sort of caused a bit of a stir and we thought that sounds interesting and a little bit scifi and when I clicked on the link I realised you can actually apply for a development kit and you may actually be able to get one of these things to test out.
>
> (Clark, Phase 3 interview 2)

Clark said after experimenting and evaluating the new AI tool, if his PLN colleagues also found it useful, then the tool would be implemented into primary science. He stated it would be similar to the process that had led to him adapting and introducing the mini electronic bit kits into his classroom, for 'living things' topic, also shared online. Other teachers, Bob and Archie made comments around familiarity with technology as advantageous to being an 'early adopter' of more progressive practices suited to science education.

> I use to very much develop my pedagogy around science and technology ... (mentions specific people/Educators names on Twitter) again from a pedagogy perspective and an encouragement perspective around being innovative in teaching and learning…
>
> (Bob, Phase 2 interview)

Then development of pedagogical knowledge to incorporate more current technology- supported practices is perceived to be a necessary part of teaching development (Schuck et al, 2017; Nochumson, 2020). As Eloise expressed on her Phase 3 evaluation artefact "I do use it (PLN chat) for STEM where I research how technology can be integrated meaningfully". Using an online PLN to be supportive in this professional development goal was not unique to this teacher. Teachers also used their PLN to learn of newer digital tools for archiving their PCK finds (see 4.3.2) but also cognitive tools and pedagogical tools like models of inquiry learning (see 4.2.2).

Engagement with science-based content mediated by PLN use, brought with it a perception of enabling sharing of 'latest' ideas to fit with 'latest' pedagogies.

> I think that I'm seeing relevant and up to date and innovative ideas as they're sort of happening in classrooms around the world. So it's almost opened up my classroom to being almost world-wide because people are so generously sharing what they're doing in science and STEM in particular. (Ruby, Phase 2 interview)

However this same participant voiced a concern that latest teaching ideas online were not always equating to better practice as evidenced by a comment from Ruby,

> I don't love the idea of pre-packaged programs and a lot of people on there are just touting their pre-packaged programs and that is not how I feel is the best way to teach and learn in the

sciences is to have a book and stick to that program. (Ruby, Phase 2 interview)

Teachers were keen to incorporate and adapt activities by competent science educators who generously shared actual rather than pre-formulated experiences. A bonus for busy teachers, they said, was when ideas related particularly to a primary specific learning context. There is scope for a PLN to be useful when planning science lessons, according to the Phase 1 survey item, more than half the teachers (51%) agreed and a further 12% were in strong agreement (see Table H2 in Appendix). The data from Phase 2 elaborated the usefulness of a PLN for planning science and STEM activities.

> …so yes I definitely do look to my Professional Learning Network for ideas in my planning but another thing that's really changed I think since I've been having more of a STEM focus is that I don't tend to plan a whole term of work really in depth ahead. I have a vague idea of where I'm going but I actually like to leave it a bit looser and let the learning kind of take its' own journey, and I think that's been the change that's happened as I've seen the focus on learning being more STEM focused, being more meaningful for the students.
>
> (Ruby, Phase 2 interview)

In this previous remark Ruby is showing a more emergent, evolving practice based on PCK where student interest guides the daily classroom programming and has resulted from learning within her PLN. This has implications for ways teachers are usually required to work with longer term programming documented well in advance of teaching a unit of work.

PCK was not just the knowledge preserve of individual teachers. Participant perceptions expressed during interviews and evidence of sample chats provided in phase 3 indicated a more collective notion of PCK was available to them online. Reciprocity meant that distributed knowledge of science PCK shared in PLN spaces was changing: constrained at times, with potential for improvement, as Jane's Phase 2 interview response was helpful in understanding,

> So I find that you've got to be up-to-date with what's going on everywhere and especially as the curriculum starts to get more involved and people start to understand and use it more efficiently, all of that sort of networking will improve.
>
> (Jane, Phase 2 interview)

Jane's perception here was that the distribution of informed perspectives online would benefit all teachers as the quality of the circulating ideas and collective understandings improved. Please see Discussion of Findings, section 5.2.2.

4.1.4 Improving Teaching for Student Interest in Science Learning

While student outcomes were not a main focus of this study, they are central to professional development as a reason for teachers to improve their practice. "PLN activities give me more understanding of what I am teaching as well as engaging ways to teach my students so they are interested and motivated" (Anonymous participant 28, Phase 1 survey).

Closed item phase 1 survey responses related to reasons for teachers to use PLNs for developing PCK such as "learning ways to improve student interest" rated highly if looking at combined categories of Agree and Strongly Agree with approximately 82% (n=49) of primary teachers represented and no teacher strongly disagreeing (See Table H3 in Appendix).

Primary teachers in this study perceived the importance of broadening their online professional networks was to better prepare 'future-focused' students as Ruby shared:

> Well I think it helped me have a greater focus on things like critical thinking, and co-operation and creativity and those other aspects of what you might call 21st century skills or however you want to package them up because I don't think I focused very much on those prior to broadening. (Ruby, Phase 2 interview)

Furthermore, what teachers learned from their PLN enhanced their knowledge of ways to allow for differentiation for students based on interest and stage of education.

While differentiating learning is of general pedagogical knowledge value it was also related to science education more specifically. As stated in open question response from Phase 1 survey, "Teaching basic science to children with additional support needs (special ed). Using online tools enables me to find motivating, desirable science lessons at the correct level for my children i.e. sensory science" (Anonymous Participant 15, Phase 1 survey). Yet a smaller majority (in comparison to other survey items addressing aspects of science teaching practice), 59% (n=49) of primary teachers were in agreement (Agree & Strongly Agree), that they used their PLN for helping to address diverse learners' needs for differentiated science opportunities (see Table H4 in Appendix).

> I definitely think that without participating in online groups, forums and things I wouldn't have some of the great ideas that I've been able to use in my class, so, just things that you haven't heard of or ways that you haven't thought of and you might never have needed to use that in the past but you have a specific student in your class with a specific need and all of a sudden you have something you otherwise wouldn't have had without the help of other people, so I think that it can also sort of help with their interest and engagement in that there is just new things that are coming out all the time and I can share those with the kids, if it's appropriate. (Natasha, Phase 2 interview)

Primary teacher participants recounted that they integrated their use of PLNs to extend their teachable "moments" in real time, for their students to experience real world links. This represents a different kind of PK from the past where excursions were the closest approximation to this or it may not have been possible to give a realistic representation. Earth and Space is one such topic.

> When you follow those high quality educators you do get new fresh ideas even following something simple like International Space Station on Instagram, they sometimes do live moon (space) walks and last year I was reading some readers with some students who were going, "what's the ISS? International Space Station"… they were fascinated so it's real life connections whether following an organisation or following a person to inspire your teaching that's what I like about the social media side. (Angela, Phase 2 interview)

Student interest and engagement had been highlighted in open question of the survey in Phase 1, Person 16 wrote, "Learning new and interesting and insightful ways to teach science will hopefully increase student engagement in my class." It was useful to consider if all teachers of primary science that is single classroom grade teachers and those who teach primary science across one or multiple grades and/or high school feel similarly about using their PLN for learning ways to promote student interest. A closer look is represented in Figure 4.8.

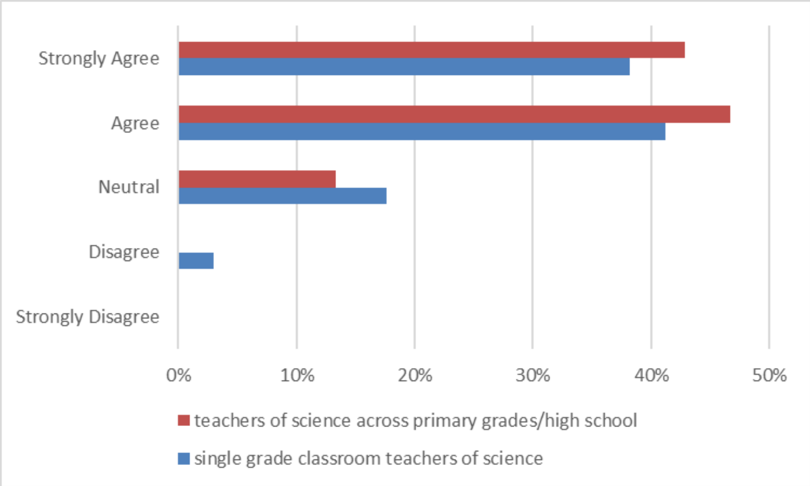


Figure 4.8

Comparison of Single Classroom Primary Teachers' of Science and Primary Teachers' of Science Across One Or More Grades Agreement About Using Their PLNs to Learn Ways to Promote Student Interest in Science (Phase 1 Survey Data, n=49)

The graph shows there is minimal difference of agreement between primary teachers of science whether they taught primary science to a single classroom of students or were teachers of science across multiple grades of primary students, in using their online PLN for improving student interest in science activities. Promoting student interest features as a teaching requirement in the national teaching standards for the majority of participants. Professional standards reviewed held points related to using current resources and integrating technology meaningfully to engage student learning (Australian standard 3.4, AITSL, 2018) and similar to "teachers select instructional resources that relate to their students' interests" (USA Middle Childhood General Teacher Standards, 2012, 2016, p. 29) and "maintain student interest" (UK Teacher Standards, 2011, 2013 p. 11). This seems to be a use of PLNs, seeking ways to promote student interest in science, suited to all teachers of primary science, regardless of science priority in their work position.

Learning about strategies to improve student engagement was also valued by participants as being a possible professional development outcome from using their PLNs as Bob shared during his first interview, "engagement, passion and interest, no I think that's number 1 thing, it's given me greater tools to engage my students and grow ideas to help them beyond what I'm just teaching them on a daily basis sort of thing". (Bob, Phase 2 interview)

> The benefits of the PLN that transfer into my provision are maybe different ways of presenting topics, more easy to get a handle on, people are suggesting different places to go for resources or things that you can use that aid that student engagement.
>
> (Jess, Phase 2 interview)

The readiness of access for teachers to learn professionally at the same time they share their newly developed understandings of skills and content with their students, are distinctive characteristics of online PLN-mediated professional development which mitigate some issues of more traditional, out of classroom, forms of professional development (see discussion 5.3.4).

Summary of Section 4.1

In seeking up to date professional knowledge to refine their teaching skills in science and technology, primary teacher participants used their PLN to access the latest tools, learn of ways to implement them in science; and latest research findings to justify these practices. Expert advice from science and STEM experts, individuals and associations, colleagues, locally and internationally from diverse backgrounds facilitated primary teachers in developing their CK, including their science PCK, as long as sufficient detail was provided. Participants' main purposes in frequently engaging with their PLN was to action these new ideas of science pedagogy, planning and implementing differentiated science lessons for the benefit of their students' interest and improved learning outcomes. Teachers found characteristics of the nature of science in PLN spaces, with the processes of science inquiry highlighted. This affinity allowed teachers to refresh and refine epistemic CK either increasing their confidence in teaching students, or affirming practice. Key features of their participatory roles and the beneficial interactions for developing science PCK are discussed in the next section.

4.2 Key Features of Using a PLN for Developing K-6 Science Teacher Knowledge and Skills

Primary teachers' PLN construction intentionally evolved with individualised and group professional development needs. Beneficial features of refining their PLN; repurposing PCK from other non-science PLN activities and learning from others ways to improve their science teaching practice were key themes. In sharing this teacher knowledge through differing participation roles, primary teachers found their own and their colleagues' professional identity online was influenced and co-constructed as affirming mentors, active inquirers, and progressive teachers. The distinct benefits of using a PLN for individually and collectively relevant professional development are themes discussed in this section 4.2 where teachers found their PLN activities also augmented more traditional forms of TPD.

4.2.1 Multiple Platforms Fit Professional Learning Needs

Platforms were refined based on their usefulness to fit specific purposes such as ease of sharing resources with multimodal visual representations including text, keeping private use separate from professional use and ability to have extended discussions.

The most commonly used platforms by survey respondents ranked highest to lowest were as shown in (see Table 4.5) The three platforms most used by this group of in-service primary teachers (bracketed platform names indicate equal ranking) were Twitter, Facebook, (Google+, YouTube). This is a finding both consistent and contrasting with other research (See discussion of findings, section 5.1.1 for possible importance of these disparate findings).

Table 4.5

The Five Most Popular Platforms in Primary Teachers' PLNs (Phase 1 Survey Data, n=49)

Name of Platform	Frequency
Twitter	28
Facebook	26
Google+, YouTube	20
Blogs, Pinterest	19
Linked In , Instagram	10
Wikis	6
Edmodo	5

Interview data concurred with survey data as Twitter featured for almost all interview participants, with fewer mentions of Facebook for professional purposes. Teachers provided reasons for using multiple separate online platforms and contexts for various purposes, such as concern to keep private and professional online content distinct, as quoted here:

> Well I follow selectively but I also don't mix my media, I use Twitter for work I use Instagram for sport now I don't use anything on Instagram other than sport and nothing other than work on my Twitter channel. So I've got all my channels down. (Clark, Phase 2 interview)

For several teachers, decisions as to the most useful platforms were based on the user capabilities within the platform design, in terms of ease of sharing resources and distributing information.

> …it was more connecting more with alumni rather than connecting with anything to do with my work, rather than an open forum where people can seek me out to share professional concerns, Twitter is a much more active space ...will share our thoughts, dreams, concerns, ideas, and that enables a much more nimble approach ….to sharing our best practice. (Archie, Phase 2 interview)

Multiple platform choice was sometimes guided by perceived limitations or flaws in algorithms and too much advertising product placement. Charles described his view on platform constraint impacts for his professional learning using his PLN:

> It's an interesting space managing your own professional learning because the tools that we utilise are often built with inherent biases, so some of the feed you often see is related to I guess what sits behind that particular app… it leads me to only see certain things that are not at all conducive to what I'm trying to gain out of a professional learning focus.
>
> (Charles, Phase 2 interview)

One participant, in contradiction, saw this as an opportunity to leverage multiple resources from educational technology companies for the benefit of his school and students which was entrepreneurial. Archie shared:

> …the computer science teaching community who are very active on social media as they have access to that technology so again there is interest in using personal learning and it's through the computer science community that I've realised I've been able to establish very lucrative and successful collaboration... a valuable contribution to the school's resources. (Archie, Phase1 interview)

Archie perceived that his school was not as well-resourced as other schools and found his

PLN was useful not only for his own learning but finding ways to resource his students' learning.

Sometimes multiple platforms were reported as too confusing and onerous to manage which prompted some teachers to change their PLN construction, to specificity of platform, fit for purpose. Educational value of contexts varied and even when teachers reported using a single platform for work, they accessed and reported use of other learning contexts from within it, e.g. accessing Seesaw from Twitter. Different groups on Twitter (aggregated by same hashtag #) were constituted of quite different people and communication styles which impacted priorities for what was shared and how frequently content progressed. All of these parameters affected teachers' participation and learning potential for primary science CK and PCK and the extent to which teachers' learning met effective professional development criteria (Darling- Hammond et al, 2017).

Survey results (n=49) indicated that 86% of primary teachers used 2 or more platforms when they started their PLN.

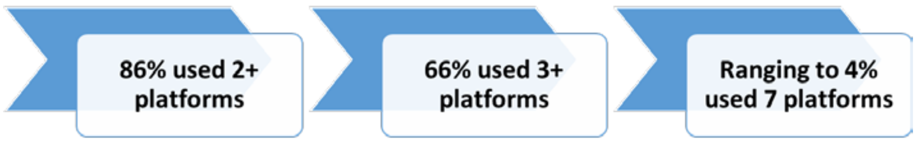


Figure 4.9

Primary Teacher Participants' Use of Multiple Platforms from Phase 1 Survey (n=49).

Due to time constraints, or more personally preferred selections, multiple platforms were refined on the basis of favourite links. Participants' original PLN changed over time and with frequency of use as Ruby described.

> Twitter is my primary tool, I am on Facebook but don't use it very much at all and I used to have an Instagram account that was also education based but I cut that off because I thought I wanted to focus on one thing and do it really well, so Twitter's my jam.
>
> (Ruby, Phase 2 interview)

Science based links and connections pertinent to professional learning, mentioned by participants throughout three phases of this study, were diverse. Favourite links from participant quotations in Phases 1 and 2 included science education centres, websites and video lectures, educational institutions, prominent scientists and science educators, chat groups or fora, other websites, apps, digital tools and media confirming multi-platform contexts.

Teachers Accessed Contexts Beyond School for Enriched Science CK and PCK. Teachers reported enriching their science teaching, and subsequent student learning within the primary classroom context and beyond immediate work places, through PLN activities. Local and global connections were valued, where local contexts were sometimes surprisingly preferred, despite the obvious capability to access expertise from further afield. Phase 3 data showed the usefulness of local links with local schools, teachers in different departments, in an educational/geographical region sharing experiences, ideas, resources and expertise due to similar interests, curriculum and school aligned goals. The following teachers epitomised this proclivity for local context, online communities:

> …a lot of things that are communicated and ideas from other media and decided to discuss them on Twitter. So John (name changed) who has the same job as me but literally has the same job but in a different sector, he shared "hey there's this cool new piece of technology, looks like they're testing some equipment to try and actually get. (Clark, Phase 3 interview)

Local sources of expertise were preferred at times for more immediate contextual similarity in curriculum content. "…they're pretty much up to date with what's going on but then they're also local so its practical as well as informative. (Jane, Phase 2 interview).

A contradictory position was expressed by other teachers (Jess, Ruby, Bob, Charles, Archie) who appreciated advantages of seeking advice beyond local contexts.

> I have a local network of support as well but sometimes you get different opinions different ways of doing things from opening it up wider online PLN and also experience from other parts of the world……you can get very you know bogged down in your region, your local curriculum and sometimes opening it up wider is really useful.
>
> (Jess, Phase 2 interview)
>
> I have also developed new connections with other teachers both nationally and locally who are interested in implementing inquiry learning effectively, and had some direct message conversations with educators who were not at the workshop.
>
> (Ruby, Phase 3 evaluation artefact)

Teachers were accessing their PLN to learn of opportunities for their students beyond the immediate classroom context. The survey finding of 65.3% of primary teachers agreed or strongly agreed (Agree & Strongly Agree categories) with using their PLN to "Promote learning opportunities beyond the classroom, e.g. Class excursions, citizen science projects & field trips" reinforced this purpose in using a PLN (see Table H5 in Appendix). Finding beyond the classroom opportunities, with strong links to science curricula and by experienced providers of this content, were valued as Jane pointed out the purpose of her PLN use was "well to collaborate, to gather ideas, to update your knowledge and to know what else is going on out there, in the world that you can use with you know resources and excursions that you can use with the curriculum." (Jane, Phase 2 interview).

Other ‘working beyond the classroom’ activities reported were sourcing experts for co-teaching, or virtual presence in the classroom.

Phase 2 interviewees spoke to the varied usefulness and quality of information and participants including Charles reported that selective decisions and using a PLN had obvious advantages of their professional learning needs being achieved in ways not otherwise possible.

> I can be connected to a practitioner here locally or globally or I can be attached to a course or if I want to be more rigorous I can draw upon a larger number of academics or maybe experts but I sometimes loathe using that term, but paraprofessionals that are in the field that are doing great things that I wouldn’t ordinarily be able to utilise. (Charles, Phase 2 interview)

PLN activities facilitated professional development by introducing to and supporting teachers in new practice (PCK and skills). Participants’ perceptions were employing these skills led to exceeding required curriculum content outcomes. This was an important finding, supported by examples of primary teachers sharing resources through PLNs, elevating and deepening (hopefully not contradictory terms) learning for students.

The survey result for ‘using PLN for primary topic specific curriculum knowledge’ (n=49) indicated 74% of primary teachers were in agreement (agree and strongly agree combined), that professional knowledge relevant to primary specific context was valuable; strengthened by interview evidence.

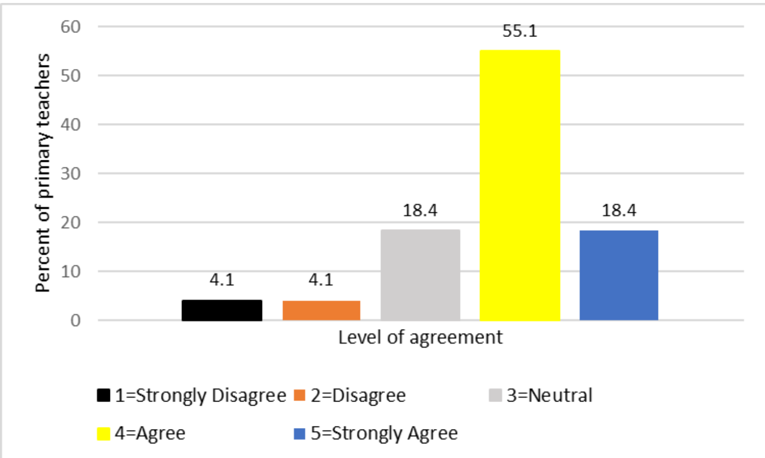


Figure 4.10

Primary Teachers’ Agreement in Using PLN for Primary Specific Curriculum Knowledge (n=49)

Interview data provided examples of direct impact on student learning outcomes, like deeper content knowledge, and learning ways to conduct science enquiries, as PCK of their teachers changed. Two teachers out of five (Phase 3) remarked that their student learning outcomes had taken on value beyond engagement and interest, with the enrichment of content knowledge exceeding curriculum requirements. Jane described,

> You know there is so much new work happening in science everyday that's happening so if there's a new way, new process or idea and presenting it to the children, what that means is then they're able to use their inquiry in a different way because you're able to facilitate that and mentor them through that process. I think that's a really, really important thing to do, yes absolutely do see the benefit with their outcomes.
>
> (Jane, Phase 2 interview)

An example elaborated by Bob was for his students to Skype with another primary school class in New Zealand who were local 'experts' on geology and volcanic activity as their school was situated near volcanoes. Bob's 'beyond the classroom' practice reflected authentic ways of investigating science content. Student learning outcomes benefitted from a more in-depth exploration of the required science curriculum content. This was possible through relationships built up with educators through this teacher's PLN.

> Having my students be able to use my network and discover things from around the globe for example. One of the Skypes yesterday we had a school within 5km away from the base of the active volcanoes in NZ so they were actually able to talk about some of the science around volcanoes and some of the geological sciences and as a result my students have that deeper understanding beyond what the syllabus is because of that connection. (Bob, Phase 2 interview)

Expert contributions of advice or help, from numerous prominent scientists and educators mentioned by name, were in video format, online chat fora or uploaded resources, ideas and links. Teachers credited enhanced science teaching and learning as inspired with online help and advice.

> …so I have used them a lot in the past to draw upon skills and knowledge so that I can incorporate that so children are getting that happening or opportunities to explore things from a real science perspective. (Natasha, Phase 2 interview)

It is noteworthy that many contexts were not science specific; discussions about more general pedagogies were promoted, which primary teachers repurposed for science when suitable. This multiplicity of contexts utilised, has potential repercussions for science teaching discussed in the next chapter (see section 5.1.7).

4.2.2 Adapting General PK, and Other Subject PCK for Science.

General pedagogical knowledge within a PLN can range across all subject domains in primary curricula and was a strong theme. The usefulness of a PLN inclusive and beyond science and technology, to other subjects, would seem to elevate its value for primary teachers.

> …this is not like a special guest comes in once a term if you're lucky and try and make teachers understand that literacy and numeracy like you can teach everything through science, you don't have to just teach your literacy and numeracy as stand-alone siloed subject areas which is the way it's done for the most part. (Clark, Phase 3 Interview 2)

Teachers' perceptions were that general pedagogical knowledge was still useful and could at times be applied to primary science learning. One example was assessment which was mentioned during interviews as having a wider application than the content or subject domain in which it arose.

> I think the general ones are really good when you talk about assessment, that goes across all KLA's when you talk about say play-based learning, play-based learning in all grade, in all KLA's, so all those general conversations can influence any aspect of your teaching not just science. (Angela, Phase 2 interview)

Angela's perception was the value of using a PLN is not siloed with a subject and has important advantages across all primary school learning areas. While a majority with 67% of primary teachers surveyed in agreement (agree and strongly agree categories) that their PLN activities were useful for finding primary science suitable assessment strategies, it is a low statistic comparatively in this study. This could be due to their perceptions of the broader applications of assessment strategies.

Primary teachers used their PLN contacts to support meaningful and differentiated learning experiences across all key learning areas as can be seen in the example from Bob where his knowledge of his students meant he encouraged them to extend their thinking in science using philosophy.

> … other examples have come out of other chats such as Socratic circle, so taking a concept whether it's a scientific or a technological concept but it can also be come from any other subject and it allows the students to have that philosophical discussion.
>
> (Bob, Phase 3 Interview 2)

General pedagogical tools were exemplified in participant provided chat excerpts. Discussion online focused on the usefulness and nature of various educational models for example inquiry based learning.

Beyond general PK, primary teachers used strategies like adapting or repurposing other PCK for science teaching and learning.

> I might see somebody has created something that is a good link with another topic that we

> may be doing. So quite a variety, not so much is content but more the process and the product so there might be a way of doing something or of producing something that I might use.
>
> (Eloise, Phase 3 interview)

An example was reading information texts in English and relating this learning to report writing in science, which has some advantages and limits, please see next chapter for Discussion.

Computational thinking and design thinking were mentioned as part of the primary science and technology syllabus where teachers may be looking for support or inspiration or sharing what works well, as Bob shared,

> So in NSW there's a big push towards computational thinking and around design thinking within our science and technology syllabuses, so a lot of the chats will end up focusing on topics like that, so they're great takeaways that the classroom educator can take away and they also allow the educators to ask questions and seek help.
>
> (Bob, Phase 2 interview)

Teachers were taking these models and adapting them to their specific learners' contexts. This differentiation of student learning was evidenced in Phase 3 PLN significant chat excerpts accompanying participant teacher evaluation artefacts. It was possible to see teachers had simplified or renamed stages in design thinking model and expanded descriptors of stages in the learning process, for the benefit of their students' ease of understanding. Primary teachers shared their versions of the model for ways they scaffolded students' learning with these cognitive tools using their PLN. Collaborative learning in job embedded contexts are prominent in Darling-Hammond et al's (2017) effective professional development criteria (See Discussion Chapter 5).

Teachers in this study were able to provide examples of their teaching that had been strengthened by their time online which meant they could extend a multi-discipline approach to learning with greater confidence and benefit from distributed, collective knowledge and expertise.

> As primary educators my particular role at the school I work for is finding that perfect blend almost. So my kind of official title is academic enrichment, so I'm expected to find rather than these subject silos I will blend history music and maths including history and geography so my pet project is high altitude balloon flight and through that there is so much data and it's so rich in, cutting across so many subjects it's just fantastic.
>
> (Archie, Phase 2 interview)

This participant then followed up with the researcher in an email with that unit of work which involved community links via PLN to local meteorological organisation and geographical organisation to borrow equipment for students to make, test and use to gather data with weather balloon technology.

> If I were to take another example something that has informed my science teaching, a network for mathematics or English where I've engaged in something around how students read texts that might lead to a natural progression of well how does that apply to a science area? How do we take you know vocabulary and apply that when we're reading scientific texts? So there are lots and lots of natural cross –integration that takes place and (inaudible, helped?) by those broader PLNs. (Charles, Phase 2 interview)

The teachers quoted here evidently had positive perceptions of the usefulness of their PLNs from broader parameters than purely science which had flow on effects to enrich the student learning and facilitated cross-curriculum connections. Teachers accessed specialty resources including knowledge of more personalised learning for their students through flexible learning content, tools and apps. This seems to elevate the value of PLN use for primary teachers who teach across the curriculum.

4.2.3 Contingent Participation in Science-Focused PLN spaces

PLN contexts allowed for current issues, for example STEM education and new curriculum requirements, to be discussed. This discussion expanded primary teachers' PLNs and their educational views. Both a synchrony of content and designated synchronous chat times appeared as weaker themes as some teachers were avid about the professional learning benefits when participating regularly. Although two teachers from Phase 2 were yet to participate in these, they commented on their perceived value of "real time" discussions for developing science professional knowledge.

Several data sources contributed to understanding the detail and nature of teachers' PLN-based interactions. An example of summarised coding of emergent themes, from participants' responses to one Phase 2 interview question is shown in Table F2 (Appendix F).

The detailed nature of teachers' interactions varied across platforms, as part of the affordances of that space, with collegial advice and support, as a key theme. Primary teachers' decisions to participate in the PLN roles of observer, moderator and contributor were contingent and situation-specific. Moderators have oversight of certain platform groups or they can be manager/filterer/distributor of threads of chat posted by multiple individuals during synchronous real time online chats. Contextual details of each interaction affected teachers' participation. Teachers shared that their reasoning for participating in online science education chats were influenced by interest in being: mindful of controversy, at times being intentionally avoidant; being helpful to others and; highlighting or refuting misunderstandings.

Reasons for different participation roles. Participants shared some of the reasons behind their participatory choices in their science-focused PLN activities. While several teachers showed enthusiasm for taking on the role of moderator during their PLN activities, as Ruby expressed, "I like being right in the middle, I like that responses are in, like engaging in conversation. You can have a little mini-debate, if you want that; the person is there to come back with a rebuttal" (Ruby, Phase 2 interview), a majority of teachers never took on this participatory role according to both survey and interview data.

Some teachers may have moderated in spaces other than a science specific chat group, maybe a STEM or technology based one.

> I have run group chats before for #AussieEd and another for #PSTchat which is preservice teacher chat. I have to believe in the topic. I have to be somewhat expert; I use the word expert somewhat loosely because if there's something I will like to share and I want to moderate the discussion. (Angela, Phase 2 interview)

Whether primary teachers felt sufficiently expert to be able to moderate on a particular science education topic, or had the time to do so with the added responsibility, also affected uptake of this highly participatory role.

Regularly assuming the role of moderator has a burden of responsibility. This role required devising suitable chat question list; giving help and advice via responses from chats by keeping up with reposting and acknowledging others' contributions, etc. Phase 3 chat excerpt images also indicated the level of time commitment and effort involved in this moderator role. Although collective question building, and pre-voting for suggested questions to evoke discussion during designated chat time, were strategies used at times to distribute this load; collation of questions was part of a moderator role. An example of this was the use of an image posted by a moderator. The image was a static screenshot of the first frame of a colourful video prefacing the upcoming weekly one hour synchronous chat questions, designed to inform teachers who join the chat, before the rapid interchange of ideas. All of these details impacted on primary teachers' willingness to participate more frequently in a moderator role as was clear from Natasha's comment, "I would say "No" because time wise there is just no way I could fit that into my life but I just think the people that moderate these groups I just don't know what they get out of it." (Natasha, Phase 2 interview). Whereas Jane's response accentuated the time constraints as a key factor in her decision not to participate as moderator, "I don't run group chats, I run face-to-face inservicing but I don't run group chats so I prefer to be just observer in group chats mainly for the time factor" (Jane, Phase 2 interview).

Molly, Ruby and Clark reported online spaces had a feeling of inclusivity as a “nonjudgmental”, “risk free zone” to share opinions, which promoted a comfortable space for professional growth. See Table H6 in Appendix for participation roles most frequently used by primary teachers during their PLN activities.

Respectful communication featured as necessary in offering counter opinions.

Themes included, controversial opinions can shut down conversations but other participants made comments suggesting debate may be more likely in this context than face-to-face offline contexts.

Participants observed online ‘critics’, which resulted in concerns about perceived extreme views and decreased willingness to participate or increased avoidance of some interactions and participatory roles due to potential consequences.

> I’m wary of the negative space that those (synchronous chats) can be. You know people offending people with comments or that sort of stuff so I very much will sit back and just look at things subjectively and have a think about what I see and what works for me. But wouldn’t often make comments on things because I’m wary of offence and the way other people can get in online communities. (Natasha, Phase 2 interview)

Natasha offers a counter view to other participants’ “comfortable space” to share comments online. Hesitance to engage in debate however may have negative repercussions for science teaching professional development, in particular where argumentation is a valued skill, as discussed in section 5.

Some teachers noted that obvious competitiveness was an inhibiting factor on their decisions to participate in online spaces which was a surprising finding with repercussions for ongoing PLN management decisions.

> When you’re moderating a chat group, controlling a group of teachers can like, I’m having trouble getting this one across…(inaudible) If there’s a competitive element to that I’m not really interested, I’m more interested in the good work of schools than listening to the soap mentality, ‘at ours we do science like this and ours we do science like that’.
>
> (Charles, Phase 2 interview)

However some interviewees were affected positively by the competitiveness in terms of needing to improve their practice and grow their expert rich networks.

Themes such as reciprocity, participatory roles, inquiring through quick question and answers also in-depth discussion and sharing science PCK were evident. Phase 2 participants used synchronous ‘real time chats’ for the purpose of inquiring and Ruby shared enjoying working within her PLN, engaging in discussion during fast-paced question time, with global experts or beyond immediate staffroom colleagues. Practice- oriented questions during online one hour designated chats were focused and topically specific which teachers appreciated. As Angela commented that designated chat times allowed people to discuss the same subject matter together, which she found useful, and digress into other side conversations on the topic.

> It allows tangents to happen in real time if they need to happen, if people are there and then present it allows connections relationships to occur. So you might start, someone might pipe in and say 'hey I've got knowledge of x, y and z' and you can start that private conversation on the side then and there….so if you've dedicated that time and are having that discussion, it provides a richness that is sort of missing if you go back and read the summary afterwards. (Angela, Phase 2 interview)

For most teachers being a contributor to designated chats offered yet another context where a "shout out" (posting an inquiry online), was valuable for quick responses, as Jess commented, to a more urgent question or gave the option for more sustained conversation which she was not looking for but some participants were in favour of using a PLN for deeper discussion (Bob, Archie).

> I think it's probably a bit of both (referring here to quick Q&A and in-depth questions). I suppose if there's an issue I'm looking for some advice on then I know I can put that question out there and get lots of ideas back. I suppose I probably don't instigate looking for the wider discussion on ideas but I would contribute to it if I felt I had something valuable to add. But in terms of my learning I probably seek out the more direct question rather than a more philosophical debate. (Jess, Phase 2 interview).

The synchronicity of content, referring to the currency of sharing thoughts, research and advice on the same contemporary educational issues represented another theme across all phases of the study.

When teachers took on observer roles, these were not mentioned just as passive or peripheral but presented as being thoughtful and purposeful in reflection. The nature of social media allowed for observing to be professionally useful as one participant stated, "because of the way social media has enabled people to join in the conversation after the conversation has closed, it is still possible to kind of contribute and see other people's contributions to what was said" (Archie, Phase 2 interview). This was another advantage of PLN activities where the usual time constraints of ongoing discussion need not apply.

While Angela's view suggested it lacks the richness of participating at the time, Archie pointed out, later entry to a discussion did not preclude primary teachers from being part of the science educational conversation.

Beneficial, Situation-Specific Interactions. Participants contributed based on: situation-specific evaluations of running threads of postings or; an intention to share their own teaching successes or; forwarding suggestions and links from others. Selectivity registered as quite a strong theme where teachers identified that beneficial interactions for science teaching and learning often resulted in inquiry advice and implementable approaches, strategies and resources relevant to a primary specific context. The content of these interactions were deemed of value to improving their own and inspiring others' practice.

Participation was contingent on usefulness, helpfulness and relevance of shared material as well as richness of conversation through well-developed relationships.

Limitations were around controversy in opinions or content and underutilised possibilities of PLN chats for developing science PCK.

Beneficial interactions for learning about science teaching were based for some teachers on sharing and a concern for encouraging "best" practice, as mentioned by Archie "It's more about promoting best practice in science rather than saying you know 'actually I don't agree with you or your political, social or economic stand'". (Phase 2 interview).

> So I think people sharing best practice and innovative practice but also sharing questions and seeing you know a lot of the time science is about investigations and or what are our thoughts on this or how will we tackle this? And sometimes the not having the answers is just as important as the having them. (Clark, Phase 2 interview)

A strength and confidence in their science and technology curriculum knowledge underlined some teachers' motivations to get involved in PLN interactions.

Another theme that arose from the study was open-mindedness, also mentioned by Oddone et al. (2019), and critique for resources shared.

> I think as an educator you have to be open to different perspectives and your way is not always the correct way or the way that what's happening because science is always evolving and changing so you need to be pretty open minded as a science teacher, and to be honest you find as you go through if you're using the curriculum properly, you're opening the children up to inquiry and their inquiry might not result in answers that you perceive to be correct but the process is what's to say the things they come up with aren't going to change the way things really are so I think I'm pretty open to what people think and try to take on board what's practical , that's just what's worked for me and I'm always respectful of what people might suggest but I don't have to take it on board. (Jane, Phase 2 interview)

> Professionally – I pride myself on being scientifically accurate/well grounded to teach

primary science. Having said that – I am certainly willing to learn and embrace changes or clarifications in the science understanding when they are made known to me – always with the appreciation of the level of Science which we are trying to present to primary school children. (Molly, Phase 3 evaluation artefact)

Participants expressed concern when general PK and science based PCK were represented in online postings and chat in ways that were controversial. This differed to perceptions of contrasting opinions or critical debate which were welcomed by some teachers. An example of situation-specific participation was when misinformation occurred about definitions of terms and restricted ideas of PCK relating to science as part of STEM.

An interviewee provided her thoughts for wanting to contribute to such a discussion:

> I feel that there's a lack of understanding ….so that idea if you're doing digital technologies you're doing coding or if you're doing digital technologies that you're doing STEM,… that if you're doing science you're automatically doing STEM. They're two different things…so people are tagging in STEM chat things that are a pure science experiment. A science experiment all alone just doing the experiment isn't doing STEM so I think …that science is just by default STEM education, I don't agree with. (Ruby, Phase 2 interview).

> For example on Twitter I'm often interested in challenging a particular norm or I guess an assumption about science teaching especially when we talk about STEM and STEAM and STREAM and all the things that've become part of that acronym and particular political agendas that are around are all influences on our schooling I guess, so yes I do make comment there. (Charles, Phase 2 interview)

In contrast, some teachers responded to controversy by avoiding contributions, as Clark described, "Avoid them, everybody's got their opinions on things I don't engage with arguments online if people want to say their view, that's fine" (Clark, Phase 2 interview). And from Archie, "so because I use social media to present a professional identity what I don't want to do is get embroiled in controversies which could be contradictory to my professional identity, representing my school." (Archie, Phase 2 interview)

One teacher gave his anti-case perspective of the perceived limitations for using "real time" chats.

> In terms of following hashtags that kind of thing, I stay well out of it because they tend to become the cesspool of the ill-informed they tend to be people who want their opinion heard not necessarily because their opinion is correct or valid so I've learnt over the years probably to avoid that stuff to be honest, but tends to be not that useful. (Clark, Phase 2 interview).

Value was also limited if perceptions were that motivations were questionable, such as teachers raising their own online profile rather than engaging for sake of reciprocity in sharing ideas, knowledge, experience and questions of practice.

It was noteworthy that while some teachers were intentionally avoidant at times, they were willing to contribute and to get involved in challenging chats for purposes such as helping, educating and updating others. Other reasons included: being unable to refrain from speaking out if ideas were too contrary to their own knowledge of important features, such as progress changes required in science teaching; and concerns for students' learning needs; or just if they found the online ideas too difficult to ignore.

Participants used PLN activities to reciprocally build their own and others' professional knowledge. Concerns were expressed over origins of misinformation and ways it was perpetuated by people, perceived to be 'less than experts' but, who are the leaders of discussion content. "…often the more aggressive users of social media are often the most heard and they may not be accurate or the most informed." (Charles, Phase 2 interview). This may represent a limitation on the advantages of accessing collective "expertise" affecting possible science PCK.

When science interactions are more favourable, PLN use can result in online co- teaching with the benefit of science PCK being shared. An example was an inquiry learning project where students were able to ask for advice on best pathways to investigate their science topic and used the expertise modelled by a scientist to compare their own thoughts for inquiry directions.

> If I were to take you back to a particular learning program maybe about 12 months ago, we engaged directly with Doctor (mentions celebrity scientists' name) in a real phone conversation via a, (Inaudible?) board here in the school and students were able to ask him direct questions related to ah an inquiry question that they were investigating. So he was part of my professional learning network who I had engaged with intermittently online and reached out or the students reached out to him to directly work to gather information, so it was beyond interest, it was beyond engagement, it was more about well if Doctor (mentions name) said this how can we test this here at school, or he's given an answer that doesn't follow this path or can we follow this path. (Charles, Phase 2 interview)

The example, provided by Charles, illustrated the detailed nature of expert relationships to build professional knowledge for teacher and model effective science for student learning. Using effective models of practice; and active learning through collaboration, made possible through online PLN activities, fit Darling-Hammond et al.'s (2017) criteria for effective professional development. Teachers sharing effective models of practice is a benefit of PLN interactions for developing their science teaching professional knowledge.

When PLNs are as disparate and personalised as the individual teachers' interest and professional development needs, synchronous designated chat sessions on science education provided contexts for sharing science PCK.

> This chat helped me to reflect across a variety of topics as the questions were the most engaged with questions from the #primarySTEMChat 2-year history. It allowed me to connect and discuss with the other educators' online pedagogical strategies, to empower learning focused on science and technological teaching.
>
> (Bob, Phase 3 significant interaction evaluation artefact)

Designated chat times facilitated later reflection on archived threads of conversation, often and potential for professional development is evident from Bob's Phase 3 statement. The need for effective management to benefit from later "delayed" usefulness is discussed in section 4.3.2.

4.2.4 Supportive 'Others' Affirmed Science Teaching and Co-constructed Professional Identity

Another perceived benefit of PLN use that teacher participants mentioned was affirmation of their teaching practice. Participants accessed ongoing support from other teachers and supportive professionals through their online PLNs, for instance during implementation of newer ideas of science practices in the primary classroom, from other teachers and supportive professionals in their networks. Angela commented, "...it was also affirming that when we tweeted out something that someone goes I agree with that, that's a good idea if you put it that way and it's someone else who is respected in the field." (Angela, Phase 2 interview). For other teachers such as Molly, it was reassuring of her current practice, appropriate to grade 6 primary school students, were affirmed by colleagues online.

> …it probably doesn't change what I'm doing, I'm doing it with confidence and students are getting the right skill set from me so it's probably more the validation for me that I'm still on target, I'm teaching graphing the right way or whatever and it validates what I'm doing. It probably hasn't changed the student learning, it probably has given me confidence that what I'm doing is right. (Molly, Phase 2 interview).

For Archie, it was sharing in the daily joys and tribulations of the teaching day likening the collegiality in his PLN interactions to an extended staffroom that offered affirmation to him.

> One # (hashtag) I regularly follow is 5 o'clock morning club where we are all recognising each others' efforts and labours essentially, it is more of a support network rather than a group of people who are actively sharing resources, occasionally you will have people saying I've

> had a great day today because I did this with my class, great way of just broadening the staffroom. (Archie, Phase 2 interview).

The perceptions of teachers interviewed regardless of their own science/science education background was positive about the supportive collegial benefits of affirmation, validation available through their PLN.

> For the most part being able to put that out there appeases many individuals 'I'm a good teacher and I know why' and having that confirmed whether that's a like or a love heart or a retweet, that immediate reinforcement I think helps our beginning teachers in particular, yeah. (Charles, Phase 2 interview)

These teacher endorsements that using their PLN can affect teacher confidence in teaching primary science enhances the survey result which indicated a majority of participants (47% agreed, an additional 39% were in strong agreement, n=49) with feeling greater confidence in teaching science when using their PLN to learn something new (see Table H7, Appendix H). While this was the highest level of agreement on the survey, confidence was not as strongly represented in later phases, perhaps because interviewees were already confident in their science teaching knowledge. There was a perception of comfort as Molly expressed in feeling more confident and reassured from using a PLN to ensure that her science pedagogical and content knowledge is current and reliable.

The participants were using their PLNs to develop their professional profiles, in addition to building their science professional knowledge base, through seeking expert and collegial advice. Participants' comments reflected ways sharing indirectly raised their own professional profiles and identity was co-constructed through other teachers' contributions within online interactions representing nuanced themes. As other teachers asked them for help and advice, in answering these posts, participant teachers' identity was being shaped to some extent by being part of the interaction, as we can see from Jess' comment:

> … at times I try to cultivate that network by answering other peoples' questions to maintain my presence and my experience so I might be a person that they know they can come to and ask for support as well. (Jess, Phase 2 interview)

Some teachers wanted to be mentors in their PLN groups and communities. This development is through self- and co-regulated learning processes (Hadwin et al., 2011). For less experienced teachers of science as Jess spoke of her willingness to share teaching experience and specialist knowledge in primary school science.

The frequency with which teachers engaged online with posts and interactions also served to build their online profile as active learners and progressive science teachers of newer practice. It is important to note this was not teachers' central focus. Priorities were their own and others' professional learning, development leading to improving student learning experiences and outcomes.

> I'm also connected to the Royal Society again another learned institute which I think prides itself on having been the oldest learning institutes for promoting teaching and learning and research in science. And because of those kind of physical organisations that exist, one becomes kind of connected through their social media or personal learning networks and then say actually apart from our membership we'd like you to be active on our social media promoting our core values almost. So there's that kind of shared identity.
>
> (Archie, Phase 2 interview)

Archie describes this co-construction of professional identity through his PLN activities which added value while he developed his proficiency as a teacher of science.

Teachers were intentional in deciding whom to include in their networks and into which groups to be included offering another theme of inclusivity which featured. Selectivity in building a PLN and participatory decisions affected ongoing PLN construction and could also impact online profile as one teacher remarked, " the more you put out there the more it influences the way you are known…" (Charles, Phase 2 interview)

Competitiveness, a nuanced theme, was related to the theme of professional identity with participants expressing a dislike for self-promotional aspects of PLNs, for instance the boasting of teaching successes, when the foci of their PLNs were perceived to be for improving student learning outcomes as Jane pointed out.

> I think…we need to be careful what our PLN is for,… because as an educator our primary focus must always be the children so whatever we are able to do it can only be great if the children benefit from it and their success is greater as a result of it. So I think I don't have time to listen to people to blow their own trumpets, I'm happy to hear about what their successes might be but at the end of the day as a teacher your success is what your children are able to achieve, what inquiries they come up with what theories, how well can they do the processing and really support their findings and justify them. (Jane, Phase 2 interview)

For other participants, competitiveness in their PLNs inspired them to upgrade, refine and share their own development progress with examples of teaching science in newer ways, constructing a professional identity as progressive, as Charles related,"… But what I find now is we are far more exposed through professional learning networks to challenge each other and to go out and have a look at what someone else is doing…"(Charles, Phase 2 interview).

Teacher participants' online profile was not a top priority but did rate as an ongoing consideration in PLN construction and management where professional development was valued both as self-initiated as well as required activity.

4.2.5 Distinctive Personalised TPD Complemented Other Forms of TPD

A nuanced theme from interviews was that access to professional online learning complemented other forms of teacher professional development, offering multiple blended contexts (discussed sections 5.1.1 and 5.3.4). Blended contexts were available through Teach meets, conferences and webinars with face to face or "virtual face to face" interactions. Later online discussions kept conference ideas circulating. Another participant mentioned it was often easier to network in face-to-face contexts once online relationships were established. Reflection on the value of using a PLN in these situations was in personalisation of self-directed choices, which was a moderate theme. Some teachers perceived this form of professional development as useful as face-to-face PD with time convenience and satisfaction of quality interactions also emerged as a recurrent theme.

There is strong agreement that primary teachers' PLN activities have value as professional development even when compared with more traditional professional development in offline face-to-face contexts, Anonymous participant 12 in Phase 1 survey open question 13, stated, "Seeing ideas from Twitter in action by teachers in the classroom, with a whole class, inspires me to give it a try. Having a person who used to be a teacher tell me how to do something from a whiteboard is not always as inspirational."

From the survey question asking for participants to rate their agreement that using their PLN for primary science professional development was as useful as face-to-face professional development, it is possible to see in Table 4.6 that 75% of these primary teachers were in agreement with this statement (agree and strongly agree combined).

Table 4.6

Primary Teachers' Perceptions of Using PLN for Science Professional Development as Useful as Face To Face PD (From Phase 1 Survey, n=49)

Level of agreement	Frequency	Percent
Strongly Disagree	1	2.0
Disagree	5	10.2
Neutral	6	12.2
Agree	27	55.1
Strongly Agree	10	6.1
Total	49	100

Participants' perceptions that PLN activities were useful compared with face-to- face (in person) teacher professional development, was unusual as primary science involves hands-on, equipment-based learning.

> I think PD these days unless you're doing system-based it's so expensive for quality PD you only really get the view of the presenter and the people who are there and sometimes it's very dry PD where you sit down all day and just think content whatever and hours of people talking so I think it allows conversations to happen. It allows people from different geographical areas to come together and it allows different perspectives. (Angela, Phase 2 interview)

Although these teachers have already opted for alternative PD being online, this finding is not entirely consistent with other research where face-to-face modes were first preference (NESA professional learning report, 2017).

A theme from Phase 3 which enhanced earlier phase findings, was that online PLN interactions complement, and are often the precursor, to face to face professional development according to Angela, Bob, Clark and Ruby.

> I'm quite happy to contribute, ask questions, you know help people out, and say to people on Facebook just message me or ring me so we can talk about it rather than keep putting it up on this Facebook or something cos it's too hard to keep typing in things all the time because you, there's often so much to say that I'll often say if you want to chat then ring and we'll talk. (Molly, Phase 2 interview)

An example explained, was an inquiry mindset presenter was invited and sponsored to present workshops by several online educators who were enthusiastic to learn about this. Another example of PLN advantages in blended contexts (formal/informal) came from Bob,

> Other things I'm involved with regarding that is, a lot of the Google webinars so they're at a particular private webinars that Google for education run, are related to science and technology education and external from, it is technology, it is also face to face…so it has that online component so it's also not just forum based networking. (Bob, Phase 2 interview)

There was also the bonus capability of following up from face-to- face professional development workshops with online discussion and resource sharing, mentioned by several teachers (Jane, Molly, Clark, Ruby, Eloise). Eloise provided an example of learning about and participating as a school in "The Big Day In" conducted at UTS. This event is for school students to participate in STEM activities with academics and their teachers which then led to teachers' online STEM discussions among involved, interested school teachers. Online PLN activities perpetuated student and teacher co-development at more formally provided workshops. Continuity online, provided ongoing professional development support for primary teachers, who built relationships and widened their networks about science within a STEM context.

The benefit of using PLN for building relationships within wider networks of professionals, immediate access to experts, was a strong theme (see previous section 4.1.2),"So it seems a very powerful way of being engaged with other educators…" (Archie, Phase 2 interview).

Using a PLN was perceived as valuable for teachers who have not specialised in a science. Some primary teachers were perhaps drawing on limited science education experience from their own educational background as just over half of surveyed teachers (55%, n=49) had studied a science subject to tertiary level (see participant demographics, section 3.4.1). Alternatively, teacher participants felt their previous science education was more historic than current and PLN activities offered meaningful ways to develop up-to-date practices.

> …for myself part of that development process has been directly attributed to what I've learned in my PLN but also having that reflective nature and going I want to be better as a professional. I can't just rely on experience so to speak and my 4 years training, I've got to go 'how can I leverage a larger body of understanding to make my practice the most have the highest efficacy for my students?' (Bob, Phase 3 interview).

Bob expressed here the value he placed on his PLN activities for his own professional development, refining his teaching to improve student learning outcomes.

Several teachers expressed an appreciation of how advantageous it could be to articulate and share pedagogy, where using their PLN had "really broken down barriers around what's happening in neighbouring schools where as once upon a time a community school was just responsible to its community we're now more prominent as part of a broader education fabric." (Charles, Phase 2 interview)

> …you've got to engage in the profession outside of the four walls of your classroom and outside of your school environment…. If you're not engaging with other people then you're only arguing or consolidating things you already know, stepping outside your comfort zone, talk to people around the world, global people to extend your knowledge.
>
> (Clark, Phase 2 interview)

Clark's position makes valuing of blended PLN contexts into teachers' daily activities of broader professional learning as integral to his personal best teaching.

Seeing specialists' contribute and post their own questions, exemplified by Molly, a science specialist teacher, could empower other teachers to share their science understandings and learn where to get advice.

> I had initially asked a few primary Science teachers (directly not online) and received mixed points of view about the terminology. That is why I looked online in ACARA and then when I could not find what I needed, I went to a high school online group for clarification. (Molly, Phase 3 significant interaction evaluation artefact)

This wider engagement is so readily possible within a PLN making it quite distinctive an advantage over other forms of professional development as is frequency of access and convenience. Teachers ranged from sporadic use to frequently using their PLN throughout the day.

> I would say it's sporadic, mostly you come across a hiccup or hurdle or you want some advice on something, so maybe planning or reflecting back on something that's not gone so well, try something and assessment as well, different ways of assessing, definitely not using it all of the time but it's there for support. (Jess, Phase 2 interview)

> I use professional learning networks every single day, we use as a team a combination of Adobe connect, Microsoft Teams, some Google applications and Twitter to communicate with each other as a team. (Clark, Phase 2 interview)

Angela stated during interviews that multiple blended contexts, whether local, beyond immediate, face to face or online, enabled time efficient sharing of teaching practices.

> Now I might use it, I tweet at conferences if there's something interesting. I use it to share practice, I use it to search for better practices or to identify practices where I go 'oh that's interesting' I'm going to share that or retweet that, keep up to date with sometimes the literature because someone might have read something I've missed, I'll think 'oh great, and I'll put it to one side, and I'll read it' also use it to organise face to face networking… (Angela, Phase 2 interview)

All of those interviewed had other roles to fulfil within their schools so quality of time spent using their PLNs for science professional development mattered. When the majority of primary teachers surveyed are using their PLN for building their science knowledge base, and according to data from this survey item (n=49) Agree and Strongly Agree = 34, or 69% of primary teachers agreed, it is important that they are satisfied with both the time they spend online in these professional development activities and the quality of their interactions. Survey results give another indicator, as can be seen from this moderately skewed distribution (-0.507) with 73% in agreement overall they were content with the quality of their science-based PLN interactions, and no-one strongly disagreeing despite limitations discussed (see Figure 4.11).

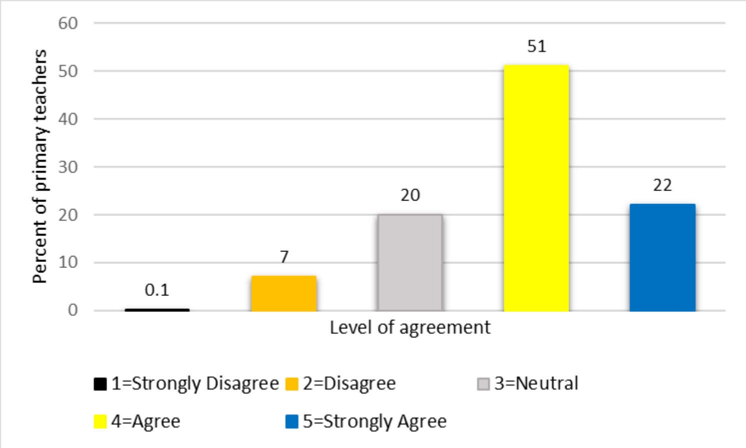


Figure 4.11

Primary Teachers' Level of Agreement on Quality Satisfaction With Science-Based PLN Interactions (Phase 1 survey, n=49)

This was satisfaction with interaction quality was further substantiated during participant interviews.

> No I think that people do a lovely job I love that people share so much and I think that's the way you make the world go around and make everyone a better teacher not everything works for everyone and not everything works for every student...
>
> (Natasha, Phase 2 interview)

In her Phase 2 interview Jess explained that "…there's also a number of individuals who have great subject content knowledge but also the pedagogy that goes alongside it so it's always great to learn from them actually, and their personal experiences." (Jess, Phase 2 interview) There is a richness to the diversity of activities within online PLNs for professional development that can be actively shared. "I now use a web site (Explorify) that developed my questioning skills throughout both Key Stages enabling pupils to develop their thinking" (Anonymous participant 17, Phase 1survey). Primary teacher participants' discussion online developed primary specific contextualised science content knowledge and PCK, not just tips and resources.

Primary teacher satisfaction with quality of the professional development has long been a concern for face to face, provided professional development sessions as Charles explains his reasoning.

> One of the things that I find quite interesting in the space is that traditional professional development was usually one person or small teams of people who stood and delivered content….. it might have been powerful but the engagement of the participant was quite you know traditional fairly sedentary, lecture style, really not an opportunity to take away too much other than, mmm that's interesting, maybe I'll go away and read about that, maybe I will try and implement this back at my school…(Charles, Phase 2 interview)

Reciprocity and ongoing support during implementing changes of teaching approaches or skills are harder to achieve in more traditional, sedentary, presenter-as- expert, style of professional development sessions as noted by Charles. Some reported online PLN activities instigated as well as supported their science teaching professional development, a distinct advantage of the multiple contexts which are characteristic of this online format.

While teachers referred to it as “managing” their own learning, their perceptions indicated greater agency over the process and content than might be possible in a more usual ‘provided’ teacher professional development session, as Natasha shared,

> It’s good to have fresh ideas fresh ways of looking at things so convenient that I can access it whenever I want to it’s not as formal as sort of courses and sites. You can just get bit and pieces and collaborate in a more informal kind of way. (Natasha, Phase 2 interview).

So having a PLN can allow for more highly participatory professional development, as required and not just at designated times as typical of a more traditional approach.

Teachers Rated the Importance of Personalised PLNs for Reflective, Self-directed TPD. Primary science teachers’ perception of the importance of self- initiating shared inquiry and answers, within an online network, was very strong with 86% agreement (agree and strongly agree categories combined). Most notable also is not one teacher in the study disagreed or strongly disagreed with the statement, that self- directing PLN activities is regarded as important for teacher professional development, 14% rated this item neutral (see Appendix H8).

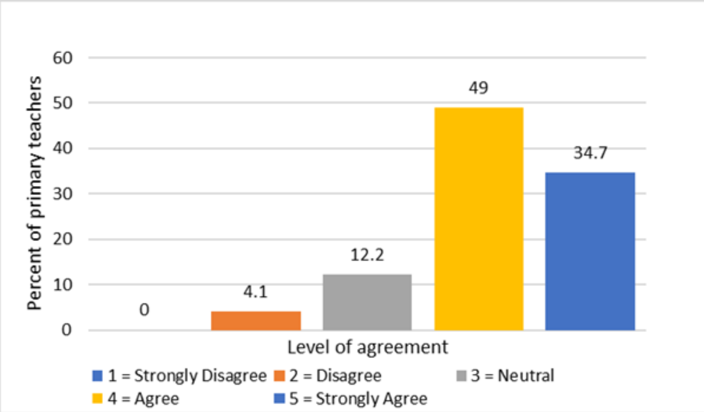
Teachers’ enthusiasm at newness and possibilities and personalisation of PLN activities was based on their own professional development goals.

> …it (PLN) allows me to go beyond what is given so to speak into what I want to study what I want to go deeper into and so it gives me access to some of the top researchers that are out there who are looking at the best practices and I can ask them questions and I get responses or I get feedback back from them. (Bob, Phase 3 interview 2)

It allowed reflection, and critique, of their own and others’ science teaching, to clarify their reasons for teaching science and STEM in a professionally meaningful way.

Teacher participants perceived online networking as valuable for both provoking and crystallising their professional learning with “tenacity” into changed practice.

There was a high level of agreement (83.7% agreement, agree+ strongly agree) for self-direction in using their PLN in taking the initiative to source new ideas to support professional development needs of emergent practice, represented in Figure 4.12) is unsurprising and also confirmed by the interview data.



"… so if we're looking at a particular science content in a term I will look through, troll through or search and find on Twitter for example, I just send a message and say, you know, 'look this is what we are doing , can you please share a little bit…'
(Eloise, Phase 3 Interview)

Figure 4.12

Survey item, n=49, When I need to learn something new for my science teaching I take the initiative to learn it using my PLN

Primary teachers were seeking similar things within their different, highly individualised PLNs to support them in refining and keeping their teaching current, as Eloise confirmed in her interview,

> So yes I use it purposefully to change the way I teach because I know that what I did 2 years ago even is not really relevant to now with a lot of things that have moved with new ways of teaching and new ways of learning, so yes I definitely would use it to change my practices. (Eloise, Phase 3 interview 1)

This characteristic of a self-directed approach to their ongoing professional development was evident among the primary teacher participants and their intentional use of their PLN.

Teachers even if they could not pinpoint emergent practices, were confident in their perceptions that PLN activities prompted beneficial changes in teaching practice as Angela said,

> I know there's this whole push around proof of impact and data collection but if my teacher judgement says it's working, I'm going to continue it and sometimes I don't even know how it started, as I've changed things. (Angela, Phase 2 interview)

After node similarities became evident in analysis using NVivo coding comparison node similarities query function, a second level of qualitative analysis allowed exploration of a comparison between two teachers. These comparative tree diagrams (see Appendix F3 and F4) allow the complexity of individual needs, as well as commonalities in participants' responses for using a PLN to develop their science professional knowledge, to be visualised.

In comparing PLN interests for primary teachers (Ruby and Natasha), a tree diagram for coding similarities using NVivo, suggests they have much in common (23 nodes) as well as personalisation of links and content based on teachers' self-identified professional development needs and goals (Appendix F3).

Another two teacher, Bob and Clark, both with ICT and STEM education special interests, similarly compared in NVivo showed perhaps more in common (29 nodes) in terms of ways they are using their PLN for science-focused professional knowledge development (see Appendix F4).

When zooming in on the central band across sets of tree diagram comparisons, these four teachers even with special interests had nodes in common of "intentional, multiple platforms, help and advice, PCK, time constraint, collegial support planning engagement (professional community) and value" all of which are consistent with major themes across all phases of this study.

As participant Clark mentioned PLNs allow for self-directed yet mutually beneficial learning and possible development, "so I try to look for things, that will be of benefit or are interesting or a good article or something that's I don't know something that's actually going to help people" (Clark, Phase 2 interview).

This comparative analysis provided further evidence of personalised value in variations within individual teacher's PLNs. Using a PLN for these teachers had personalised relevance and also value in contributing to developing a broader collective primary teacher PCK base.

Phase 1 survey results upon analysis suggested no participants disagreed that their PLN activities promoted reflection on their primary science teaching practice with 16% in strong agreement, 69% in agreement, 14 % neutral and no primary teachers disagreeing or strongly disagreeing with this item (see Table H9, Appendix H).

Teachers commented on the thought-provoking reflective value of chats and that these contributed to their professional development. See discussion chapter, section 5.1.2.

An overall indication of the perceived value of PLN use is that 84% of primary teachers were in agreement (agree 49% and strongly agree 35% combined) their PLN activities promoted changes in their science teaching practice. No teacher disagreed or strongly disagreed, see Figure 4.13.

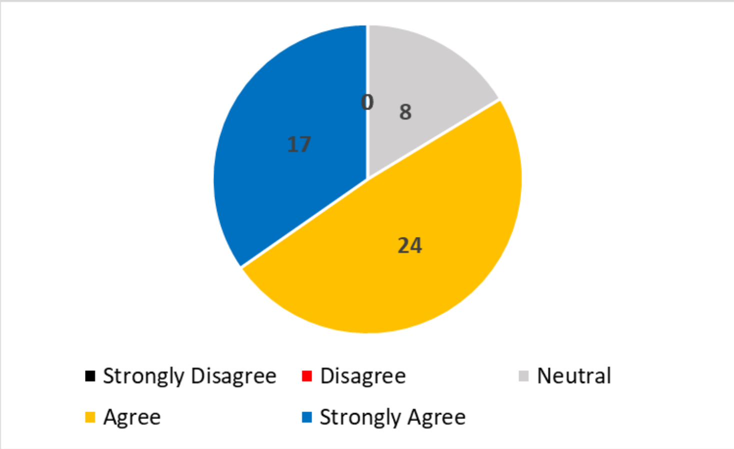


Figure 4.13

Participants' Level of Agreement that their PLN Activities Promoted Changes in their Science Teaching Practice (Phase 1 survey, n=49)

PLN activities were useful as primary teachers reflected and tailored their science teaching professional development in ways that had personal resonance and in accordance with their own changing needs.

Summary of Section 4.2

Teachers were refining their use of multiple platforms to suit purposes of distinctive TPD that augmented other, usually more formal ways. Teacher participants were resourceful in adapting other general professional knowledge and use of PLN activities for other non- science PCK to inform their teaching of science. Participation in science-focused PLN spaces was contingent on the chat content online and primary teachers' feeling sufficient expertise and a need to contribute or not. For teachers, Jess, Archie, Clark, Molly their PLN use was more about their collegial and expert connections for opportunities to extend their learning in a self-directed way and mentor others. Varied participation roles contributed to teachers' co-constructing theirs and others' professional identity online. The process of sharing their own and learning about other's practices was affirming and primary teachers found distinctive benefits for developing their PCK informed by their PLN activities.

4.3 Considerations in using PLNs to inform K-6 science teacher development

In using a PLN there were considerations participants perceived as affecting the efficacy and value of their PLNs for developing as a science teacher. Themes identified were limitations of time, frequency of use and intentional selectivity which participants commented as affecting relationship building and their need for effective management strategies. Primary teachers mentioned employer recognition of the value of PLN activities could encourage more teachers' presence online and may contribute further value.

4.3.1 Time Constraints, Frequency and Selectivity Impacted Building Productive Professional Relationships

Time and frequency were recurrent themes in answering all of the research sub- questions for this study and strongly contributed to primary teachers' perceived value of using their PLNs for continuing professional development. Teachers are obviously busy and time constraints came up in relation to teaching responsibilities; managing work load, but also as an advantage and disadvantage of PLN access and ongoing use. Timely advice, on a need-to-know basis, was a huge benefit of using a PLN for primary teachers, regardless of the number of years teaching science at primary level. Personal time available, prioritising their time to be spent online at all, and if so, deciding most beneficial ways to use their PLN affected participation and curation practices.

Participants remarked convenience, a weaker theme, was about accessing PLN beyond work hours and at times of personal suitability. Convenience was also in reduced search times for relevant information or helpful advice through having a well- managed and effective set of links within a PLN, which one participant described as a kind of internet filter. As Jane commented during her Phase 2 interview, "some of my contacts are great they'll send links that cuts down a whole lot of that time factor" and later in the same interview, "

> be careful not to fall into that information overload you know where you think everyone's got an answer to something 'cos with science there's just not one right answer and I think it's just that whole time management thing that's important to do… (Jane, Phase 2 interview)

Perceived disadvantages of PLN activities included the almost addictive quality of checking for updates, and/or having competing priorities such as family life and other work responsibilities and are not unique to this study. Interviewees commented on the variety of these disadvantages relating to finite time in the day to devote to PLN use as part of ongoing management considerations. As Ruby stated, " … it does take over a bit sometimes as there are so many notifications so it's about maybe trying to set aside some times like I'll go on at a certain time so I won't affect our family life and stuff." Her colleague Natasha had similar thoughts as to usefulness for her; " I don't have time to get involved and immersed in blogs and forums like that so for me to be able to do, people to do quick comments or just sharing" (Natasha, Phase 2 interview)

Bob found value in balancing the obvious inconvenience of time zones impacting on synchronous chat times with benefits of international contexts when taking on moderating responsibilities within his online PLN.

> I've probably moderated about 10-15 chats globally at different times...(mentions chat groups)… so different chats at different times will reach out to me to moderate and if I'm available and if the hours work for when I'm up in operation, obviously if I've got to wake up at 3am in the morning it's not necessarily the best one, so I do what I can (Bob, Phase 2 interview)

Frequency of PLN use was highly individual and participants ranged from sporadic to daily use across two or many more platforms. For some teachers it was an inevitable part of 21st century work;

> It's indicative of most individuals engaged in the work force, we're sort of tethered to our devices and our network. I don't really ever feel disconnected from my network. I've got push notifications that are coming through on email but I'm accessing my learning networks quite regularly throughout the day as well as beyond the work hours including the (almost inaudible) weekend. (Charles, Phase 2 interview)

For others it was not so indispensable, yet all primary teachers interviewed, found value in the flexibility of their frequency of PLN use, tailoring it to changing work and home life demands with ease.

Main selectivity criteria in construction of meaningful professional relationships for support and advice were; helpful, relevant, like minded, critical contrast, interest, number and lack of self-promotion. For Charles a diversity of views was a valued feature of his online links and he managed his PLN using selective criteria to allow educators with differing perspectives.

> In terms of management, I make intentional decisions about who I follow, and who I don't follow, I make decisions about keeping an open mind to that as well. I don't want to hear my own thoughts, don't want to have that oh what's it called that sort of echo chamber if you like. (Charles, Phase 2 interview)

Selectivity of number also related to not just following people based on an individual's popularity as a way to extend their PLN. Another selection rule was a credibility filter, attending to quality over quantity. Participants suggested there was not an ideal number of PLN contacts, merely what worked for them.

Time was central to developing professional relationships. Beneficial relationships were useful for learning, sometimes leading to virtual teaching and also learning experiences for students. One teacher remarked that time spent in online discussion contexts may not have immediately visible advantages for student learning, rather a longer-term view was required;

> It takes time because you don't necessarily see that when it's just in that text form on Twitter it's once you build on that and build a relationship with others that trust level and that's when those additional things come forward. (Bob, Phase 2 interview)

In Bob's situation this changed his classroom practice. Professional collegial links using his well-developed PLN took nine years of construction. He perceived that these PLN activities had contributed to rewarding, reciprocal benefits for professional development and his students' learning in science.

'Recommended colleagues' in participants' PLN needed to be valid and reliable.

These terms were used by Molly to mean people with relevant information often distinguished early in PLN construction for having shared values and being notable in their reciprocity (give, not all take).

> I like resources, reliable and scientifically backed proper resources, not just someone who has stuck something on Pinterest" and later in the interview "I'm pretty constant with who I go to because I value one local and one's secondary and I feel confident that people in those are going to be valid and realistic in what they say. I trust them (Molly, Phase 2 interview)

The key to selecting these reliable sources and deciding which to follow was that they enabled being part of a broader, dynamic professional network encountering teaching ideas beyond teachers' immediate schools as Charles explained.

> I might be looking to gain connections with people that are doing something innovative or something different, they may be doing something that I'd like to think about or that. I'll give you a recent example, on Friday week I went to Canberra to visit a school, and that school shared something with us, they were pushing the envelope a little on… (Charles, Phase 2 interview)

There was a characteristic generosity of sharing, where helpfulness was one of the key reasons teachers were present online. Teachers' reciprocity in developing their own and others' knowledge online was evident from Clark's statement:

> I've got a sort of personal filter that says if it's not helpful or useful for someone else don't share it and if someone shares something with me that isn't helpful or handy or they put

political rant on there, they instantly get unfollowed. I've just got to filter that way. (Clark, Phase 2 interview)

Selectivity of newly added PLN links was based on relevance and was not selfish but characteristically generous with participants' concern for collective usefulness. Participants mentioned they were selective of contacts and resources based on content that was not purely of use to themselves but perceived to be helpful to others. These interview responses add significance to the survey finding that 61% of primary teachers (often and always) added to their PLNs based on quality of previous interactions. Surveyed primary teachers, gave most frequent reasons in adding to their PLN as seen in Table 4.7 and Figure 4.14.

Table 4.7

Primary Teachers' Most Frequent Reasons for Adding to Their PLN (Phase 1 Survey Data, n=49)

n=49	Never & Not often	Sometimes	Often & Always
Quality of my previous interactions	6 %	33 %	61 %
Evaluation of expertise credibility of other members/ followers	6%	35 %	59 %
Recommendations from colleagues	16 %	27 %	57 %
Serendipitous (lucky) finds	12%	35 %	53 %
Notices/ suggestions from platform (feeds)	16 %	53 %	31 %
Recommendations or requirements of my employer	55 %	22 %	22 %

It was a surprising finding that platform feeds and recommendations by employers were less preferred ways for teachers to add to their PLNs.

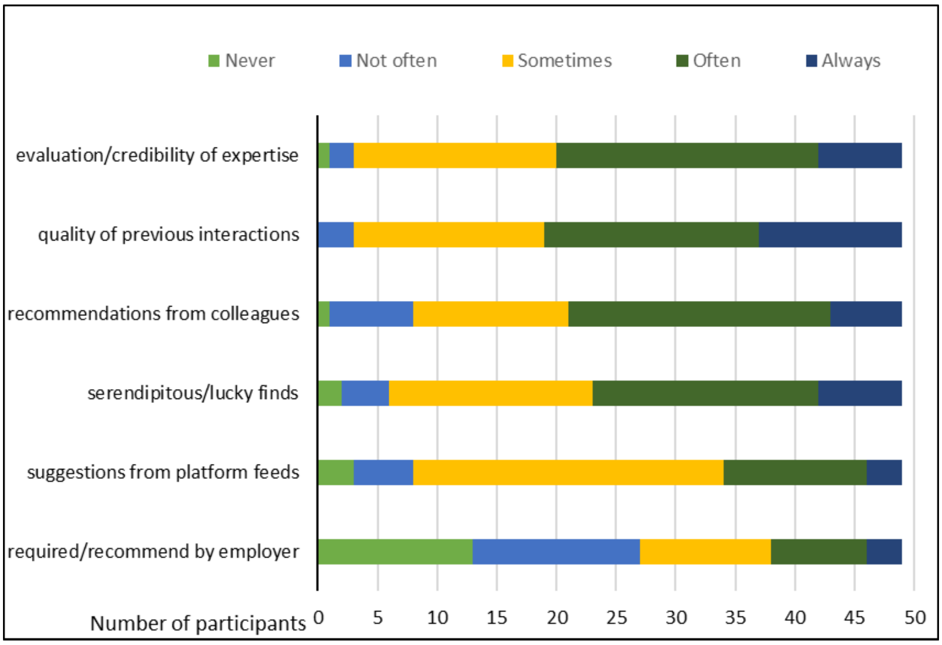


Figure 4.14

Survey Participants' (n=49) Rating of Decision Basis for Adding New Connections to Their PLN (e.g. People/groups to follow)

Valuing professional connections was expressed during the interviews, particularly if primary teachers of science felt they were the only specialist in a school or geographical region.

> …because there's very few people that specialise in the area, and quite often you might be the only person that has the expertise in a school which means you might have no- one else to bounce ideas off. So a professional learning network becomes essential so you can shout out to the rest of the community, see what best practice and see how other people are doing it. (Clark, Phase 2 interview)

This perspective from Clark led to understanding adding to a PLN was based on primary teachers actively sharing vocational passion and seeking expertise. Advice from experts and others, such as teacher to teacher within PLNs was appreciated as having a real world relevance and applicability. This has positive implications for primary teachers' professional development as Darling-Hammond et al.'s criteria (2017) denote (see discussion section 5.4).

4.3.2 Need for Effective PLN Management Strategies Facilitated Usefulness

Teachers reported that they found the usefulness of their PLN in a daily capacity and for longer term. Revisiting new ideas and readings required some efficiencies of PLN management and online curation strategies.

The number of connections was important for most participants' PLN management. Only one teacher said he grew his PLN with little regard for constraining new additional links.

Reviewing and monitoring of daily feeds and making appropriate responses were management activities. Prolific messaging and instantaneous responses from expert others made them very attractive as a continuing professional development option. However the opposite of too many posts, Tweets and notifications, and threats of information overload, resulted in necessary curation decisions. Teachers were adjusting their settings to receive notifications and alerts as emails or distributing and sharing across their own different platforms as well as sharing with others in an effort to be time efficient.

> I manage that by not engaging with it as regularly and I will sign up to receive it as an email thread or as a notification so that I can be engaged with it more regularly so it depends if I'm out there on a reconnaissance mission or if there things I'm happy to have. (Charles, Phase 2 interview)

Continuous management was needed across and within multiple platforms used.

Within a platform, multiple groups and content of interest were organised via digital bookmarking and other digital tools. Curation tools such as Tweetdeck and Wakelet were mentioned for collating and organising hashtags whether during synchronous chats or after. Answers to specific questions of practice were managed and archived for flexible, later reflection and use as Bob shared during an interview.

> ...Other interactions are from an international perspective like (names a group) which is on a Friday morning which I don't necessarily contribute to because I'm teaching at that time however I will use the feed and read the feed picking up on the conversation that people are talking about and then from that follow the links there and get that deeper understanding. (Bob, Phase 2 interview)

This study demonstrated that online PLN chats can evoke reflective comments and promote reflection on readings, research, other teachers' implementation practices, experts' recommendations and compare them with their own thoughts, teaching and learning practices.

> …there are numerous other archiving systems I use favourite of that and then I use the bookmarking element from it so I can then go back and have a look at my 10-15 quotes that I have put aside and then I think 'ok how do I think over this more? how do I go deeper with this? What other questions do I have about that I can ask back to that person?' (Bob, Phase 3 interview 2)

Delayed usefulness from PLN curation activities allowed for re-engaging with content at a later date and following up on inquiries after time reflecting on the content of the interactions.

Effective management facilitated reflection on primary science teaching. Administrative "filing systems" for online sharing were also advocated as a useful curation strategy.

Phase 3 interviews and participant artefacts mentioned Padlet as another way of archiving for sharing purposes and even a co-construction of a shared resource by Ruby,"… presented a range of things during his presentation and that was just one thing in the, he'd shared videos in the Padlet and then I made a shared Padlet for others to put their videos in." (Ruby, Phase 3 interview)

Curation had become a recent issue for several teachers who commented that they did not think they managed their PLNs effectively and had yet to develop ways to do this to their satisfaction.

> …if I really think there's a great idea I share that and email it to myself and in my email I've got a folder which says "Twitter", it just says Twitter and I dump it in there and then I think I know I've seen that something and I know I've emailed it to myself, I go in there and I'll scroll through it but I've got such a large pool in there that that's not very effective… (Eloise, Phase 3 Interview)

Delayed usefulness, a nuanced theme, exemplified by setting aside readings and ideas for later learning, is an interesting addition to the anytime immediacy of access with near instant response times to queries posted online. As seen in Figure 4.15, a variety of PLN curation strategies were mentioned during interviews as participants managed their PLN. Themes were apparent from coding during analysis of interview transcripts.

Teacher	Comments from Interviews relating to PLN management themes	Theme: curation	Theme: selectivity	Theme: frequency
Angela	"Whenever I'm at conferences I use TweetDeck which allows me to follow the hashtag of the conference and interact with only that conference." (Phase 2)	X	X	X
Jane	"making sure you've got people that you can be in touch with when need be or when something new is happening, it all comes down to that time management and what's important for you" (Phase 2)		X	X
Bob	"Basically I don't necessarily see feeds over riding each other because I generally have my feeds categorised" (Phase 2)	X		
Molly	"But I am very conscious of not having too many sources to go to, it just consumes your time and the other thing is you find you're checking them all of the time." (Phase 2)		X	X
Natasha	"… it's task based so I probably don't definitely look at anything, I use it when I have a specific need. So I guess that's how I do it effectively I just don't do for nothing. I hone in for what I have a purpose and for what I have a need for." (Phase 2)		X	X
Ruby	" just scroll back over the period of the chat to the beginning of the chat and you select all of those tweets and come into archives so you can look back over the chat" (Phase 2)	X		

Figure 4.15

Participants' comments from Phase 2 and 3 interviews about effective PLN management considerations and strategies

Eloise's comment in Figure 4.15 also shows theme of selecting multiple platforms for their specific fit for purpose usefulness and evolving construction as part of effective PLN management.

4.3.3 Employer Recognition of PLN Activities

Recognition of PLN activities' value for contributing to their professional development mattered to primary teachers in this study. Employer acknowledgement of value arose as a nuanced theme.

> I was unable to attend the event because it was considered outside of my usual duties. By being included in the chat I could see the live sharing of information, participate in conversations and contribute to the community even although I wasn't there.
>
> (Clark, Phase 3, significant interaction evaluation artefact)

While all participants were neutral or positive regarding the importance of self- directing their professional development via a PLN only 35% answered "yes" to recording their time spent in PLN activities as professional teacher development (65% selected "No"). This low percentage maybe, in part, as one New South Wales interviewee commented, that not enough teachers realise they can use it for teacher identified professional development quotas required for their professional accreditation (confirmed by email from NESA-PD on 19th of March, 2019 and 14th October, 2019).

Document review revealed extracts of professional teaching standards for Australia, UK and USA, where majority of participants taught. All of these documents have language, in describing required standards, that theoretically could apply to online networking. In theory, these documents have potential to support PLN use as ongoing teacher professional development (see Appendix G).

Theoretical support for using online PLNs to contribute to teacher professional development, in accordance with national professional teaching standards documents, suggests that employers have scope to encourage teachers to log these hours to contribute to their maintenance of professional accreditation. Yet there is a mismatch between teachers' perceptions of self-directing their TPD as important, for example using their PLN activities for professional development, and valuing of this by their employers as seen in Figure 4.16.

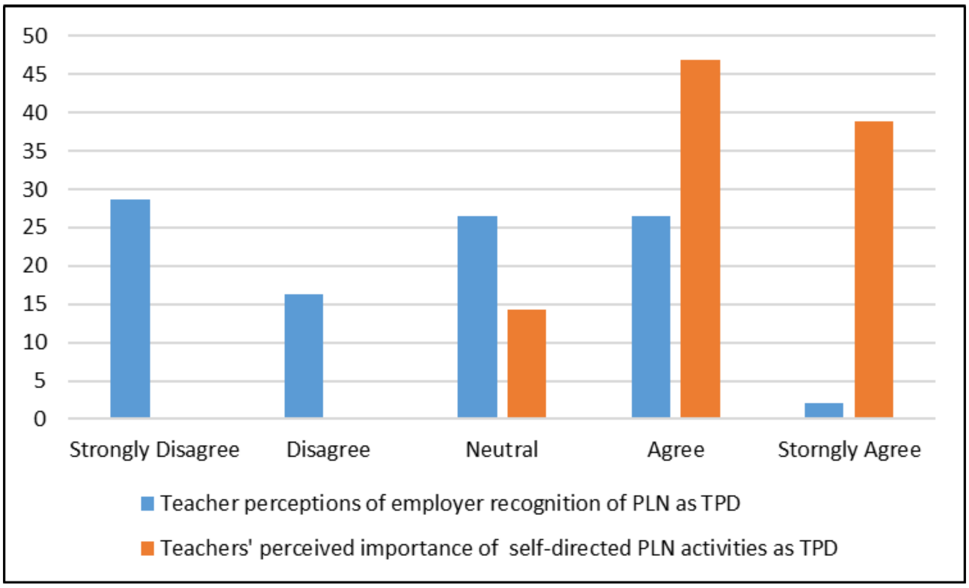


Figure 4.16

Comparison of Teacher Perceptions of Employer Recognition of PLN Activities as Teacher Professional Development With Perceived Importance of Self- Directed PLN Activities For Professional Development (Phase 1 survey, n=49)

As the comparative graph in Figure 4.16 shows, primary teachers' perceptions of importance of self-directing their professional development using PLNs to action those opportunities are considerably higher than their perceptions of their employers recognising PLN activities in contributing to teacher professional development.

Opportunities for further professional learning and development was enhanced as a stronger theme after Phase 3 artefact analysis and thematic analysis of interviews. All five teachers mentioned opportunities from learning collegially; learning from experts; and included invitations to provide, or be part of, further professional development. In using his PLN Archie expressed, during his Phase 2 interview, "it's more shared and being inspired by other people's ideas essentially." And Jess had a slightly different way of expressing a similar perspective, "I think online PLNs are an added level of opportunity to learn from other practitioners and to develop our own practice" (Jess, Phase 2 interview).

Bob shared he was inviting one of his inner circle of online network colleagues to conduct some professional development. Opportunities for teachers (based on their online profile), to communicate primary science and technology ideas practice with others, were not unusual as can be seen from Bob and Ruby's comments.

> I know they've got this amazing expertise in an area but then again I wouldn't have known that unless we met on Twitter and had that deeper conversation about where we were as a professional and where our schools were at. So it's the opportunities to meet face to face

> beyond the online presence that's very, very helpful. (Bob, Phase 3 interview)

> The other thing the PLN has opened up opportunities for me to participate in things. So lots of thing I've been acknowledged with have opened up opportunities to go and present somewhere which has built your network even bigger outside Twitter.
>
> (Ruby, Phase 3 interview)

Teachers became aware of others with similar professional interest and development needs as well as experience to share within their evolving PLN and for Bob it affected his programming and teaching on a regular basis as he had shared in his Phase 2 interview.

Jess pointed out, using a PLN was an efficient way to do professional development with collegial collaboration however available time was an issue."…I mean obviously there are huge development opportunities from being involved in an online PLN but you know we're all juggling multiple hats of all-encompassing jobs so I think time is a big constraint for not being there (Jess Phase 2 interview).

Teachers perceived the personalisation of their use of multiple platforms and contexts as advantageous to using a PLN to suit their own professional development requirements.

> Our knowledge constraint is not limited by the people in our schools we can go beyond our schools particularly to if the particular administration of a school is pushing one agenda and it doesn't suit you and is too slow for you or too fast for you or you can confirm your learning or have your learning confirmed by the huge number of individuals willing to commentate on education. (Charles, Phase 2 interview)

Personalised yet school aligned professional development was valued by Ruby as noted from her Phase 3 evaluation artefact.

> …has assisted me to think more deeply about how to embed an inquiry focus in my Science classroom. Tom (name changed) highlights the importance of explicit instruction with inquiry and also the importance of having content knowledge to aid inquiry – two things which gelled with me (particularly as our school follows an explicit instruction model across the school. (Ruby, Phase 3, significant interaction evaluation artefact).

Participants suggested that recognition from employers (for this study only 29%) of using PLN activities to partially satisfy professional development accreditation could raise its perception of value for more primary teachers.

Summary of section 4.3

Primary teacher participants perceived their online PLN activities facilitated their professional learning and for most, offered professional development. TPD was denoted by changes in their classroom practice, whether using more emergent curriculum and strategies, newer PCK or enriched CK and/or improved student learning. Realistic descriptions of PCK and images that allowed for achievable classroom science were valued from expert others as discussed by Angela and Natasha. Time limitations and facilitating frequency of use resulted in most teachers developing some curation strategies to maximise the efficiency and efficacy of their professional learning time and provide support as they implemented the new ideas. While the majority of primary teachers do not log these extended hours of work activities, there is the possibility for greater awareness by employers of their possible value. Teachers in this study perceived that using their PLNs for personalised, convenient and practice- changing professional development had considerable personal, affirmatory, and professionally relevant, value for themselves and their colleagues.

4.4 Summary of chapter 4

In summary, key features of the emergent value of PLN activities for primary teachers' professional development in science education was found to be based on: selective PLN construction, contingent participation for beneficial interactions, and effective management of multiple online contexts for self-directed, co- and shared-regulated learning.

All participants intentionally managed their PLN for learning quality, using the convenience, richness of multiple contexts and unprecedented access to expert others to develop their own and others' science teaching knowledge and practice. PLN interactions were affected by stage of teaching career with few differences between general classroom teachers of science, and specialist teachers of science across multiple grades of primary students in this study with high agreement for seeking new ideas and effective science PCK. Participants' selective rules for adding contacts and ongoing PLN management was to establish positive working relationships, co-constructing professional identity.

Purposeful, reflective and evaluative processes, as well as responding to more immediate requests for advice, with a generous sharing and collective mindset, were participation characteristics. Evaluative decisions to engage in science-focused online chats was situation-specific with contribution more favoured than moderating.

Contingent participation within their PLNs depended on feeling inspired to contribute. Decisions for not contributing were intentional avoidance or about feeling sufficiently expert in science, perhaps related to stage of career, though this would need to be confirmed in future studies. Impacts of avoiding interactions were: missed opportunities for argumentation which may be helpful for science teacher professional development; but avoiding negative repercussions on professional identity. Participants perceived that time constraints, frequency of use and software for curation and aggregation for later perusal of PLN-accessed actionable primary science PCK, hindered value. Most participants wanted to know and do more to manage their PLN in archiving useful pedagogical advice and resources for individual use and a collective science knowledge base.

Value for science TPD was evident in affordances of self-directed inquiry within multiple contexts of a PLN as distinct from more traditional TPD for extending primary-specific (curriculum and topic-specific) knowledge and up-to date science teaching practices, available from access to latest research. Primary teachers' contact with experts through their PLN encouraged deeper content knowledge for themselves and their students. Further TPD opportunities, local and global, to inspire and affirm science and technology PCK and support sustained changes in practice during classroom implementation were commonly perceived beneficial uses of PLNs. Primary teachers also perceived benefits to using PLNs for other subject domain PCK and general PK. The practical, educational and support value of online PLNs was recommended as tertiary learning for PSTs. PLN activities align with professional standards in theory and participants perceived more employer recognition and wider documenting of TPD online time was required. To further build integrative efficacy (Teddlie & Tashakkori, 2009), an extended interpretation of findings about value in using PLNs for science teacher development, using relevant theoretical and research references, is discussed in Chapter 5.

Chapter 5 **Discussion**

In prefacing this discussion it is important to note that theoretical constructs from sociocultural perspectives have provided the necessary underpinning of the interpretation and discussion of findings presented in this chapter.

It is impossible to consider learning of individual teachers when the social milieu and cultural influences of differing contexts is so apparent in online international networks. For that reason, sociocultural theory informs the basis for this discussion with recent additions from theorists who favour an epistemic knowledge culture as being most relevant to our online highly knowledge distributed world: "Engaging in discourse and representational practices in what we call 'shared epistemic spaces' constitutes a kind of knowledge and way of knowing that bridges between the personal knowledge and public knowledge…" (Goodyear & Markauskaite, 2013, p. 110). Teachers were engaged in self-directed professional development (Knowles, 1975; Rennie et al., 2019; Wang & Cranton, 2014) to the extent that they reflected on and identified their own strengths, areas for improvement and interest in science teaching to develop through their online inquiries. Teachers in this study were also acting collectively online to augment and enhance each other's science pedagogy in responding to varied others' questions of practice, while posting queries pertinent to their own practice. In addition to self-managing or regulating their professional learning, primary teachers were influential in co- and socially-shared regulation of learning (Jarvela et al., 2015).

Furthermore, there is complexity of nature of these online spaces in terms of the context, content and substantive discussion that they can support. While not all PLN spaces can be considered to have the stability of composition and shared goals to meet parameters of a community of practice described by Wenger et al. (2011), aspects of value as defined by them were evident among this study's participants' response stories. Immediate, potential, applied, realised, reframing and aspirational value for ways participants' science teaching developed though PLN use are discussed in close relation to effective professional development criteria from Darling-Hammond et al. (2017). The layers of discussion in this chapter detail, in particular, science teaching professional development by relating findings to the consensus model of professional knowledge in science (Gess-Newsome, 2015). Contemporary research findings of others are utilised in this chapter, for contrast and comparison, which helps to identify surprising findings among the data (Swaminathan & Mulvihill, 2017). This study contributes detail beyond other studies for insights into ways that primary teachers co-construct and collectively engage in PLN activities that can result in self-directed, personalised, reflective professional development, of value for science education.

In answering the overall research question pertaining to value sub- question one provided themes relating to primary teachers' selective PLN construction, particularly purposes in initiating a PLN , the value in using multiple contexts, cultivating PLN- mediated relationships to learn of new ideas and share support and affirmation of current and newer teaching practices. The value of their PLN use was heightened with its effective management which supported participants' reflection on science PCK.

The detailed nature of primary teachers' informal online interactions revealed varied and contingent participation within science-focused PLN contexts. Participants reported instances of building and sharing collective PCK. The nature and extent of value from these interactions informing primary teachers' professional development contributes to answering research sub-question 2.

Subquestion 3 addresses primary teachers' perceptions of value for developing professionally with themes indicating value as a teacher of science and as a primary teacher generally. The value of primary teachers PLN activities in relation to a theoretical PCK model (Figure 5.1) and professional development criteria are summarised to provide an in-depth understanding and fresh insight to the key research question. This chapter provides the evidence-based discussion of primary teacher participants', perceptions of value of their PLN activities for their professional development in science education. Please see Table 5.1 for a summary of this study's findings discussed in the previous chapter, where intensity of colour represents prevalence/importance of theme which is then related to Gess-Newsome's (2015) Consensus model of PCK and skills. The stronger/deeper the colour blue, the more prevalent the theme (also see Figure 5.1 in section 5.4).

The conclusions drawn from this study's findings, and implications with suggested future research directions follow in Chapter 6.

Table 5.1

Summary of Research Sub-Question Major Themes: Primary Teachers' Perceptions of Value of Their PLN Activities for Professional Development in Science Education

RQ 1 Initial and ongoing PLN construction	RQ 2 Nature & detail of PLN interactions	RQ 3 Value as science teacher professional development
Seeking:	Contingent participation	Changes in PCK for science & technology:
• New ideas up to date, useable knowledge	• Situation dependent	Emergent practice
Help and advice :	Participatory roles	Teachable moments
• Experts: scientists, industry & educators	• Intentional avoidance of controversy	Innovative new practice
Collegial support:	• Compelled to contribute	New digital tools and teaching ideas
• Affirmation	• Moderator responsibilities	Co-teaching with experts
• Mentoring	• Reflective observer	Support for planning & implementing
Co-constructing identity	• Competitiveness as inhibiting/inspiring	Repurposing & adapting general PK
Multiple platforms fit for purpose:	Relationship building	Cross KLA & multidisciplinary
• Distribution	• Respectful, productive communication, open-minded	Differentiation for students
• Personal and school goals	• Reciprocity	General PK adapted for science teaching
Blended contexts	• Time spent	Nature of science
Selectivity:	Identity profile management	PLN inquiry processes & suitability
• Relevance, valid & reliable core	Multiple contexts:	Future-focused, progressive
Time constraints	• Global, local beyond school	Primary school student interest & engagement
Frequency of use	• Extended staffroom	
Evolving PLN	Synchronous designated time chats	Enriching CK with expert advice
Selectivity:	• Synchrony of content	Importance of self-directed choices
• Number, internet as filter	Questions of practice	Personalisation- content & convenience
Favourites	Low CK prevalence more PCK	Reflective practice
Latest research findings	New ideas for science & technology	Employer recognition of value, affirmation
Delayed usefulness:	Quality of science interactions:	Complementary to & distinct from other TPD
• Chat histories	• Sufficient detail of PCK to implement	Further TPD opportunities
Effective Management:	• Realistic depiction of PCK achievable in classroom	
• Curation strategies	Primary school specific	
• Archiving tools	Frequency of use	
Collective resources	Convenience	

5.1 Primary teachers' selective PLN construction

In answering research question one as to the characteristics of initial and evolving PLN construction by primary teachers, this study revealed a range of critical and reflective decision-making criteria that participants used to selectively choose which platforms to use and choose groups within these for meaningful interactions. Selected online contexts tended to be favoured based on; teachers' purpose, professional development focus or needs, ability to distribute their own comments and, sharing mechanisms inherent in platforms. Primary teachers were not focused on building an exclusively science-based PLN but all participants interviewed found value in being selective in their construction choices. PLN context choices were made to suit their own and others' changing science teaching professional development, particularly relating to specific science topics and primary school specific pedagogical knowledge (see revised consensus model, Figure 5.1).

Primary teacher participants used Twitter as their preferred platform similar to other findings for preferences of platform within a PLN (Carpenter & Krutka, 2014; Owen, Fox & Bird, 2016). Carpenter and Krutka (2014) finding, for example, that Twitter was most commonly used among K-12 teachers (25% of their sample were primary teachers). Prestridge (2017) similarly found Twitter a favoured platform for ICT specialist teachers, but differs from some pre-service teacher studies where Facebook was most commonly used (Kearney & Maher, 2019; Nielsen et al., 2013).

Preservice teachers (PSTs) in Kearney and Maher's (2019) research indicated Pinterest then Facebook as their two most popular platforms used where 60% of their sample were primary PSTs. Similar findings were reported by Nielsen et al. (2013) among PSTs with 100% of their sample using Facebook everyday over other social media but over half (59%) using it for science learning.

It seems then that pre-service teachers may not be prioritising use of the same platforms as their in-service colleagues. PSTs were using Facebook and in-service primary teachers in this study preferred to use Twitter for their professional learning and development. This could have implications for the kinds of support or even awareness of the professional support for preservice and early career teachers from their colleagues that could be relevant and important to implementing quality primary science lessons. It also represents an example where potential value (Wenger et al., 2011) is not being realised and collaboration with examples and feedback from more expert colleagues (Darling-Hammond et al., 2017) are considered to be formative in effective primary teacher professional development. Previous researchers have also asserted the vicarious (and mastery value) of pointing out "the importance of seeking out collaborative opportunities to preservice teachers as they learn how to teach science" (Mansfield & Woods-McConney, 2012, p. 49) from more expert teachers who can model PCK effectively. PLN activities offer numerous science teacher efficacy-building opportunities.

An alternative interpretation of the finding that Twitter was the preferred platform used by inservice teachers not Facebook (second most frequently used platform), is that it may not be concerning. Many science educational groups appear across both platforms (Twitter and Facebook) for their delivery. It could however compromise in-service teachers' science professional development if Facebook is their preferred platform, when educational groups conduct designated "real time" chats where issues get tabled openly and only in Twitter, for example.

The question then becomes how to get more primary teachers online, given the perceived benefits for their professional development and indicates some educational prioritising or intervention is needed. Perhaps teachers need further evidence of advantages to using online platforms and contexts professionally, before they engage with a PLN. If primary teachers saw immediate and applied educational value (Wenger et al., 2011) to using online platforms and contexts professionally to boost their science content and pedagogical content knowledge and support their PCK&S (skill building) (Gess-Newsome, 2015), as well as value for their students they may well participate, as their colleagues in this study reported (see sections 4.1 and 4.2).

5.1.1 Purposes for initiating PLNs with a focus on science education

In seeking answers to reasons why primary teachers initially construct a PLN, 10% of primary teachers in this study (n=49) began with job requirement as the only reason. Eighty-three percent selected self-initiated learning as another reason and was inclusive of either tertiary, or job requirement. It is of more concern that only 4% of primary teachers in this study had initiated a PLN as a tertiary level requirement of their pre-service teacher education. Building and using a professional learning network has different considerations and parameters (such as credibility and reliability of the practices and evidence presented for science and technology education) that are not consistent with more personal use of social media networks where popularity and number of links may outweigh quality of links. Reticence to build a professional educationally-oriented online network may be a reflection of personal use detractions like these. Encouraging more teachers into PLN use at all may be difficult if the usual pathway is a progression from personal use, "many respondents used Twitter for nonprofessional purposes before beginning to use it professionally" (Carpenter & Krutka, 2014, p. 422). Similarly, Luo et al. (2017) reported their preservice teacher sample were familiar with Twitter but none had participated in a professional live Twitter chat prior to their study, regarding it more for personal, recreational use.

One teacher interviewed, Angela, said students should begin at university with teacher educators encouraging the PSTs to go beyond their tutorial group to link with other university PSTs or early career teacher groups online to broaden and deepen their professional support networks. This is similar to a recommendation from Luo et al. (2017) who said, “one of the greatest merits” of introducing professional use of Twitter to undergraduates is to develop a PLN (p. 233). Other participants’ made similar statements about this being a necessary contribution to PST learning, which seems to suggest an existing gap. Encouraging PLN use at undergraduate level of education might be useful for science education PSTs, and subsequently supporting their early career practice. This PLN activity would allow early career teachers to be part of the wider science education community, able to access relevant evolving curricula; culturally respected knowledge of science and develop greater awareness of nature of (or features) of science (Hottecke & Allchin, 2020; Romero-Maltrana et al., 2019).These were aspects of science education which participants in this study, from all stages of their careers, reported as supporting and enhancing their development of primary science teaching.

Participants’ online practices of selection, highly contingent participation and maintenance were reflective and evaluative throughout their choices of platforms, contexts, groups and individuals with whom to engage, share and co-produce resources (although the latter practice tended to be rarer but more open to all). Different contexts can influence the extent to which teachers’ learning meets effective professional development criteria (Darling-Hammond et al., 2017) and primary teachers were selective in using platforms specifically like using single platforms as distinct for personal use or for professional use to the exclusion of others. Even within a singular platform there were numerous contexts accessible for professional learning and subsequent development such as Archie describing accessing electronics sites and the science museum from Twitter. It is perhaps unsurprising that so many teachers (86%) were using two or more platforms in their PLN to leverage different contextual affordances and overcome certain constraints of other platforms. It was foregrounded by Macia & Garcia (2017) whose research on teachers using Twitter concluded there were distinct benefits for ways to increase professional development through being affiliated with multiple online groups (p. 137). Even within a singular Twitter hashtag, “professional use was multifaceted” by educators for an average of four purposes (Carpenter & Krutka, 2014, p. 423) and academics and educators studied over a year, used different contexts for purposes of retweeting and forwarding links which differed in learning from more highly participatory chat (Greenhalgh et al., 2020). Primary teachers in this study were deliberate and selective in their use of multiple contexts across and within platforms for their professional learning with positive impacts for participants who perceived emerging benefits for aspects of their professional development in science education and for other disciplines.

5.1.1.1 The value of multiple contexts for sharing PCK. Teachers maximised affordances of blended contexts such as using informal PLNs as complementary to other forms of professional development (preceding or following up, face to face); multimedia representations of practice and invitations to other PD opportunities; or extending the reach of learning beyond their own, even to international classrooms. Examples included, Clark learning of a webinar to attend virtually; Jane learning of new science excursion venues and following up face to face PD sessions online; Molly forming online networks after face-to-face PD. Ruby contacted and organised with a group of educators in Twitter for a face-to-face PD session with an inquiry mindset expert; and Bob connected his class to others overseas to learn about volcanoes, earthquakes and geology. Teachers valued blended contexts to varying extents for informing primary science education possibilities. Sixty five percent of primary teacher participants agreed or strongly agreed to using their PLN to "Promote learning opportunities beyond the classroom, e.g. Class excursions, citizen science projects & field trips". Interview data showed teachers valued finding learning opportunities and expert advice for themselves and their students beyond the classroom, with strong links to science curricula and by experienced providers of this content. Primary teachers were refining resources and PCK from ways it was presented in these online contexts. Eloise explained that refining resources was so newly learned PCK fitted the primary teachers' own contexts. This was to make PCK specific to the classroom but also related to flexible learning content, and methods for teaching best suited to their students. That local contexts were often preferred by some teachers almost to the exclusion of looking further afield internationally was an unexpected finding. One of the documented advantages for teachers in using their PLN is being able to reach beyond school walls (Trust, 2013). However it was more understandable when teachers expressed the relevance of locally specific and contextualised information as valuable and that local was often among other nearby and regional schools. If tending to participate in online groups more locally (sometimes a platform constraint), teachers may be missing some of the evident value in diversifying and learning regionally and internationally where some richness of content in different perspectives are possible. For other primary teachers the diversity of international perspectives was more welcomed for scope of ideas and avoiding similar opinions which was perceived as potentially stultifying professional growth. While some teachers restricted their professional use to singular platforms to keep personal and professional separate, for most teachers, multiple contexts or "panoply" as Rehm & Notten (2016, p. 216) referred to it is what made a PLN so valuable. As study participant, Clark said so eloquently in his final interview,

> …there are different platforms for different purposes from some platforms from Twitter where I'm like sharing knowledge, trying to inspire help, and get people, anyone who wants to follow it can, and anyone who doesn't want to doesn't have to. But then there's closed networks around things like software that haven't been fully developed yet and test things and trial things and have that closed network as well so I suppose, depending on the platform depends on what you get out of it and what it was for and what you use it for.

(Clark Phase 3 interview)

In this quotation it is also possible to see the themes of exclusivity and inclusivity with niche and open chat groups. These themes align with points made by Gomez et al. (2016) who noted that for maths educators, the right network for the problem is required and may result in NICs or network improvement communities.

Primary teacher participants were forming smaller purpose-specific groups with reliable individuals, to address different professional development issues. Collectively, members shared a mutually understood language (sometimes abbreviated to point of exclusivity) and intention to work out a problem of practice and benefit themselves and others: the collective supported individual professional development. In this study participants (Molly, Bob, Ruby, Clark) reported honing their PLN to an effective core group. This process of refining groups, according to Clark and Bob had taken years of sustained effort and relationship building, also ensured valuable sustained discussions.

Images that gave examples of primary science practice, resources, representations of science models and approaches were valued. Multiple visual and audio representations within contexts, evident in the phase 3 participant artefacts and selected significant online interactions excerpts, contributed to teachers' participation decisions and interactions. At various points in this study teachers remarked on images as enhancing their understanding of the details required for implementing science experiments and lessons as demonstrated online. Other teachers like Angela noted insufficient details and overly positive flawless representations of practice in images conflicted with their own primary classroom contexts.

Primary teacher participants were interested in and focused on realistic depictions of practice with their online inquiries. Teacher interviewees reported that they were careful to portray actual photographic images when sharing their own practice more widely via their PLN. Realistic portrayals of PCK (&S) (for example images of teacher-modified inquiry learning models and recounts of implementation) were also highly valued with a request for examples of 'what does not work' discussions as well as the glossier 'idealised versions' as exemplars of primary science practice. As van Driel et al. (1998) pointed out, different PCK is evident even among teachers with same curriculum to teach and the same training. Providing a multiplicity of PCK representations could positively influence primary teachers' planning and implementation of science (Smith, D., 1999) with the development of knowledge from shared and collective practical wisdom. So teachers' use of their PLN to share a wide range of science and technology PCK is valuable and a useful finding of this study for primary teachers.

Use of PLN to improve professional practice was a strong theme throughout the study reinforced heavily and in detailed evidence from Phase 3 participating teachers. Further research about the impacts of imagery is required. It would be of value to know the effects that images situated within discussions of pedagogy, mixed in with TPD event schedules and resources advertisements, have on teachers' PLN engagement and ways they develop professionally. Participant artefacts, provided in Phase 3, included examples of models of practice with graphics which primary teachers had uploaded and debated, with modifications shared. These were valued by participants for contributing to the development of their approaches to inquiry-based learning, computational or design thinking. Accessing and learning from effective models is one of Darling-Hammond et al.'s (2017) seven criteria for effective professional development and primary teachers were actively engaged in discussing the viability of various teaching and learning models; sharing personalised amendments to these for their own classes during their online PLN activities. Images may also have culturally specific connotations, which need to be understood by those posting them, otherwise inclusivity may be compromised. Stereotypes for example can be unintentionally perpetuated by quick grab pictures. An example provided in a Phase 3 participant's artefact had scientists depicted in white coats, with female science presenter/scientist watching while male scientists/presenters did the science which limits the positive value of the clear enthusiasm on their faces. A recommendation for further study is semiotic analysis and iconography of detail like connotation, denotation and iconographic symbolism (Van Leeuwen, 2011) within multimodal representations which could lend further insights to effects on teachers' networked learning.

Multiple representations of science content and teachers' familiarity with using these varied presentations (PCK) also has implications for improving student learning in junior secondary science according to Waldrip, Prain and Carolan (2010). These implications could also be pertinent for teaching primary school children and part of a teacher's developing PCK. Teachers' understanding of diagrams, illustrations, moving images, photos, models to represent scientific concepts and negotiating suitable explanations with children, requires model fluency (Smith, D., 1999). In this study teachers were often sharing visual aspects from practice, layouts of materials and modified models of teaching and learning approaches, for example the continua of inquiry learning. Primary teachers' PLN activities had extended impact as participants also shared representations with their students such as a design and produce or an inquiry framework or an engaging you-tube video explanation or lesson provocation for interactive whiteboards (IWB). Magnusson et al. (1999) recount research where teachers with stronger subject matter knowledge are able to think of variations to suit their learners but it is not sufficient. Knowing how and when to use representations of a scientific concept; encourage students to produce their own interpretive version of their understanding (Tippett, 2016; Preston, 2017) as well as ways to assess these, are part of a science teachers' evolving PCK and self-efficacy (Nichols et al., 2016). Teachers' PLN activities offer considerable value for extending both types of knowledge: SMK which could be more evident and PCK, already present and shared by teachers to a greater extent.

Primary teachers' developing PCK for science education not only requires multi-modal representation but also seems to be impacted by it within their PLN. Primary teachers reported the effect of PLN situated imagery as polarising (some inhibiting, some encouraging) their motivation to participate. Further research of multi- modal representation within a PLN is required as primary teachers' in this study indicated their participation was influenced, which has implications for professional development.

5.1.1.2 The value of PLN-mediated relationships for developing science PCK and science teacher identity. Strong themes of selectivity emerged in this study. These findings centred on participants' decisions about forming relationships for seeking and providing other teachers with collegial advice, informed by respected or reliable sources. Eighty-eight percent of primary teachers agreed they were looking for supportive professionals within their PLN, 86% were seeking improved content knowledge and 69% were using their PLN for expert advice (all strongly agree and agree categories combined). Expert advice could mean answering questions for help or mentoring others based on requests for resources, strategies and links. Reliable sources did not just include other teachers but science educational organisations and academics. Seeking the latest research and sharing article links for value in keeping up with latest pedagogical changes was a frequent ('often' and 'always' categories) PLN activity for 40% of primary teacher participants and "sometimes" done by a further 40% of teachers surveyed.

Primary teachers in this study were discerning with regard to their selectivity of links, connections and who to follow, seeking and adding trusted people within their networks as valid, reputable sources with strong educational intention. This finding is comparable to Way (2012) who talks of people as "trusted sources" (p. 16) and Grosemans et al. (2015) also mention trusted collaboration as important for professional learning. Similarly respect for credible experts and other teachers for contributing to professional learning are mentioned by other researchers (Carpenter & Krutka, 2014; Neumann et al., 2018; Noble et al., 2016).

All participants in this study were clearly able to articulate their intentionality and did not require prompts for thinking selectively about purpose in using a PLN. Their reasons for interacting were clearly motivated by specific professional development needs arising on an individual and at times communally required basis. An example of this shared development was when a possibility to apply for and trial a cutting-edge technology (AR) testing kit was discussed enthusiastically on Twitter among three teachers who shared their interest and convinced each other to try it out for science educational application. Unlike the participants in Krutka et al.'s (2017) study on reflection and identity, primary teachers in this study did not need to be coached into thinking why they were using their PLN, although they were clearly coaching, encouraging and supporting each other in new practice, satisfying another criterion for effective professional development (Darling-Hammond et al., 2017). More general interest in staying up to date and in continuing relationship building with colleagues were other key motivators.

Quality of content has been critiqued in past research but in this study participants refined their PLN construction to a stage where they were content with the quality of their online interactions. Quality of content mattered, as well as reliability of information and resources, so sharing PCK was with a view to being realistic and setting goals of positive changes in their practice. An emphasis on building relationships through respectful PLN interactions were rewarding as teachers gave or provided encouragement to make changes in their teaching of science. In fact in this study the majority of primary teachers (73% with 22% strongly agreeing and no-one disagreeing) were satisfied with the quality of their online PLN science-focused interactions.

Furthermore, online PLN spaces offer high ‘sociability’, a sense that communication and informal sharing is welcome (Weidlich & Bastaiens, 2017). Several primary teacher participants similarly, in this study, noted that their PLNs offered a diversity and extensive choice of “sound social spaces” (p. 485) affinity spaces, CoP’s and niche groups. Relaxed sharing in these kinds of PLN spaces was a positive inducement to online collegial discussion extending daily interactions to develop professionally. Teachers’ willingness in answering other’s postings was contingent upon online arenas described as “low risk” and “welcoming” by more than one participant. This seems particularly important as science may not be a specialty for some primary teachers, with limited science educational background as just over half of surveyed teachers (55%, n=49) had studied a science subject to tertiary level. Kearney & Maher (2019) found some PSTs felt intimidated by international experts in larger open online groups which inhibited their overt participation. Seeking conducive, welcoming spaces for advice and ideas was the reasoning behind primary teachers’ initial construction using multiple platforms and evolving PLN with continued use.

More importantly primary teachers in this study valued the relationships that they took extended periods of time to build online within their PLN. These relationships supported their professional learning and development. This is consistent with research from Visser et al. (2014) on the affordances of Twitter to, “build meaningful, virtual and face-to-face interpersonal relationships in online contexts”(Visser et al., 2014, p. 408). Relationship building also fits with Darling Hammond et al.’s (2017) PD criterion of “sustained duration” as some participants commented on the longevity of their links and time taken (up to 9 years for one teacher) in the evolution of refining their PLN to a reliable core of favoured experts. Participants also enjoyed further reaching access to diverse, new experts as Bob and Ruby remarked throughout the study. Discussion threads and debated issues lasted days or substantially longer and in some cases were archived for revisiting reflective chat. Similar sustained and longer-term engagement in discussions in teacher initiated online groups, which is uncharacteristic of more traditional professional development is mentioned by Lundin et al. (2017, p. 24).

Several participants in interviews stated their PLN afforded working with diverse experts which benefitted development of their knowledge and teaching skills. Access to expert advice encompassed not just scientists but also industry specialists such as web-designers to integrate technology, local councils, city planners, community groups and science societies, science educational institutions and science educational industry experts in software and equipment as ways to develop their PCK and PCK&S (skills in practice). According to Panizzon et al. (2013) advantages are twofold as access to diverse experts allows "teachers to develop their pedagogical content knowledge (PCK) and thereby change their classroom pedagogy" (p. 68) but also allows "student engagement with real-world science and the kinds of experiences that help broaden students' awareness of future career options. "(p. 79). This potentially longer term student benefit was expressed by several participants and was strongly emphasised by Jane, Ruby, Charles and Archie as intended value from their own development. Archie was concerned about the social justice aspect of equal access to careers for his students and used his PLN to elevate his students' achievements more publicly for these purposes. Ruby was future-focused for her students with specific reference to promoting girls' involvement and visualisation of possible careers in STEM. An example that Ruby provided was when expert female scientists etc. became part of her classroom learning through initial direct contact using her PLN interactions.

Mentoring or providing advice had a reciprocal effect of co-constructing participant teachers' professional profile as helpful experts and sharers of advice. This finding is not dissimilar to the findings presented in research by Lundin et al. (2017) for teachers using a thematic Facebook group to share "pedagogical ideas and premises" (p. 18) and building an identity as a teacher of science (Carrier et al., 2017; Unger, 2020). Bob mentioned he perceived his self-directed online learning, reflection on it and sharing this with others enabled him to be an early adopter of science and technology, ahead of or leading research-based educational trends of changes in practice. All of these purposes, motivations and actions towards self- directedness are core andragogical principles in practice (Knowles et al., 2012, p. 147). Similarly Jess conveyed her willingness to become known as a person for others to ask questions of online for mentoring and reliable expert advice in science education. These teachers' presence and contributions online were shaping their identity as teachers of science and the way others online perceived their advice further contributed to this construct.

There was mention by primary teacher participants in this study of using PLNs for self-promotional purposes as a concern that may inhibit other teachers using these spaces. One participant perceived an issue with educators being elevated to expert jobs based on an online persona/identity rather than effective practice in reality. This tension between mutual benefit and self-aggrandisement is comparable to mentions in previous research (Lantz-Andersson, Lundin, & Selwyn, 2018) and the building of professional online profiles for influence. This is also in keeping with the concept of co-constructed “idealised” performance structured identity by Robson (2017) and “stretching” from research by Oddone et al. (2019) to describe teachers’ online practices in the public arena. Primary teachers in this study were aware of and, as Archie commented, bemused by this process of professional elevation of some with thousands of followers through a co-constructed online identity. Participants commented that they used other selectivity criteria as well as numbers of followers, in building their PLN, while still reciprocally engaging online, which necessarily affected their own professional identity.

Sharing to build PCK through online professional community engagement, included links with universities and latest science education research findings (for 80% of primary teachers). These contacts seem to be precious assets and reason enough for practising teachers, who may feel a long way from their initial educational preparation, to seek and continue to develop their knowledge at their own pace and time. This theme was disparate in comparison with professional offline learning research by Aubusson et al. (2015) where few (28%) of their participants believed primary teachers at their school wanted science and technology readings for professional learning. It is difficult to think of another viable option for accessing the latest science education research findings if primary teachers are not engaged in further formal study. PLN activities were perceived by participants to facilitate staying informed of the latest educational research which offers a very valuable aspect of professional development. Reading educational research, reflecting on ways it impacts teachers’ own student learning provisions, and staying apprised of pedagogical change is supported in primary teacher national professional standards accreditation and professional learning documents as professional development (see Appendix G) affirming the value of teachers’ PLNs for these purposes.

5.1.1.3 The value of new ideas, professional support and affirmation for science teaching. Affirmation, validation and reassurance in online contexts from broader community gave primary teacher participants greater confidence in their science teaching, whether justifying their current approaches or supporting implementation of new ones.

Teachers were looking for professional advice and help, surprisingly not all teachers were looking for collegial support in affective terms. One participant commented that he perceived “no value” in looking for like-minded views or validation.

Affirmation represented a theme of moderate strength in this study, however all participant teachers felt very positive towards teaching science. This is consistent with other research such as Hartshorne (2008) and Watson et al. (2014). In contrast with Grosemans et al. (2015) who wrote, “to receive support for one’s situation” (p. 153) does not result in professional learning offline, using

PLNs for collegial support contributed to primary teachers' positive feelings of "affirmation", and "inspiration" in turn promoting teachers to consider adoption of new practices which was exemplified through all research phases. This study, where primary teachers easily conveyed their enthusiasm and responded to the excitement of others as inspirational online, is in keeping with the key theme Unger (2019) identified of acknowledging and sharing work with and by others.

A majority of participants (86%) were in agreement with feeling greater confidence in teaching science when using their PLN to learn something new. New ideas for teaching and learning science, resources, contacts for advice, methods of organising, planning, responding to students, prioritising strategies, new approaches and ways to initiate and maintain student interest were all sought from these participants' PLNs. This theme is in agreement with findings from Krutka, Carpenter & Trust (2017) where PLNs supported P-12 teachers' professional growth in "one or more of the following domains: affective, social, cognitive and identity (Trust, Krutka, and Carpenter 2016)" (p. 248). Affective aspects varied slightly in their study in terms of confidence and excitement in ownership of learning, whereas in this study, the affective domain featured confidence, affirmation or reassurance, validation and inspiration for motivation as more prevalent themes.

5.1.2 Effective PLN management supported teachers' reflection on PK

In seeking actionable knowledge many teachers faced the challenge of aggregating and curating their PLN discoveries, collectively pooling and co-creating resources. Some teachers had effective management strategies and used helpful digital tools such as 'favouriting', bookmarking, collating and archiving software and apps.

Most participants reported not doing this efficiently enough to their satisfaction. This is important as the theme in this study of delayed usefulness meant teachers were looking for ways to store and reflect upon or implement their new teaching content and strategies at a later date, for convenience or just approaching professional development more incrementally. This theme of delayed usefulness also referred to the time invested in building valued reliable, online relationships within multiple contexts of their deliberately constructed PLN. Delayed usefulness of readings and setting aside strategies for later implementation is unsurprising as Grosemans et al. (2015) found informal learning activities were ways teachers gained new ideas to try in their classroom contexts. Tucker (2019) found reflection on readings was a useful part of Twitter based PLN activities for professional growth among post graduate educational professionals, and primary teachers accessed latest research on Twitter according to Nochumson (2020).

Primary teachers in this study also mentioned the benefit of archiving pedagogical theoretical ideas elicited from their PLN activities for their progressive development. Three language teachers in

Tour's (2017) study aggregated resources from their online networks as an important professional learning activity, while Beach (2017) identified "saving information for future retrieval" (p. 68) as her 6th theme for elementary teachers using online networks. Primary teacher participants willingly spent after work hours in the quest to find new ideas, read and see the possibilities to improve their own and others' practice within their PLN activities. Reflective thought as a consequence of PLN online activities has value for teachers' professional knowledge and practice. Reflection can be found in professional learning standards documentation internationally and models of effective teacher professional development (Darling- Hammond et al., 2017) as a necessary criterion.

However archiving PLN gems of actionable primary science education knowledge was not limited in this study to purpose of simple retrieval. Primary school teachers, with their newer PCK, made amendments, repurposed and recontextualised resources for their own teaching of science and also reported using suitable ideas for STEM lessons. Sometimes aggregation and archiving for motivation and aspirational value was for intended future professional development. Ruby, Eloise and Bob carefully described these processes as reported in section 4.3.2. This is important as it coincides with an effective TPD criteria of sustained duration (Darling-Hammond et al., 2017) which is mentioned in research as an issue with professional development programs (Sandholtz et al., 2016).

Most interviewed primary teachers in this study mentioned longer term PLN activity provided the follow-up support for professional development during classroom implementation phase. This is the time teachers actualise new professional learning in practice and need support (Kennedy, 2016; Smith, G. 2015). Further a theme of PLN use as complementary to other forms of professional development, specifically where PLN was used to source and organise PD opportunities or to offer support post more formal PD sessions was expressed by primary teacher participants in this study. This generally involved blended contexts already discussed with examples from this study (section 5.1.1.1). Blended contexts are suggested as successful in offering time and support post PDP for primary teachers of science to continue their development (Bell & Sexton, 2018). Ongoing opportunities for PD is noted by Rodesiler's (2017) study of a teacher created online professional development program; conducting PD workshops for other teachers as a result of learning from Twitter (Nochumson, 2020); and as amplifying feature of PLN use for teachers (Oddone et al., 2019) which implies further value.

In Phase 3 interviews, primary teacher participants provided examples of ways they refined their pedagogical content knowledge and skills, as a result of reflecting on their PLN activities. This form of science teacher knowledge and action is described as PCK&S (Gess-Newsome, 2015). Reflections were reported as relevant to establishing the successes, or otherwise, of newly learned and implemented practice with their own classrooms of students. Interview data from phase 2 had indicated PCK&S was an area that could be improved within PLNs in terms of teachers discussing more of the "what didn't quite work and why" science teaching experiences, using newer approaches, to refine these, for future successful implementation. These PCK&S discussions represented instances of primary teachers' co-regulating each other's learning and possible development.

Primary teachers' PLN activities evoked reflective practice on their science teaching as (16% of primary teacher participants were in strong agreement, with 69% in agreement, none disagreed). This contradicts other research which suggests public PLN spaces do not allow for substantive reflection on teaching (Kelly & Antonio, 2016; Rensfeldt et al., 2018). Ascertaining the reflective nature of PLN use is tacit knowledge, in that it is not always explicitly obvious in online interactions. In this study reflection by primary teachers was made accessible by the interviewing process and participant created artefact of the evaluative template. Online interactions may not always be sufficient for reflection (Kelly & Antonio, 2016) which is a concern as it is considered a necessary feature of science teacher professional development according to Loughran (2013) and others. Furthermore critical reflection is one of the important tenets of self- directed learning in order to achieve a transformed perspective (Wang & Cranton, 2014, p. 194) and significant in the third evaluation phase of self-regulated learning (Triquet et al., 2017; Zimmerman & Schunk, 2011). Primary teachers self-reported being reflective in this study. For instance, Bob in the results chapter shared some metacognitive inner speech in the form of reflective questions about how he can use the latest things he learned from his online network to go deeper with his own understanding of PCK and practice. Inner speech is a stage in development from public intrapersonally shared knowledge to internalised thought (Vygotsky, 1978) and self-directive strategy (Schunk & Zimmerman, 2011). Bob's articulated reflection was an essential feature of his PLN relationships to enable his continuing professional development and teaching science more effectively.

Reflective practice and evaluating successes and non-successes of their teaching in consideration of student learning outcomes is a regular practice among primary teachers on a daily basis (Schon, 1983; Shulman, 1987; Bold, 2011). In reference to a self-selected significant chat for its professional development value one teacher in this study commented *"It assisted in increasing this confidence and awareness of approaches allowing me to target key areas to improve on." Bob (Phase 3 evaluation artefact).* Opportunities for reflection were reported by primary teachers in this study but were not usually conducted within online spaces. However reflection around what was discussed and discovered online, and ways it related to their own science lesson implementation, and teaching practices more generally, was evident. Krutka, Carpenter & Trust (2016) identified reflecting as one of "five key elements as common to PLN experiences" (p. 152).

A point that participants made in interviews was that PSTs need more direct instruction as to setting up and using PLN effectively. While not directly relevant to this research's questions except in teachers getting the most value out of their PLNs could start when they are PSTs. Previous researchers have noted “without proper training on the use of informal learning tools, teachers may experience difficulty in effectively participating in this mode of learning” (Jones & Dexter, 2014, p. 370). This would seem relevant for teachers learning more about possible ways to manage and curate their evolving PLN to facilitate both participation and later reflection.

In contrast to participants in this survey who selected recommendations from their social media feeds as a less likely way to add to their PLN, it has been suggested as a useful curation technique, as this capacity allows multiple website feeds to be managed (Trust, 2012), providing a way for teachers to gain and organise their updates. Practical advice around PLN management and other aggregation and curation techniques would assist primary teachers to get more value from their PLN. Paradoxically these are often provided online within a PLN such as recommendations to use TweetDeck to organise synchronous ‘real time’ chats which seems almost a necessity before attempting to moderate such multi-voiced online chat sessions. While self-directed and socially-shared learning are characteristics within online spaces, there may be an argument for some more explicit instruction in the possible ways to effectively access, aggregate and curate a PLN to ensure efficiencies of time for primary teachers.

5.2 Detailed nature of primary teachers’ PLN interactions

In answering research question two, primary teachers participation was contingent on the relevance, helpfulness and usefulness of interactions for either takeaway, actionable knowledge; building reciprocal and respectful collegial relationships over sustained duration as well as transient connections; learning from experts and organisations; or their willingness to join in interesting or controversial conversations where their own expertise may be of value to others. Teachers participated in online interactions after situation specific and contextually dependent evaluations of details of conversation threads. Evaluations included the subsequent value of participating such as mentoring others, learning more personally as compared with potential risks in participating in controversy or repercussions for online professional identity. Avoiding controversy may limit development opportunities such as argumentation. Multiple kinds of time constraints affected teachers’ reasons for choosing to interact or not.

5.2.1 Building and sharing collective science PCK

In this study, the value that primary teachers accorded shared knowledge, where educational expertise was evident within PLN interactions, meant that learning from the collective exceeded and facilitated learning on their own. A similar finding from previous research indicated “when networked, participants can draw on their collective knowledge and skills to exceed what individuals might accomplish working alone." (Noble, McQuillan, & Littenberg-Tobias, 2016, p. 204). Fischer (2017) similarly reported this as evidenced among biology teachers using Twitter. Collective skill building was described by primary teacher participants Angela, Charles, Ruby, Bob and Eloise who constructed and widened their networks and utilised their network contacts as ways to share current and future intended practice ideas, making provisional plans for their students' science learning.

Primary teachers used their PLNs to assist in planning science units, according to the Phase 1 survey item, more than half the teachers (51%, n=49) agreed and a further 12% were in strong agreement with this use for their PLNs. While planning was mentioned, the kinds of detail around what to include about a specific science concept to be taught as per the CoRes papers suggestions for collectively developing PCK (Loughran et al., 2012; Nilsson and Elm, 2017) was not evident in samples for this study. That is not to say they do not happen, only they were not part of this study's data collected. Perhaps this represents another area for greater potential for primary teachers using a PLN: to enhance the detail of their science PCK.

In fact all through a learning cycle where teachers may encounter problems of actualising their intended plans, participants found their PLN activities, typified by consultation of others, were useful. Using a PLN for resolving questions of effective practice resonates with a Vygotskian socio-cultural view of learning. Primary science teachers' learning was mediated by more expert others within science education PLN online culture, beyond their perceived current level of development. It is fair to say many of the participants' interactions do not rate as complex problem solving, and were more about searching for practical advice and resources with immediacy. An example was Charles using his Twitter contact with a celebrity scientist educator, inviting him to join his class where students were initiating individual inquiry projects and this teacher wanted authentic scientific process advice to support his current knowledge of practice and the students' learning. Eloise (Phase 3 participant) mentioned that teachers were at all different stages of development and Molly found her PLN activities allowed her to be the expert mentor for others and facilitate their progression through difficulties of practice. Several participants mentioned being both the learner and at different times, the more expert other within online discussions addressing issues pertinent to their and others' personalised development. Discussions varied in substantial coverage of pedagogical issues, but surpassed the usually reported tips and resources 'quick finds'. Interactions that result in primary teachers' personalised zones of proximal development being accommodated were a distinct advantage that participants valued from self- directing and regulating their PLN activities.

One of Darling-Hammond et al.'s (2017) effective professional development criteria of 'supporting collaboration' typically in 'job-embedded contexts' (p. v) is well exemplified but not limited to the evidence provided by Clark. This study participant was teaching kindergarten to use mini electronic bit kits to make soil moisture monitors for gathering data to inform later plant growth.

After doing this Clark utilised his PLN to share this PCK with others and was then questioned by teachers online and asked to communicate and effect change across other classes in other schools. This is also consistent with Van Waes (2016) findings that more experienced experts found immediate and applied value with more people in their networks which included less experienced colleagues. Tsiotakis and Jimoyiannis (2016) describe the collective nature of online platforms for professional learning in describing "community memory, which is a record of 'what has happened',i.e. the community knowledge, community evolution and development, as well as its operational history and the community repository, which includes participants' activities, learning material, and artefacts created through both, individual and collaborative actions" (pp. 47-48). In these ways of sharing PCK in online contexts, the expressed knowledge is held online for other teachers to make a contribution and science professional knowledge bases are collectively built, retained and shared continually.

Collaboration between teachers and other experts was noticeable throughout the study and exemplified in Phase 3 evaluation templates where Ruby reported constructing a communal Padlet online, inspired by expert-led face to face professional development workshops, available to all primary teachers within and beyond her PLN. This was generated as an evolving resource for herself and other teachers who were planning an engaging introductory aspect to their lessons and/or seeking stage appropriate scientific explanations for use with students during inquiry based learning projects. So this exemplifies co-construction of pedagogical content knowledge where interpersonal communication during PLN mediated activity led to Ruby's own learning. In her Phase 3 evaluation template Ruby reflected on newly learned ideas from others regarding more effective ways to maintain student engagement in science lessons, and reported that she subsequently altered her practice as a result of this internalised, critically reflective process. Ruby's online learning within her PLN led to further development in refining and consolidating her skills for engaging and maintaining student interest. This PCK was inspired by teachers collectively wanting to solve their shared problem of ways to keep students' interest throughout a science unit of work. Shared construction of the mutual goal of a Padlet of lesson starting PCK for the benefit of the group represents an example of socially shared regulation of learning as defined by Hadwin et al. (2011).

Collective PCK accentuates the value of PLN activities for primary teachers of science as a profession in addition to the value for individual teachers. Emphasis on PK and PCK was evident in the text and image rich online learning spaces in which primary science teachers co-developed and updated each others' teaching possibilities. Goodyear and Markauskaite (2013) comment on fluency in sharing and using multi- representational means is a requirement for engaging in professional work across epistemic spaces and developing necessary expertise. Further that sharing of wisdom constructed within professional learning contexts and reciprocity, can lead to collective knowledge building, and perhaps distributed success, (Trust, 2012; Meijs et al., 2016; Fischer, 2017; Lantz-Anderssen et al., 2018), as " one has to acknowledge that much professional work is intrinsically collective. Sharing knowledge and coordinating action make it possible to distribute labour across people with specialised professional skills" (Goodyear & Markauskaite, 2013, p. 103). This is keeping in mind concerns raised about the potential within online networks for the opposite, of distributed ignorance. An example PLN users having sufficient epistemic tools to recognise flawed declarative and procedural knowledge when it is shared (Arfini et al., 2020) but this concern is raised more in reference to "fake news' versions of science and ill-informed opinions gaining momentum in social media (Nochumson, 2020; Hottecke & Allchin, 2020).

Although relevant for primary teacher PLN users, in this study, misinformation was mentioned rarely. Molly suggested it was evident online with regard to science curriculum interpretation by teachers that she felt a responsibility to correct. Clark had perceived the more 'vocal' educators online were not always the more informed and misinformation was raised by Ruby with regard to perpetuating confusion. Ruby remarked that teachers in her PLN expressed a mistaken view that teaching and learning science is the same as teaching and learning STEM. Teachers were using their own educational background knowledge to filter and correct or respond to social media circulated pedagogical myths. This need for selective and discerning evaluation of pedagogical content within a PLN also highlights the importance for PSTs to have the necessary robust preliminary science educational background and awareness of PLN construction for sharing professional content; as well as effective science teaching models shared and moderated by experts, to avoid Clark's concern that online interactions could become precincts of the ill-informed. Science associations, science teacher associations, tertiary academics, scientists and other experts have an obligation to contribute to online science education expertise. This is equally important for teachers and students to understand and impacts on understanding the nature of science in times of social media for communication of reliable science knowledge (Hottecke & Allchin, 2020).

There were collective science professional knowledge affordances from the amalgum of content in a PLN for primary science teachers. Synchrony of content, meaning the discussion of current educational topics and issues of contemporary interest, was valued by primary teachers, particularly in reference to understanding intricacies of implementing new curriculum introductions. Synchronous 'real time' chats while popular were not unanimously favoured. Other researchers have reported on these contexts as effective for networking, sharing resources and affective support, and participation in moderated chats as having relationship with changes in practice (Carpenter & Krutka, 2014, p. 424; Macia & Garcia, 2017; Nochumson, 2020). For the primary teachers in this study they provided surprisingly more depth and detail beyond resources by looking at pedagogical issues. Conceptual tools such as models for teaching inquiry and design thinking were presented during informal online chats, shown in Phase 3, participant selected, significant interaction artefacts. Although discussion on comparison and contrasts was light and seemingly left to individuals to draw their own conclusions, the learner is ultimately responsible for their own learning (Shulman, 1998).

Another example of more in depth science PCK based discussion about rich inquiry-based learning for their schools was provided by Ruby (Phase 3 interview 2). Ruby described explicit instruction to enhance inquiry learning as a practice favoured by her school though not as prevalent in online sharing where there is emphasis on students actively 'learning by doing', or hands-on science. There is a need for primary teachers to encourage learners towards deeper thinking in a minds-on way as well as hands-on learning in science lessons which comes with teachers' quality of content expertise and pedagogical content knowledge (Shibeci & Hickey, 2000; Zwiep & Benken, 2013). The availability of varied approaches to primary science learning was a strength of PLN spaces. There is the opposite concern however where there are particular PCK emphases prevalent across postings, perhaps to the neglect of other science teaching approaches which influence professional development possible.

In this study however participants reported that their science education understandings improved in co-construction and interactions with colleagues and expert others, which fits with Trust's (2012) "collective knowledge" with various experts online; Hume's (2016) description of teachers and experts collective use of science hub website for planning primary science units.

5.2.2 Varied and contingent participation within a science-focused PLN

The details of primary teachers' contingent participation in science –related PLN chats which entailed some controversy, was an interesting finding for this study. The concern is that intentional avoidance of participating in chats could limit development opportunities. Primary teachers may be missing out on some important science professional development in using argumentation which is skill-building that they can share with their students (McNeill & Knight, 2013; Ryu & Sandoval, 2012).

Many studies have researched the ways teachers participate online (Krutka, Carpenter & Trust, 2016 and 2017; Prestridge, 2017; Trust 2013; van Waes et al., 2016; Zhang et al., 2017). For this study relating to science education, primary teachers were conditional in their online engagement. The theme of contingent participation with controversial discussions online is not exclusive to this study as PST's from Luo et al.'s (2017) study reported feeling uncomfortable in refuting during debates because of perceptions of others' expertise. This study indicates that this perception is also relevant for practicing primary teachers. Alshamali & Daher (2016) point out primary science teacher PD should include modelling of scientific reasoning skills and problem solving using inductive and deductive reasoning, which could perhaps be exercised during controversial interactions. Some primary teachers felt the need to contribute in countering science and STEM misinformation or misunderstandings observed in online posts. Choosing to contribute to pedagogical debates within a

PLN seems to offer another way for primary teachers to further their professional development.

Natasha and Clark remarked on how their participation in synchronous chats was contingent on their evaluations of the specific content and contexts of conversations. These participants shared their complex reasons for being selective in participating in 'real time' chats, such as being mindful of possible personal repercussions and, later professional implications of their responses. An advantage however was that science pedagogical topics of interest to individual teachers, were often of synchronous topical interest more universally, within primary teachers' PLN groups, amid varied educators and discipline experts. Primary teachers often expressed this heterogeneity of voices were valued for both "like-minded" views (Maloney, 2015; Tour, 2017; Trust, 2012; Trust et al., 2016) and providing differing perspectives and knowledge (Reasoner, 2017). However primary teacher participants found that online spaces allowed for conversations in the absence of having colleagues available, if for example they were the only science specialist in their school, or interested in developing professionally in ways that their school aligned professional development was not necessarily providing at that time of need. This is similar to the interdependence among networked academics described by Van Waes et al. (2016) and use of PLNs to relieve their professional isolation (Carpenter & Krutka, 2014), and also similar to teachers who are casual employees and feel unsupported by the school (Merceica and Kelly, 2018).

Teachers' participation in PLNs has also been found to be contingent, varying with personal attributes of teachers. Prestridge (2017), for example, studied ICT teachers' online participation roles and styles, and noted these were affected by personality and motivational dimensions of teachers. An interesting point made was that different levels of engagement result in varying depths of learning possible, for example if a consumer online, this was quite a surface participation style with repercussions for learning. However, in this study primary teachers did talk about "getting" answers to quick questions of practice, but most included in their PLN usage, more focused and sustained relationships from interactions as a valued part of their poly-context PLN. Mobile learning, with its poly-context affordances across multiple layers and diverse settings is described similarly by researchers. "Roth and Erstad (2013) emphasised that mobile practices, especially networking between learners are 'polycontextual' in the sense that they are not bounded by one context…(p. 125)" (Schuck et al., 2017, p. 124). Multiple platforms and contexts were of value for primary teachers' commitment, in this study, to reciprocity and mentoring or providing help and advice to others. For Jane it was across excursion providers and other teachers, for Charles it was across global technical companies; local council experts and other schools; for Archie it was science museums, local science societies, computer and software providers. There are many more examples in findings chapter 4.

Expert and collegial advice were strong themes where participating as part of a broader professional network sharing inspiration and new practices were valued. Teachers benefitted from forming these professional relationships as well as finding out answers for themselves online and offline. Mansfield & Woods-McConney (2012) found that collaboration with colleagues boosted primary science teachers' sense of efficacy. Primary teachers in this study tended towards participation that was contingent, contextually dependent and varied with their intended purpose. Participants reflected upon the best ways to implement collegial and expert knowledge shared, building towards their own and reciprocally their colleagues' PCK development. These participant learning activities are describing the phases of co-regulated learning where a shared goal and task can boost collective and self-regulated learning (Hadwin, Jarvela & Miller, 2011). Collegial collaborative and active job-embedded learning are features of effective teacher professional development (Darling-Hammond et al., 2017). There does remain the question: is professional development as effective for everyone regardless of level of engagement or participation in their PLN? (Prestridge, 2019). This study offers insights of the value participants found in varied participatory roles within their PLNs to contribute to answering this question.

In this study, participation in PLNs went beyond 'contributing' when primary teachers took on moderator roles. These roles are described as often centric and as bridging groups of clusters within teacher networks (Macia & Garcia, 2017). Findings revealed that primary teachers in this study most often observed and contributed within their PLN. Interview data showed that primary teachers may have been moderating online but not many in science chats. During interviews, while Ruby and Bob expressed excitement in moderating fast-paced, focused conversation, other teachers were less enthused by this role because of the significant time and responsibility in fulfilling this role regularly. Constraints included not feeling sufficiently expert so a reluctance to share, perhaps related to stage of career, but there were too few participants to confirm. Other constraints were lack of confidence in science knowledge, as stated by one participant during interviews. Research from Mullins & Hicks (2019) indicated PSTs felt their lack of experience inhibited their participation and valuing of Twitter chats as useful. In contrast, Van Waes et al. (2016) found novice trainers with less expertise (within their sample of university teachers, most also researchers) were more likely to use networks for aid and assistance. There would be benefits in sharing wisdom and first attempts, particularly when primary teacher participants expressed interest in seeing more authentically, realistic coverage of science lessons in addition to exemplary successful ones to help them develop their PCK.

Further limitations were taking on the role of moderator during contentious online chat among adults which may also impact on the teacher's professional profile as Natasha and Clark expressed during interviews. Inconvenience with different time zones when engaging in a synchronous chat hour was also mentioned by Bob.

Moderating also has interesting implications for what Salmons (2010) describes as an absence of gatekeepers and "disintermediation" possible within online spaces, such as direct access to expert advice. The value of this facility to access experts as required was a very strong theme among participants in this study. However the role of moderator, in some ways, can be a gatekeeper in terms of what gets shared en masse, versus what is coming in during a synchronous chat. The posts that moderators selectively attend to (cannot attend to every post in the moment) and repost or comment upon for example, filters and directs the conversation. Still this constraint was not mentioned during interviews as inhibiting where most participants considered PLN spaces safe and comfortable spaces to share ideas of practice, based on selective construction.

Primary teachers' professional identity building was affected by moderating and being an active contributor. Perceptions of expertise develop when teachers are the ones distributing knowledge, although ultimately each teacher is responsible for deciding which new knowledge and practices to prioritise. Teachers acting as moderators online "differentiate themselves by presenting a professional identity where they take responsibility for explaining the professional advantages of a particular approach while opening up for teachers' own responsibility to use the approach as best fits" (Lundin et al., 2017, p. 25). Although Unger (2019) saw it more as collectively acknowledging open sharing of science teaching resources and practice, coining the term "affinity identity" for groups of teacher online. This co-development of knowledge and identity is another example of socially shared and co-regulated learning (Jarvela et al., 2016).

Primary teachers in this study expressed an open-minded approach as important with online learning. Open-mindedness is mentioned in previous research (Oddone et al., 2019). Primary teachers expressed the view that they had the responsibility for working out what 'best practice" meant for them and the approaches they selected to adopt as effective for teaching science with their students (see Archie, Clark & Jane's remarks in section 4.2.3.2).

Observing chat posts from others was considered to be reflective by several participants in this study not just passive lurking. Some primary teacher participants learned through this role that respectful communication, only challenging ideas they felt strongly compelled to counter, would mean they could choose also to avoid controversy, maintaining a positive online presence and professional identity. That lurking was seen as productive and not indicative of disengagement is aligned with previous research findings (Tsiotakis, & Jimoyiannis, 2016). This perception contrasts with Zhang et al.'s (2017) position that a beneficial reaction relies on reciprocal contribution to chat, even if their assertion, that peripheral participation is limited in value for a network, is justified. Primary teachers were gaining further value from their PLN by acting on observed information and advice for developing professionally.

Competitiveness of interactions was raised as both a negative and positive aspect of PLN activities. Competition was suggested as underpinning the protectionist views raised in Prestridge's

(2017) research categorising teachers' social media use in sharing content for self-generated professional learning. However this was not the case with a generosity of sharing as more characteristic of primary teachers in this study. For several participants, there was an inhibiting factor when the priority was showcasing and grand-standing online, while for others this very showcasing was about sharing student work to inspire others as an initial step in encouraging pedagogical change. Fitzgerald and Schneider (2013) commented on the value of sharing stories, "to showcase how primary school science teaching can be re-imagined, re-invigorated and re-energized" (p. 10). This assertion was echoed by primary teachers' perceptions of value of their PLN activities in this study. They perceived these activities as beneficial for motivating teachers to improve practices; being curious about changes in science education and improving their teaching. For example, Charles said he would learn from others' projects where boundaries of innovation were being pushed; Jess said that being a mentor inspired others to adopt newer practices; and Clark collegially tutored his latest science and technology soil probe idea. This was with the proviso that the material shared was provided with sufficient detail for others to implement.

5.3 Primary teachers' perceptions of value of PLN activities

In answering research question 3, teachers' perceptions were that their PLN activities resulted in benefits but with some limitations. The most evident benefit was learning useable, actionable knowledge which often led to changes in their practice through resolving questions about novel or more effective ways to teach primary science. These activities often resulted in extended knowledge of ways to offer student learning in primary science. New teaching ideas were sought by 94% of primary teachers (strongly agree and agree categories combined). New ideas particular to teaching science and technology (science PCK), enrichment of their science content (CK) and deepening student engagement were especially valued by participants.

Science education focused PLN interactions were also valued as chat contributors were all discussing the same topic of a current pedagogical issue or approach in science and technology. These offered areas of communal relevance, particularly when PLNs are so disparate and tailored to individual preferences. Sustained duration of building reciprocal professional relationships, with examples of experts co-teaching provided by several teachers (Bob, Charles, Clark, Ruby) during interviews, were perceived to improve their topic specific knowledge (TSPK) and practice in their classroom (PCK&S). The resulting professional development of enriched content knowledge and more emergent, responsive to student needs, reflection and amplifiers of PCK resulted (see model in Fig 5.1). These were considered by participants as advantages of their engagement in poly-context PLN activities.

5.3.1 Extends teachers' science PCK, students' interest and learning through beneficial interactions

Primary teachers in this study shared the instances where they chose to interact, often as a contributor and beneficial interactions were ones that resulted in valued new idea "take-aways", meaning immediately actionable PCK or "usable knowledge". Appleton (2002) reported a similar finding of some primary teachers preferring to implement "activities that work" to "supplement" their science PCK in offline professional development contexts (p. 395). There were clear applications for implementing these newly encountered skills and strategies in the classroom which Hartshorne (2008) described as "essential" and Kearney & Maher (2019) described as the "main benefits" of PLN activities for PSTs. PLN activities in this study support teachers learning practically applicable ideas and while trying out new science and technology teaching approaches not typical of face-to-face professional development.

Participants reported PLN activities that were PCK laden with value in learning more about new ways to improve their practice as a matter of priority: they constructed their PLN around these individualised needs, as described in detail in section 4.2.3 and 4.2.5. In talking about PCK it is important to reiterate Shulman's premise that PCK "represents the blending of content and pedagogy into an understanding of how particular topics, problems or issues are organised, represented and adapted to the diverse interests and abilities of learners and presented for instruction" (Shulman, 1987, p. 8). Despite the obvious advantages of personally tailoring their own PLN use, there were common purposes for the primary teachers of science in this study. All participants were actively engaged in finding new teaching ideas for science and technology and to develop their professional knowledge base. This is comparable to a finding by Krutka, Carpenter & Trust (2016) who found that K-12 teacher used their PLN for "discovery of new ideas, resources, lesson plans, teaching strategies, and professional knowledge" (p. 154). Although lesson plans were a point of difference as they were not prioritised by this study's primary teacher participants.

More notable examples of science rich PCK in this study were sharing inquiry practices for learning how to plan and carry out an inquiry project or investigation with expert advice. While a confident and competent science teacher, Charles used a virtual (remote technology linked) consultation with a scientist, whose appearance was possible through their PLN presence, to advise and facilitate investigations based on students' devised questions. Charles also used his PLN to learn of and visit another school to observe teachers' science and technology design and make project processes and student outcomes there which he described as innovative and "pushing the envelope".

Ruby shared gathering science lesson provocation videos for interesting and engaging starts to a science lesson or for meaningful age-appropriate science phenomena explanations. Accessing resources from a website and putting a 'shout out' on social media for ways to best implement a primary physics unit of work on forces was described by Bob and then he was contacted via his PLN with more lesson ideas from the website's educational resource provider which he selected from to develop his science teaching. Primary teachers used their PLN to stay up-to-date, sharing and accessing new ideas which was a strong theme for this study in terms of what primary teachers were searching for through their PLN activities. Primary teachers' learning new ideas for implementing digital tools as a purpose for their PLN interactions was moderately strong with 46.9% agreeing with a pertinent survey statement and a further 32.7% in strong agreement. For these teachers it meant keeping up to date, with their intention to keep learning relevant and meaningful for their students, with an emphasis on real world contexts. Their concern was to keep their practices in step with forward-looking perspectives whether transitioning from primary to high school (Molly) or encouraging science and technology learning paths towards career trajectories (Ruby and others).

PCK was not always science specific for this group of primary teachers with technological PCK also valued. A Swedish study found that primary teachers with little experience in science and technology developed professionally when their technology PCK involved PCK "borrowed from science" (Hultén & Björkholm, 2016, p. 349). Getting science PCK and CK to feature in science teachers' practice when integrating newer technology PCK has also been discussed in another study in the context of year-long provided professional development (Pringle, Dawson and Ritzhaupt, 2015). Primary teachers were keen to share their practice and learn ways of meaningfully integrating new digital tools from others; improving their own practice, with a view to the flow on effect, to improve their students' science learning and outcomes.

Primary teachers in this study rarely discerned between what was professional development for them separate from their impact on student learning outcomes. Emergent curriculum featured as part of participants' newer science PCK in Phase 3, so a nuanced theme but one showing powerful value of PLN use for highly motivated teachers convinced of its contribution to improvement on their practice. Ruby, Clark and Bob perceived they now programmed and taught differently after using their PLN; responding to include emergent teachable moments during science classes, with greater attention to relevance to student interest and differentiated needs. The survey suggested developing PCK for the benefit of student's learning was a valued use of PLNs from the item "learning ways to improve student interest in science", as 82% of primary teachers agreed and strongly agreed (categories combined) with no teacher strongly disagreeing. Although survey results indicated differentiation had not rated highly (while a majority), with only 59% of primary teachers in agreement (agree & strongly agree) that they used their PLN for helping to address diverse learners' needs for differentiated science lessons.

Teacher participants perceived their PLN activities as having value for learning more about initial steps towards and maintaining student interest. There was minimal difference between single classroom teachers and those who taught science across a grade and multiple grades of school science agreement level of this PLN use. It has been recognised that student interest is crucial to teachers continuing to persevere with an innovative science teaching approach (Suh and Park, 2017). Maintaining student engagement are mentioned in teacher national professional standards documents (for Australia, AITSL proficient level teacher section 3.2, 3.4, 3.5 and 4.1, 2018; USA Middle Childhood Generalist Teacher standards, section core principle and standard 3 , 2012) and student interest is prioritised in UK Teachers standards point 3, "…foster and maintain student interest in the subject" (2011, p. 11) and were regarded as a priority by primary teacher participants in this study.

More general professional development, with a focus on student engagement, interest and deep learning were reported by several other teachers in the study. So general PK was also valued during discussions. Many educational models (or appropriated as such), design thinking, computational thinking, inquiry based learning, critical thinking, Socratic thinking and their usefulness within science and technology for primary students, were shared and discussed, repurposing general PCK, integrating inter- and transdisciplinarity (Vasquez 2013 in English, 2016) for use in science lessons. This is in contrast to recent research which showed the reverse of this trend, in fact, primary teacher leaders of science in UK valued science PCK for ways it offered students science skills which were thought to be generalizable to other key learning areas (CFE Research and University of Manchester, 2019, p. 2). Teachers in this study more often debated (gently) different PCK, strategies, resources and tools drawn from other content areas they had implemented in science lessons or were inspired to try from others' practical experience.

Evolving, refining, updating and shifting PCK were reported by primary teachers in this study who described a more emergent practice responsive to students' daily learning needs, students' interest in a science investigation and depth of learning through teachable moments. For one teacher, Ruby, her PLN had offered not only inspiration to teach in a more fluid, emergent format but affirmed her teaching. Her development of a more differentiated and responsively student-focused, less teacher directed approach, was quite reminiscent of Tobin & Mc Robbie's (1999) description of teachers negotiating co-participation of students in the science classroom for optimising learning and Trust et al.'s (2016) description of teachers co-constructing knowledge with students as learning partners and facilitators. Trust related this shift in teacher role to a change in professional identity. However, while a definitely comparable finding, in this study it was more closely associated to primary teachers' development of PCK, their practice as priority and student's identity as active learners and less about their own identity. This more emergent curriculum pedagogical approach was to better follow student interests, needs and utilise novel resources for teaching STEM as a direct result of online professional learning network activities which was an interesting finding.

PLNs support another specific professional learning context; for primary teachers of upper primary school students. Participant Molly suggested that upper grades of primary school may require a subtle shift in PK and PCK. Molly perceived that primary teachers' professional development needs included practice corresponding to science and technology curriculum demands of early high school, in a way that eases students' transition from primary to high school. This is important so students are well- equipped in terms of science content knowledge at a topic level and also understanding how science works and features of the nature of science. Pedagogical content knowledge; the more effective ways to investigate, explore, problem solve or experiment and represent their findings appropriately were important. Molly found her online professional networks gave this kind of advice with reliability. This was an unexpected finding but could add to the value of using a PLN for upper primary teachers. Research from Drits-Esser, Gess-Newsome and Stark (2016) suggest maintenance of professional learning is most influenced by same grade collaboration. Participating in networked online niche or affinity groups around upper primary grades has value for primary science teachers. Molly found joining a high school Facebook group (just one part of her PLN) was useful in affirming and strengthening her primary science PCK&S of teaching approaches, strategies and content tailored to upper primary students' learning requirements.

Repurposing PK and PCK from other subject domains may not always be favourable for teaching primary science. Arguments affirming this practice are that knowledge is rarely siloed in reality, or online nor in the primary curriculum, particularly with newer STEM education emphases. There are logical integration examples like literacy and science found in the Primary Connections Linking Science with Literacy primary science teaching and learning modules (AAS, 2006-2020).

General capabilities of the Australian curriculum which extend across all subject domains and includes numeracy, intercultural understanding, intellectual understanding and ICT (ACARA, n.d) are also examples. However, there are domain specific requirements too, as noted by Australia's current Chief Scientist Alan Finkel that strong, deep domain specific knowledge is required before any innovation is possible (keynote speech 2018, Brisbane STEM conference, QUT).

Beyond that viewpoint, primary teachers transferring general PK or other PCK learned through general, not science-focused PLN activities, to their teaching, may not always be effective. Inquiry learning as it is implemented in other non- science domains, may not offer enough science-specific features or complex scientific thinking such as sufficient emphasis on gathering first hand (empirical, objective) data as usually expected in science (Hume, 2016), or science processes such as repeated measures for experimental reliability, or opportunities for students to build conceptual understanding (Roth, 2014). When teaching approaches and strategies are generalised from other knowledge domains, Romera-Maltrana et al. (2019) describe the risk of "epistemic relativism" and a devaluing, truncated understanding of the distinguishing features of science.

Alternatively, in this study, there were numerous successful examples of teachers sharing ideas from other contexts with meaningful adaptations to suit their own primary classroom contexts and students. Ideas for science lesson provocations were valued by Ruby and Bob to encourage their students to engage with the lesson content. New digital tools and technologies were configured to work with younger year groups than intended as shared by Clark. Using her PLN to showcase student learning was described by Eloise; ways to critically think about science investigations using more general philosophical principles by Bob; taking skill expectations for high-school and ensuring year five and six students were well practiced in these scientific processes, by Molly. The list of evidence is long and extends beyond these few instances mentioned (see previous chapter 4) but represent the necessary intertwining of CK and PK (Krepf et al. 2017) for effective primary science PCK which many of the participants' PLN activities promoted and supported.

5.3.2 Enables TSPK development for more in-depth primary school science CK

Primary teachers perceived value in using their PLNs in ways beyond those found in previous research. This study's primary teachers used their multiple chat groups, rather than conversations in a single platform space. Content knowledge in these groups was evident within PCK postings and discussions within their PLN although discussion was not subject matter knowledge focused. Seeking content knowledge while intended was a limited use among interviewed teachers' PLNs (only one teacher mentioned a content inquiry in Phase 3 social media artefacts) and several primary teachers said more typically, their science content questions were resolved as a result of direct online searches or science curriculum consultation. Understandings of the nature of science or more epistemic CK was more evident but still not as prevalent as PCK, as presented in section 4.1.2. Rich development of teachers' PK of how students learn and lesser CK or subject matter knowledge SMK was found in a study by Britt and Paulus (2016) looking at #EDchat. A similar finding is reported of no science CK evident in first year of teachers' postings during Unger's (2019) PhD study.

Curriculum content knowledge represents another valuable part of science teachers' professional knowledge base (Gess-Newsome 2015). Teacher participants' engagement in their PLN activities evidently contributed to their deepening CK beyond required curricular knowledge. Bobs' classes learning volcanic geology from classes and experts closer to these phenomena; Clark's class learning living things needs in detail beyond the curriculum stage; and Angela's class learning bout ISS in space were all examples of enriching CK usefully learned and developed through their PLN activities. A survey item had indicated 74% (n=49) of all surveyed primary teachers used their PLN to improve their science curriculum knowledge.

PLN activities were useful, according to varying baseline statistics in this study, for across primary grade/s teachers of K-6 science using their PLN to seek content knowledge, as more of a priority than for general classroom primary teachers of a single K-6 class. This was a surprising finding when researchers have pointed to content knowledge as being more necessary for primary generalist teacher confidence and competence in teaching primary science. It might therefore be expected more generalists would make use of their PLN for this purpose. Literature suggests generalist educated primary teachers could focus on substantive CK to develop their strength in teaching primary science concepts (Appleton, 2003; Driver, 1989; Harlen & Holroyd, 1997), some even suggesting hiring content specialists for support (Cook-Whitt's thesis, 2016, p. 161). PCK is necessary for effective professional development and over time CK becomes the "more dominant factor" in developing topic specific PCK or TSPK (Neumann et al., 2018, p. 11). Yet seeking science CK did not seem to be as high a priority among generalists as teachers with more specific roles focused on science across one or more primary grades according to the data in this study. This was disappointing as one of the main aims of this study was to explore if primary teachers' PLN use could support the development of their science content knowledge. Future research could investigate ways that primary teachers augment their SCK.

Content knowledge is important in substantive and syntactic or epistemic forms, both of which teachers need to know in addition to PCK (Anderson & Clark, 2012) and PLN activities could have more science content focus. While Shulman (1987) suggested teachers were students' primary source of content knowledge, perhaps that is not so true anymore with access to online PLN spaces. It is still important that teachers' content knowledge exceed that of the curriculum, in order to effectively direct and redirect student inquiries and explanations. One participant (Ruby) remarked if teachers were not teaching content in science then she was not sure what they were doing. PCK was valued and evident in participants' PLN activities, but there also needs to be sharing of adequate subject matter or CK. As Newton and Newton (2001) commented that teachers' "science content knowledge can facilitate or enable content-related discourse" (p. 374) in the primary classroom. One primary teacher remarked,

> ...to teach it (science concept) properly you often require that deeper level of understanding so you know why you're teaching something a certain way and if someone queries it you can answer them. So I think it's really important that you have a higher level knowledge than what you are teaching. (Molly, Phase 3 interview 2)

Seeking improved content knowledge was a popular intention for 86% (n=49) of primary teachers in using their PLN according to the survey. The survey and interview evidence when integrated, indicated content knowledge was not only sought from science content experts with only 43% participants using science and science teacher associations for this purpose. This may be disappointing for science teacher associations as according to research from Bledsoe and Pilgrim (2016) almost three quarters of posts from these organisations using online social media relate to professional development in some form inclusive of disciplinary content and teacher resources as well as events.

Furthermore Van Driel et al. (1998) contend that "studies on science teachers' PCK indicate that a thorough and coherent understanding of subject matter acts as a prerequisite, preceding the development of PCK" (p. 682). Cook-Whitt (2016) in her dissertation suggests there are more variables to consider such as teacher beliefs as well as PCK, which mediate between subject matter SMK and ways science is taught in the classroom. Even in considering others' research, this study demonstrates there is under- utilised potential value of PLN spaces to support primary teachers' constructive dialogue, explanations and argumentation around science subject matter content, to contribute to teachers developing further understanding of science concepts as well as PCK, (see ch 6 implications and conclusions).

The ways science concepts are taught at primary school level is important as they can impact foundational understanding upon which more detail is built in later years (Driver 1989; Gilbert & Watts, 1983). This study showed the value of the collegial advisory capacity of a PLN at a topic specific level was evident where primary teachers can discuss students' possible misunderstandings or naïve theories. For example, Molly used a high school science teacher Facebook site to answer a PST student query, relating to clarifying terminologies of polarity for magnets and electrical fields. There must be influential and inspirational reciprocal value for primary teachers in seeing specialists among them asking questions to continually to develop their practice.

Primary teachers' PLN discussions of current understanding of primary school students' views of science content, can be clarified in conjunction with available online expert advice, from scientists and science educators, which value adds to available online science CK.

5.3.3 Affinities with nature of science (NOS) for developing epistemic CK

Participating primary teachers made clear statements about their understandings of the nature of science with remarks about the rapid progress of science; the need for evidence and analysis. This would seem to fit as well with topic specific pedagogical knowledge such as science practices and habits of mind in the Gess-Newsome (2015) consensus model as it does in a more traditional conceptualisation as syntactic or epistemic CK (Schwab, 1978; Shulman, 1986). The visibility of science processes was noted with examples given of scientists online showing their experimentation and reframing hypotheses and other scientific processes; sharing ways scientific knowledge is generated and revised within a culture over time and with new evidence (Romero-Maltrana et al., 2019) which also resonates with sociocultural theory of learning. There was scope for teachers to further realise that the inquiry practices they intentionally used in their online PLN, to self-direct their professional development, engaging, discovering, experimenting, reflecting, sharing, described by Krutka et al. (2016) as a framework to enrich a PLN, are also comparable to the kinds of inquiry participants sought to use in their classrooms with their students.

An example was provided by Charles of an inquiry learning project where students and the classroom teacher were able to ask for advice on best pathways to investigate their science topic and used the expert scientist as model to compare their own thoughts for inquiry directions. This would seem to offer a rich and deeper inquiry learning experience than general classroom teachers might offer on their own. Charles reported wanting to know how to best lead a whole class of students in the scientific process, for individual student-generated inquiry project questions, in his Phase 2 interview. This self-identified professional development opportunity by Charles led to a series of PLN initiated interactions with an online expert scientist/educator providing individualised PCK professional learning for Charles with simultaneous authentic science learning experiences for his students. The teacher and students learned about the nature of science (epistemic CK) through access to ways a scientist might think in order to structure various investigations. Expert co-teaching through technology in his classroom allowed this teacher to refine and so develop his primary science pedagogical knowledge and implementation skills (PCK&S). While this is possible in a face-to-face situation, the range of possible co-teachers dramatically expands with internet access to scientists as experts, other teachers as experts, other students as experts, industry experts etc. with the convenience of reaching them and online relationships being built.

Aubusson et al. (2015) found in their research of primary teachers' preferences for professional learning in science and technology that external expert advice rated highly. Accessing experts may not seem like a shift in practice as incursions are traditionally possible face-to-face. However primary teacher participants found value in providing time for experts in the science classroom; realising the future benefits of modelling provided by scientists. Access to experts has never been so easy with improved, ever increasing professional platforms and teachers evolving their PLNs to leverage these multiple contexts (Maloney, 2015) for their professional development in science education.

Several of Darling-Hammond et al.'s (2017) professional development criteria are being met during these expert-students-teacher online interactions which can extend the teacher's nature of science (NOS) knowledge (CK), at a topic specific level (TSPK). Teachers are developing their knowledge and skills of enacted practice (PCK&S) through learning from the online science expert. Collaborative learning from and with expert mentors (students and teacher sharing ideas and receiving advice and prompts from scientist educator) was evident. Effective models of practice (scientist's recommended processes of scientific inquiry suited to investigative questions in Charles' example) were manifest in a job embedded context (classroom via remote linkup online). This professional learning activity was to improve student learning outcomes (quality of nature of science learning, depth of inquiry learning, relevance of working with a real scientist in this example). The result was communication of professional knowledge that also had direct student learning benefits. The students and teacher were able to see an effective model of inquiry in action from the scientist's expert contributions to the lesson. Anderson and Clark (2012) remark on the value of science teachers' syntactic knowledge of science in terms of the nature of science for improving student learning and scientific literacy. This may seem to link better with the Magnusson et al. (1999) model where scientific literacy features prominently as an influencing part of science teacher PCK which is harder to find in the consensus model. Teachers in this study were learning further about the nature of science or syntactic CK, taking advantage of a co-teaching dynamic possible using these PLN and expert- mediated contexts.

5.3.4 Facilitates self-directed and distinctive TPD

Carpenter and Krutka (2014) found "Many respondents appreciated the differentiation and personalization afforded by professional development on Twitter" (p. 426). So it is not just the assertion of this researcher that online professional learning within networks, which was the reason that 69% of primary teachers initiated constructing a PLN, extended into professional development as evidenced in many examples reported by individual primary teachers. In the category of "other" for this survey item it was interesting that this included "for professional advancement" which indicates teacher recognition of PLN activities as contributing to professional development. Ruby's final interview provided a convincing summation of the professional development afforded by a primary teacher participant's PLN activities.

> Well the PLN has done I guess 2 things for me. One I learned from others' practice so it's helped me do a better job in the classroom and it gives me new tools and strategies for working with students, so that includes this practice and hopefully student' outcomes, but the other thing the PLN has opened up opportunities for me to participate in things. So lots of things I've been acknowledged with have opened up opportunities to go and present somewhere which has built your network even bigger. (Ruby, Phase 3 interview)

Furthermore this endorsing explanation of using her PLN for purposes of professional development indicates that Ruby's PLN activities support her ongoing learning in ways that satisfy AITSL charter for teacher's professional development as being "relevant", "collaborative" and "future focused" (2012, reprinted 2018, p. 6).

A key finding of this study detailed in chapter 4 (section 4.1.4) is the impact of teachers' pedagogical knowledge, learned through their PLN activities, on student learning. An example was Ruby said that upon reflection of her new knowledge and understandings, she made changes to her teaching, inspired by PLN interactions. This different enacted PCK she perceived improved her students' interest and engagement which provides evidence of the value perceived for her professional development. Most teachers in this study, similar to Krutka et al.'s (2017) findings, were unwilling to say there was impact of their PLN activities on student learning. However a significant finding was that some primary teachers clearly articulated student learning gains as directly attributable to their PLN professional development, unlike Krutka et al. (2017). Gains were inclusive of, but also beyond, student interest and engagement, as described by Ruby. Similar to Bob's descriptions, Archie, for example, perceived his students were able to learn science content in greater depth, through his newer teaching which resulted from his PLN inquiries, and gave him access to meteorological society resources and equipment for his students mapping weather data in UK. Several teachers reported a relationship between their educationally focused PLN activities and improved student academic learning outcomes which requires future study to provide further evidence.

Most teacher participants interviewed were adamant that their PLN activities allowed them to conceptualise ways to teach science in ways they had not previously considered. Their learning may not have resulted in development in that they had yet to incorporate these ideas into their teaching representing reframing value and were aspirational (Wenger et al., 2011). This is to be expected with adult learning where they can autonomously, self-pace their development (Schunk & Zimmerman, 2011).

Vygotskian notions of learning and development, while designed around describing children is also relevant to adults in that these two processes do not always coincide. "..learning is not development, however…sets in motion a variety of developmental processes that would be impossible apart from learning. This learning is a necessary and universal aspect of the process of developing culturally organised, specifically human psychological functions" (Vygotsky, 1978, p. 90). Teachers were responsible and agentically controlling their own professional development tailoring online learning options specifically to their needs and PLNs provided for this activity as reported by Nijland et al. (2018).

Primary teachers' PLN activities were valued as personalised self-initiated yet co-constructed professional development across multiple platform PLNs.

Personalisation, co-operation and collaboration through self-directed PLN activities were similarly noted to "extend their professional knowledge and contribute to their professional development" among literacy teachers (Tour, 2017, p. 186) and K-12 teachers' use of Twitter (Visser et al., 2014). Primary teachers built their PLNs to encompass a blend of more formal, institutionally associated groups, webinars, and less formal chat spaces to maximise affordances of PLN multiple contexts. This type of blurring of binary boundaries for emergent spaces of learning has been referred to as "third space" in reference to affordances of fluid, hybrid mobile learning (Schuck et al., 2017, p. 123). Even when asked about participating in an effective face to face professional development program such as Primary Connections workshops "Around four in five (primary teachers) were likely to participate in workshops if they were supplemented with online spaces to share ideas or to ask questions of experts" (Aubusson et al., 2019, p. 113).

In conclusion, there are several distinctive features of PLN activities for science professional development in comparison with other forms of TPD. These features as already discussed in previous sections are:

- the collective nature of participatory benefits with options for contingency, situation and context specific engagement including adopting a moderator role;
- the possibility for scale and scope of reach across local and global contexts; the currency and access of being up-to-date with latest science education research findings and ideas for improving future

practice;

- a convenient and accessible way to mentor and be mentored throughout experience stages of a teaching career
- unprecedented access to a rich variety of science and educational experts, experienced professionals and associations beyond this discipline for convenient and timely advice;
- allowance for differentiation according to student needs, school goals and teachers' own professional development goals
- collaborative mentoring through teachers' personalised zones of proximal development, at times concurrently learning with their students,
- sustained duration of support during implementation of changes in science teaching practice at low cost, during the "trying to implement it back at school" phase when it is more typical for limited opportunities as follow up to professional development due to course costs and teachers' perceptions that they need to keep moving on to the next educational priority.
- engagement in skills and processes similar and suited to characteristics of nature of science, as modelled by experts within PLN contexts;
- potential for greater presence of useful experts from varied science and technological areas
- an avenue with fewer gatekeepers to allow democratic sharing in the science educational conversation due to synchrony of content and asynchrony of access to content
- possibilities to engage in a multitude of varied ongoing teacher development activities benefitting from multiple contexts of PLNs
- positive perceptions of high value in using PLN as personally relevant, self- directed yet communal professional development.
- a complement to more traditional professional development sessions where a more personal needs and school goals focus can precede, augment or follow up more agenda-focused formal sessions.

5.3.5 Requires more employer acknowledgement of opportunities for primary science TPD

Primary teachers choosing to build networks in the broader professional community is another expectation of teachers in their professional standards documents. Using PLNs for this purpose is perceived to be empowering with value as professional development. Employers could make recognition of types, kinds and quality of PLN practices as professional development clearer in documentation, so teachers could log their time spent.

How online PLN activity resulted in changes of practice needs further research. As this study is only self-reported, and learning that resulted in teaching changes depended on the value participants placed on their newly acquired knowledge and its applicability to their own context. Primary teachers expressed that employers needed some mechanism of evaluation as to extent teachers were learning professional content and pedagogical content knowledge to appreciate change on the basis of learning from PLN activities. In reporting perceptions of value of their PLN activities in this study, 84% of primary teachers were in agreement with the statement *"My PLN activities promote changes in my elementary/primary science teaching practice"*. No teacher disagreed or strongly disagreed and examples in some detail were offered through interviews. This finding is comparable to Trust et al. (2016) who reported 96% of their sample agreed PLN use promoted changes in their teaching. Also, Trust et al. (2017) found 52% of participants reported changes in their teaching practice as a direct consequence of their online PLN activities (p. 5). Further similar evidence; 94% of surveyed elementary teachers and three-quarters interviewed reported changes in their practice as a result of learning within Twitter spaces (Nochumson, 2020, p. 315).

However this study found 65% of primary teachers do not record their time spent in self-identified professional development in online informal contexts for purposes of accreditation maintenance, despite the importance and value they accord their PLN activities. This is perceived to be due to employers' lack of recognition of its professional and educational value and confusion among teachers as to whether they can use their PLN engagement time formally. This could perhaps be partially explained by differing perceptions of instructional leaders as other researchers' findings were that only 23% of instructional leaders' reported PLN usage resulted in changes in practice (Trust et al., 2018). Alternatively, perhaps ambiguity or lack of explicit labelling of PLN contexts in professional standards and accreditation policy documents has contributed to this confusion.

The language in describing primary teacher responsibilities to meet national standards in the documents from UK, USA and Australia (countries where majority of participants taught), mention key themes that resonate with findings emerging from this study as to the value of online PLN for professional development. Focusing on ways to improve practice; maintaining student interest; broadening perspectives through collegial collaboration; updating knowledge targeted to professional needs; are all themes within these teaching standards that also arose as themes, in this study. This could raise the value of PLN for teachers and provide further inspiration to join this online community of educators if employers considered time spent in PLN activities as suitable professional development.

Pedagogical content knowledge was developed by participants in their PLN spaces through sharing of latest science education research links to readings (41%, often & always survey categories) and expert advice (70%, agree and strongly agree survey responses). Inspiration and motivation were mentioned more than emotional support. The capacity to utilise the archived capabilities for delayed usefulness, revisiting for later reflection or implementation, was also valued, although the available technologies for curating are not optimal, capturing all retweets and making threads difficult to follow in retrospect without huge time and effort on part of moderators or archivist.

Primary teachers have so many competing priorities within the classroom and extra-curricular responsibilities such as running coding or science or STEM clubs and learning groups across other key learning areas such as sport, arts, literacy etc. Therefore time spent in professional development really needs to be potent and perceived as worthwhile. Professional development via PLN activities was considered as useful as face-to-face science professional development by 75% of surveyed primary teachers. There has been a consistently growing movement away from passive presentations of formal professional development. It needs to be remembered though that this finding is from teachers who are already opting for alternatives to face to face professional development by using an online PLN and is not entirely consistent with other research. NESA professional development report (2017) rated face-to-face as first preference as did study by Aubusson et al. (2015). Although blended and online categories if combined would exceed face-to-face in preferences of learning environment part of the NESA report (p. 7) and primary teachers in this study did offer PLN as complementary to other forms of professional development. Furthermore Trede et al. (2019) write of work place learning and technology interfaces, as hybrid spaces, and networked online learning like primary teachers' purposeful use of PLNs, to improve their practice in science education, fits this descriptor well.

Employers may be re-assured that primary teacher participants in this study articulated ways their PLN use, for their own professional development, was linked to learning ways to teach differently from previous practice, for the improvement of their students' learning. A PLN was reported to be useful for actively learning inspirational new ideas; planning and learning ways to implement those ideas in the classroom from effective models, expert collaboration, coaching and mentoring in job embedded contexts; evaluating (to a lesser extent) and sharing the results; reflections about these results discussed openly with colleagues, who were respected and sustained over time for generous feedback when asked. These were well-evidenced ways for employers to note that primary teachers utilised online PLNs which satisfy most of Darling- Hammond et al.'s seven criteria for effective professional development (2017) usually describing provided teacher PDPs.

Further, teacher participants found using a PLN made reflecting on newer educational theories, research findings and advances readily accessible. The collective activities of sharing, raising and answering questions, solving problems of practice and availing themselves of more development experiences for which PLNs are accepted to provide (Nijland et al., 2018) became personally applicable knowledge, according to participants. Expert interactions were regarded as valuable in helping to develop their professional knowledge of science education, at times using co-teaching contexts, with perceived benefits for their students' current learning and aspirational value for learning for students and teachers alike. Pedagogical content knowledge (PCK) was often shared, less-frequently yet valuably co-constructed. Curriculum knowledge and to a lesser extent content knowledge (CK) were reciprocally shared and distributed within online PLNs becoming selectively individualised, intrapersonal knowledge pertinent and valued for self-directed, ongoing professional development by primary teachers of science. However Opfer and Pedder (2011) noted "although an individual teacher's orientation may lead him or her to participate in professional learning activities, the access, support, and encouragement to participate are heavily determined by the school" (p. 393).

Employers who appreciate the value of PLN activities, may adopt clearer expectations around using PLN as teacher identified professional development. Only 29% of primary teachers surveyed in this study agreed employers recognised their PLN activities as PD which indicates more explicit ways to document this form of self- identified development need to be established. Although Shulman (1987) warned against general teaching principles becoming prescriptive as they can be used judgmentally and ineffectually as measures of teacher efficacy. Attempts to require, curtail or regulate teachers' PLN use may be counter-productive (Krutka et al., 2017; Unger, 2019) as indicated by another survey item in this study which showed primary teachers were least likely to add to their PLN on the basis of employer recommendations (see Figure 4.14). So the recommendation for greater employer recognition of primary teachers time spent on valuable science professional development beyond work hours is made while acknowledging that self-direction in using a PLN was highly valued by 86 % of primary teachers as important. While an interesting finding for this study, teachers appreciating autonomy, agency and self- directed professional learning is not a novel finding (Kyndt et al., 2016; Korthagen, 2017; Tour, 2017; Vangrieken et al., 2017).

5.4 Value of primary teachers' PLN activities for professional development in science education

In answering the research sub-questions, this study suggests an answer for the overarching research question in that primary teachers' PLN activities have considerable value for science education professional development and potential for greater value. This study has highlighted that teachers' PLN activities contributed well to primary teachers' learning, knowledge building and shifts in science teaching can be considered as professional development in the way many of Darling-Hammond et al.'s (2017) criteria for effective TPD were evident during and subsequent to their online PLN activities. Primary teachers were inspired and supported in making changes to current practice and continual evaluations of this by self and others online. Experts were valued for their generous sharing of detailed, new science and technology PCK. Effective professional development criteria include: content focused within PCK; active learning utilizing adult learning theory; supported collaboration, typically in job- embedded contexts; using models and modelling of effective practice; coaching and expert support; chances for feedback and reflection and is of sustained duration (Darling-Hammond et al., 2017). Each criterion has been embedded in previous discussion to highlight relevant examples from the data which provided evidence of teachers developing professionally.

Further more teacher participants' perceptions were that learning through their PLN evoked reflection on practice, provided contexts for discussion and crystalised new ways of thinking about their science and technology teaching. These findings highlight the value primary teachers perceived of their PLN activities for contributing to their development as teachers of science and map onto aspects of Gess-Newsome's (2015) consensus model of science teaching professional knowledge (See Figure 5.1).

Proposed additions to the Gess-Newsome (2015) model, from evidence in this study, of ways primary teachers' used their PLN activities for personalised and collective purposes of developing science teaching knowledge, skills and professional identity are in italics font writing and their intensity of colour represents prevalence of theme in this study as summarised in Table 5.1 (See Figure 5.1).

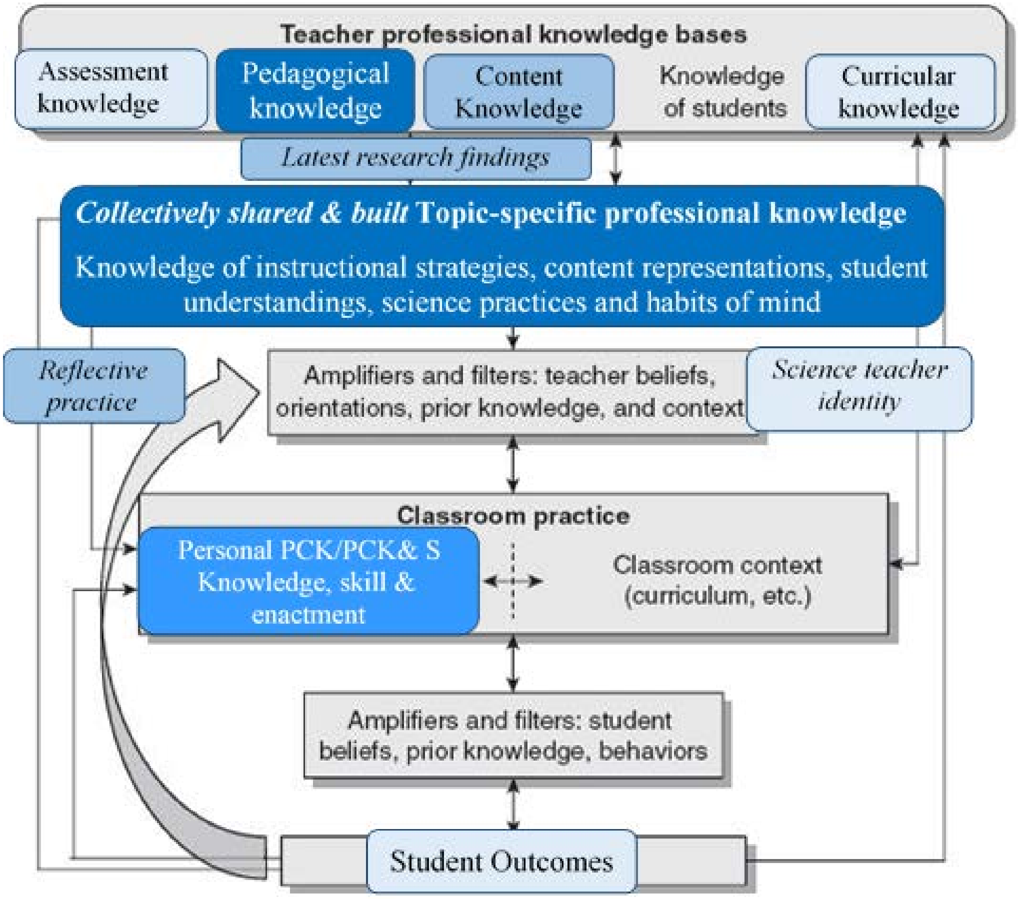


Figure 5.1

Primary Teachers' PLN Activities Value for Development of Science Professional Knowledge Mediated by Their PLN Activities. (Adapted from Gess- Newsome (2015) Consensus Model, p. 31)

Integration of quantitative and qualitative data from this international sample of participants has demonstrated that primary teachers perceived their PLN activities have value in contributing to their development of pedagogical knowledge generally. The perceived extent of this development effect, is denoted in Figure 5.1 by gradations of intensity of colour, palest blue for weaker through to intense blue strongest themed impacts. Although transposing general PK also had conflicting implications for science and STEM education.

PLN usage had more topic specific professional knowledge (TSPK) value in terms of shared instructional strategies and science practices aligned with primary specific curriculum, denoted by darkest blue in Figure 5.1. Teacher participants used their PLNs in supporting development of personalised PCK and PCK&S during implementation within primary classrooms. This was very interesting considering individual teachers had similar quests but such differing needs and zones of proximal development (Vygotsky, 1978) in terms of the problems of practice they may be trying to solve or refine. Yet the rich complexity of communal spaces and discussion groups across multiple platforms and contexts resulted in supporting the differentiation required by each primary teacher in perceptibly valued ways.

> As relationships are dynamic, it stands to reason that viewing practice as being problematic extends understandings of pedagogy. Pedagogy is complex and as teachers' learning about practice is enhanced through noticing, then pedagogy becomes both generative and informing as a consequence of an active and ongoing process (Loughran, 2013, p. 122).

New ideas for teaching and learning were highly valued in PLN activities regardless of teachers having varied educational backgrounds in science and science education. K-6 teachers' PLN selectivity and construction reflected this key purpose. The process of sharing expertise with co-regulated and less often socially shared regulation of learning contributed to teachers' constructing their professional identities as science teacher/mentor/early adopter of new science and technology teaching. Findings that their professional identity as competent, confident teachers of K-6 science was related to their ongoing PLN usage for further professional knowledge is represented as an addition to the Consensus model (see Figure 5.1).

PCK was collective and yet able to be personalised and PCK&S was supported even through co-teaching with experts. PCK at a topic specific level (Gess-Newsome, 2015) and pertinent to primary curriculum were popularly discussed online, (74%) of primary teachers surveyed were in agreement (agree and strongly agree combined) that they used their PLN to access primary topic specific science curriculum knowledge. Shout outs for ways to teach learning about forces effectively using Rube Goldberg resources; ways to teach website design from industry specialist, then adapted for younger learners; creative ways for students to meaningfully demonstrate and record their most recent research about science and STEM projects; furthering knowledge of Earth in space using social media instant links to live ISS feeds; ways to utilise meteorological tools for monitoring weather from local community research facilities are just some of the examples provided by primary teachers during this study.

PLN activities have diverse and immense practical value for primary teachers professionally as they actively develop their topic specific science PCK and share those possibilities with others. Furthermore teachers learning content knowledge and PCK&S within the same environment that they teach and concurrently with their students, using global reach to diverse experts are distinct advantages to PLN professional development. Primary teachers further developed their nature of science knowledge or the more epistemic CK of science through these PLN activities of observing and liaising with scientists and other experts. These active practices contrast with traditional methods which have been noted for the decontextualized out of the classroom and later problematic implementation with little support as being why they may not be successful at scale (Kennedy, 2016; Luft & Hewson, 2014).

To a lesser extent curricular knowledge was developed by primary teachers using a PLN for science professional knowledge development (denoted by mid-blue on Figure 5.1). This was particularly when there were newly introduced aspects of curricula, such as digital technology strands, and emphases within schools towards STEM education projects. Assessment knowledge and substantive content knowledge were part of PLN activities but less evident. In describing transposing general pedagogical knowledge (PK), assessment strategies were mentioned by participant teachers as being transferable to primary science. This would seem to indicate a closer link between general teaching PK and science PCK than Shulman (1998) described as quite separate. PLN activities were noted as providing access to interesting variations of assessment strategies shared by other teachers.

Yet development of science content knowledge (SCK or SMK) provides an undervalued possibility within primary teachers' PLNs. Primary teachers' participation was contingent, situation dependent and it would be of further value if these discussions were moderated by teachers with varying teaching experience, inclusive of most experienced and early career teachers, as well as science experts, science teacher associations, science associations and university discipline experts in science and primary education. Important discussions like teachers' understandings of topic specific concepts; collaborative planning of what to teach about a concept or what to avoid mindful of learners' possible misconceptions; access to experts for clarification; collegial argumentation about representations of content for primary school students are not yet sufficiently available.

Teachers learned and developed; refining or extending their science PCK&S during co-teaching contexts via technologies like Skype, with experts present in the classroom, using their valued PLN contacts. These professional development experiences also extended science epistemic CK and substantive CK learning opportunities for their students. Teachers reported perceptions of improved student learning as witnessed in their interest and engagement in science activities as well as more in-depth content knowledge which is a useful finding that needs to be followed up with student evidence in future studies. The palest blue "Student Outcomes" on the PCK model in Figure 5.1 is representative of this finding.

While there are underutilised possibilities within PLN's, participants reported numerous examples of the value perceived in contributing to aspects of their targeted, reflectively needs-based, co and share regulated, yet self-paced and managed professional development. As adult learners this collaboration and temporally concurrent collective work (Jarvela et al., 2015; Malmberg et al., 2017) autonomy, agency and critical reflection are highly valued (Rennie, 2019; Wang & Cranton, 2014). Educational institutions could make PLN construction affordances and constraints for science education more explicit for primary PSTs and employers could do more to recognise PLN value as professional development.

Primary teachers were accessing the latest science education research findings (almost as immediately as these were published, some even pre-testing and pre- publication hints and practices were available) through their PLN activities. This is a critically important part of primary teachers' ongoing professional development as research attends to all aspects of science professional knowledge in the “consensus model” and can influence assessment, curriculum advances, PK, content knowledge and PCK. For this reason, “latest research findings” has been added to the Consensus model in Figure 5.1. Encouraging documentation of this time spent could contribute further value of this time spent in work related, self-directed learning if it is a clearly articulated part of national standards documents; recommended and recognised perhaps but not required. This seems an important step when the majority of primary teacher participants were convinced of the value of their PLN engagement, for many as valuable as face-to-face professional development.

5.5 Limitations

A possible limitation of this study includes a voluntary participant sample incorporating enthusiasts in using PLNs for professional learning. Bradbury and Wilson (2020) found samples like this significantly changed the outlook on science teaching, and could perhaps limit generalisability to a general population of primary teachers, although teachers' tailoring a PLN to fit any professional needs would seem to mitigate that concern.

There may be other interpretations of the data, although several have been considered. The self-reporting from participants with reference to national teaching standards documents have given ways to further ascertain value for professional development.

All Phase 2 participant teachers expressed feeling positive towards teaching science and, many had specialist roles in science or STEM which could be considered a strength given the detail of their responses, or a limitation of the voluntary sample (despite disparities in perceptions and definitions of a specialist in theory and among participants). Teachers who are more reticent or less enthusiastic towards teaching science may have very different PLN usage and potential for professional development in science education from their online activities. Teachers who are less specialised may have a more general PLN with fewer science-focused links for a breadth of development in science education. Generalist and specialist primary science teachers' PLN activities could be explored for value in supporting their development and is recommended for future research.

The limited number of participants may have been due to primary teachers feeling uncomfortable with using PLN technologies for professional purposes. Small participant numbers impact transferability and subsequent use of this study to comment about the wider primary teaching profession.

Active PLN using participants may have communicated with each other about the research and similar views may have been put forward. Participant awareness of behaviours may affect behaviour during the study, comparable to that described by the Hawthorne effect. An example was when a Phase 1 participant who voided his anonymity by posting he had completed the survey, also wrote it had influenced his thinking about how to better use his PLN so others should do the survey too although it shows educational and tactical authenticity (Taylor, 2014) of the study.

A longer timeline for this study would have permitted more in-depth interviewing which may have resulted in more classroom level examples of new knowledge that resulted in shifts of teachers' practice as further evidence of their professional development.

Similarly with significant interaction excerpts, the absence of image analysis may be omitting significant evidence of development. Not quoting directly from parts of online interactions by participants due to confidentiality concerns may seem limiting.

In coding participant responses, prolific previous PLN literature had an influence on this researcher, affecting use of terms and observations made which may limit originality of descriptions, even though this study explored a less researched context using a sample of participant primary school teachers.

Despite international distribution of the initial survey and invitation to participate in this study, only a small number of primary teachers from a few countries are represented which limited statistical testing possible, impacting quantitative report terms and generalisability. Although it is hoped the detail provided during qualitative analysis of findings presented in chapter 4 gives future researchers sufficient content for comparison or contrast.

Findings are continually emerging, from more recent research during the time that this thesis is being written up before publication which contribute to understanding the value of PLNs for professional development by a wider community.

5.6 Summary of chapter 5

Previous research literature has shown that PLNs have value for professional learning, supporting different ways that teachers engage in specific online contexts according to their needs, personalities, stage of career, professional problems and interests; and with the aim of leveraging and extending their PLN's usefulness (Carpenter & Krutka, 2014; Greenhalgh et al., 2020; Kelly & Antonio, 2016; Krutka et al., 2017; Lundin et al., 2017; Macia & Garcia, 2017; Maloney, 2015; Manca & Ranieri, 2017; Mercieca & Kelly, 2018; Oddone et al., 2019; Prestridge, 2017; Reasoner, 2017;Tour, 2017; Trust, 2012; Trust, 2015; Trust et al., 2016; Unger, 2019; Zhang et al., 2017).

This holistic study provides evidence that primary teachers were developing professionally using their PLN as outlined in the seven effective PD criteria by Darling- Hammond et al. (2017) while not all criteria are necessary all of the time. Teachers' perceptions that their collective PLN activities resulted in personally useable knowledge to support their ongoing professional development is in keeping with what Goodyear and Markauskaite (2013) call the "person-plus perspective" where "…actionable knowledge is co-constructed within different arenas of practice and culture" (p. 105). Primary teachers perceived that beneficial interactions within their science-focused PLN resulted in immediately actionable PCK and reliable professional relationships for expert advice.

In the online and blended contexts of their PLN interactions, primary teachers described individualised professional knowledge building as intertwined with the affordances of the multiple platform spaces, groups and individuals, similar to the model of a PLN suggested by Kearney et al. (2016). Most primary teacher participants further reported that PLN contexts supported individual reflection, crystallised thinking, and collective PCK sharing. For a few participants, perceptions were that student learning outcomes were subsequently impacted positively, for most student interest was perceived as improved. This pedagogical shifting can be interpreted as significant in this study in that primary teachers' professional growth through collective PLN activities offered considerable development value.

Key findings of this study were that participants reported their online PLNs were intentionally constructed across multiple contexts and refined selectively so professional relationships and activities had reliable, high value. Primary teacher participants were influencing, updating, broadening and refining collective and individualised science PCK through contingent participation online with assorted valued experts. Realistic depictions of actionable knowledge from PLN activities such as primary school appropriate resources and, topic-specific pedagogical knowledge (TSPK) was highly valued. Primary teachers found online collegiality to be affirming of their new practice and intended change as well as supporting this development process (PCK&S), thus offering value and distinguishing PLN activities in this way, from other forms of professional development.

Regardless of generalist or more science-specialised roles, participant primary teachers were seeking new ideas for practice to enrich academic CK and epistemic CK or NOS, for themselves and their students, often repurposing general PK in applying it to science learning contexts (not always advisable), or updating their science and technology PCK with online mentoring and support inclusive of access to the latest research findings in science education. Additionally, PLN participation provided competition, a motivating impetus and inspiration for professional development for other teachers suggesting further value. Although controversial interactions, self- promotion or insufficient PCK information were perceived to inhibit participation value, professional identity was also co-constructed during PLN interactions, with teachers perceived (and perceiving themselves) as a progressive early adopter of science and technology or as a reliable mentor for others to ask questions. A lack of employer recognition of PLN activities as being useful as professional development for teaching standards accreditation maintenance was noted as problematic and perhaps inhibiting wider take-up and valuing of PLN activities.

This study has presented evidence supporting that primary teachers' activities in online informal PLN contexts mediated instances of individually and collectively relevant, immediate, practically-applied professional development value. In addition, PLN activities with aggregating and management strategies allowed for delayed, future– realised, intentional TPD value. Further personalised value for science TPD arose from building and sustaining long term professional relationships, as well as communal value (with other teachers, professionals, colleagues, experts), for professional development such as improved PCK, TSPK, PCK&S and CK in science education, to varying extents (see Fig 5.1). The value that primary teacher participants perceived in their PLN activities, for evident professional development, was considerable for science education, although not exclusive to it.

The conclusions, implications and suggested future directions, for primary teacher professional development in science education, emergent from this set of interpreted, integrated findings, as to the value of PLN activities, are explored in the next chapter. Implications apply to pre-service and employed teachers, providers of professional development for primary teachers, teacher educators and employers. Future directions of research relate to extending on the findings of this study investigating further value for primary teachers in developing their knowledge and practice for science education through their online PLN activities.

Chapter 6 Chapter 6: Implications, Future Directions for Research and Conclusion

The findings from this study suggest some implications for possible future action. Primary teacher participants perceived varied and considerable value from their online PLN activities in contributing to their professional development in science education. The future directions for research, presented in this chapter, are recommendations to contribute to an important and timely agenda investigating further value of PLN activities pertinent to primary teacher effective professional development in science education.

Different interest groups such as pre-service and in-service teachers at all career stages, TPD providers, academic teacher educators and employers of primary teachers of science are represented in the suggestions for ways this study could impact future professional development options.

Concluding remarks aggregate the complex amalgam of value that PLN activities potentially offer primary teachers, who seek informal professional development such as effective professional knowledge and skills growth for teaching science, through networked quality relationships, in multiple online contexts.

6.1 Implications for Primary Teachers

Primary teachers in this study gained considerable value from participating in online PLN activities such as up-to-date and readily convenient, actionable science and technology PCK. Participants were content with the quality and the variety of contexts and relationships they built over time to inform their continually developing teaching of primary specific science and technology. Topic-specific PCK was particularly well- supported within online contexts and opportunities for further professional development on and offline were also valued. Syntactic CK or nature of science evident online from practices of scientists was valued. On occasions, scientists were invited to have a remote classroom presence, available as expert models for teachers and students, mentoring effective practice in conducting various science inquiry lessons and experiments.

Primary teachers found this expert mentoring activity refreshed and refined their own understandings of science processes and knowledge which imbued confidence for their own practice. Some teachers were excited that substantive CK for them and their students could be learned in greater depth from contacts made through their PLN with other schools and educators online with specialist knowledge.

While self-directed, self-, co-, and socially-share regulated learning are characteristics of participants' interactions within online spaces, there is an argument for some more explicit instruction in the possible ways for primary teachers to effectively access, aggregate and curate a PLN. Primary teachers could benefit from learning about ways that selectivity of their preferred platforms can impact their professional development in terms of time and quality. Learning about effective curation strategies from others, could add value to their PLN, for example promoting reflection on their own practices and keeping up with knowledge of advances in science education.

It would be worthwhile to see more PCK, that is specifically science content- related shared online. There is scope to extend existing online discussion groups and even begin new ones where science content is more of a feature to better support primary teachers in the development of their science content knowledge, using a variety of expert advice available, while acknowledging it is present within certain PCK discussions. An example might be discussion of ways to elicit students' conceptual understandings and address their more common misunderstandings around certain science concepts. Substantive CK discussions may be more prevalent in high school science teacher chat spaces, and the generality or extent of this could be explored in future research. Regardless, there needs to be more primary science expert-moderated science discussion for primary-specific contexts as knowing the level of complexity with which to explain a science concept and interpretation of curriculum (newer versions) can be difficult as reported by some participants who noticed this challenge from other teachers' questions arising in PLN spaces.

Teachers, scientists and other educators could collectively build a repository of professional science CK, through their PLN interactions, which should assist teachers in providing classroom learning that is suitably challenging and engaging for primary school students. PLN discussions could be used to greater advantage, in reporting the successes, but also including the non-successes which primary teacher participants noted as not so prevalent online. This development of strategic knowledge of precedents unknown to the individual teacher or when teaching a science topic for the first time offer helpful support from the collective and varied propositional and case knowledge of others (Shulman, 1986) within their PLN. Shared science PCK of successful practice examples and counter-cases would also be helpful to support changes in practice and reflecting on their PLN activities.

Themes from this research revealed new understandings about the general PK that teachers learn and share from their PLN activities. Participants adopted or repurposed general PK and integrated other key learning areas with science. Future- focused student learning approaches, with skills like critical thinking, design and problem solving were valued. Primary teachers have experience already working in a subject domain integrated way within a primary curriculum, which may be project-, topic-, thematically-, problem- , or inquiry-based, to facilitate understanding and relevance for their students. Interestingly, the reverse situation, of science skills being usefully integrated into other key content learning areas as described in the Wellcome Trust report (2019) was not as evident in this study. Primary teachers' PLN activities allowed them to learn about new ways to shift general PK to be useful for science, but there are limitations when science requires more domain specific PCK. Primary teachers could share views on key learning area integration for significant ways that enhance and do not diminish science discipline knowledge.

Development of PCK was not always science specific in the primary teachers' PLNs. Participants meaningfully integrated and reflectively critiqued new PLN-sourced STEM and technology ideas, practices and digital tools. Primary teachers could explore integrating technological tools in their teaching of science inquiry inspired and supported by knowledge and tools shared in their PLN. It would be advantageous for more teachers to explore the value of PLNs for knowledge of useful, newer digital and cognitive tools as internationally varied science and education research hubs, teacher groups and associations share these online for a collective PCK to improve student interest and outcomes in science.

6.2 Implications for Professional Development Providers

A larger emphasis on explicit teaching of PLN use, the benefits and constraints as understood by latest research, could augment or complement teachers' formal PDP with opportunities for effective primary science teaching, seems a logical follow on from findings in this study.

Furthermore professional development providers, such as tertiary educational institutions should feel an obligation to support their early career teachers (ECTs) while making transition to full time school teaching. Online moderation of PLN-based discussion by tertiary providers would seem to offer an avenue for graduates to maintain professional links and support with lecturers and other practitioners; utilising the broader networks of academics and science specialists with whom access might otherwise be difficult. ECTs using PLNs could offer support to implement new practices where school cultures can be slower to adopt change and perhaps ameliorate some reasons for early career attrition. Moderation of chats was perceived by most participants in this study to be a detraction, although enjoyed by others, so facilitating a range of educator voices (new, mid-career and experienced) with specific focus on science discipline knowledge, primary classroom teaching, and a knowledge of social media would ensure diverse representation of issues in science educational conversations.

Professional engagement, for this study's primary teachers included connections with university-school partnership events, teaching and learning projects, and the latest science education research findings attainable through their online PLN. These less formal, self-directed tertiary learning opportunities have value to in-service teachers, as several teachers in this study expressed feeling the effects of being a long way from their initial teacher educational preparation. More moderation and presence by university science, science education and science teacher education academics' in chat sites supporting science and technology could be positive for teachers' professional development. Teacher participants in this study reported feeling more confident with affirmation and advice given within reliable relationships by knowledgeable others online which aligns with Primary School Science Teaching Survey Report (Watson & Watson, 2014) where a majority of teachers would like to be mentored in science education. Access to quality advice through PLN activities could counter historic issues of lack of science CK and PCK support, which, along with a busy curriculum, have resulted in science as scarce in a primary school timetable, averaging 1-2 hours (Watson & Watson, 2014). Academics' presence in online discussions could perhaps focus on academic CK, latest research on children's science understandings, sharing research practices to support teacher action research, and likely areas of contention, based on teaching experience.

PLN activities offer sustained support with many participants commenting on long-term professional relationships as valuable during times of implementing science curriculum that was new to them. Science teacher educators could take a role in joining PLN spaces to support teachers in their incremental development towards teaching using latest curricular knowledge such as new science, technology and STEM introductions. A greater variety of mentors, all with a primary school focus, adds to the plural voices of classroom teachers which could offer a beneficial nexus of research and practice and further professional development opportunities.

The detailed nature and content of primary teachers' online interactions in their PLNs, with experts and varied educational, science and associated industry professionals resulted in interactions characterised by quick questions and answers but also more protracted comparing of pedagogical approaches and cognitive models exceeding teaching tips. Substantive topical discussions of pedagogical issues and advancements were shared even if in grammatically truncated and abbreviated formats.

In the interests of future interdisciplinary research, software developers may be interested that participant teachers found archiving of discussion threads in their PLN platforms and apps is currently unwieldy during and even after discussions. Existing software gave teachers the valued advantage of later perusal and revisiting PLN gathered PCK, resources and tools. However later editing is a step teachers with a moderator role found taxing and a detraction from sharing as their time is limited. So more sophisticated facilities might make this process of sharing and redistributing (minus duplicated retweets) more useful and is an area worthy of consideration for platform specific software by developers.

Primary teachers enjoyed the multimodality of representations and imagery (visual and linguistic) possible within existing platforms for sharing their teaching ideas and practices. Participants commented on insufficient or unrealistic detail provided within postings for useful application in their own teaching environments. Although the influence of multimodal communication, for example the integration of imagery and professional development practices needs to be further investigated. One detraction was PLN platforms with too much advertising and product promotion. Many teachers selectively evolved their PLN to minimise these distractions with only one participant capitalising on their presence to access resources for his school.

Restrictive algorithms with localised searches; feeds with dubious agenda-driven prioritising of some posts over others; and where security measures of platforms were ineffective in blocking of impolite or inappropriate posts were limitations noted by two primary teacher participants.

6. 3 Implications for Pre-service and In-service Teachers' Professional Development

Beginning teachers and those teachers who are new to a PLN need explicit information about optimising their PLN construction. Their professional development may depend on effective management strategies, for example, use of selectivity rules, aggregation and curation with digital tools. This PK of PLN construction and management could also help to keep their time spent online efficient for organisation. This knowledge can be shared with PSTs along with ways that teachers have learned science PCK through their PLN engagement.

Primary teachers who were the only science, technology or STEM specialists in their school actively sought wider professional engagement through their PLN to further their own skills. There was important flow-on value in motivating others within their school to also upskill pedagogically. This study's participants described using their PLN interactions in Facebook, Twitter and other platforms, some using feeds from science educational institutions and associations to learn ways to implement new practices that were then shared with staff in their own and other schools.

PLN activities can support a niche group of teachers, for example, in upper primary school in order to facilitate students' smooth transition to a senior science curriculum and the requisite content, skills required and expectations of prior knowledge by high school teachers. Other PLN niche groups that primary teacher participants found useful formed around communal interest of ways to integrate technology meaningfully into science and STEM teaching and student learning. Generalist and specialist primary school teachers of science in this study perceived PLNs as having value in this way. There may be much to be learned in the ways these different groups of teachers use their PLNs for science and other disciplines and more research is recommended in this area.

On the basis of the findings from this study, it is recommended that pre-service teachers explore and be encouraged to learn varied activities and ways that online participation within broader education, research, and industry networks can begin, and extend, with their evolving practice and professional development needs. Mindful of the self-directed appeal of PLNs, primary teachers' co-produced resources and their own action research, and beginning teacher experiences could be valuably shared in their PLNs.

The support and learning within a selectively constructed PLN has professional development value for pre-service teachers, new teachers of primary science as well as their more experienced colleagues with the benefits of personalised, authentic, collaborative mobile learning (Kearney & Maher, 2019).

6.4 Implications for Employers of Primary School Science Teachers

In making recommendations for employers, there is little contention and much evidence to support the promotion of PLNs for teachers. PLNs by definition (Trust et al. 2016) are built through on and offline networks and most teachers commented on the interplay of these blended contexts as being crucial to their ongoing professional development. Employers could better accommodate and recognise teachers' participation in self-regulated, professional development activities in online informal contexts as intentional and having considerable value. Value extends beyond the resources and networking available within primary teachers' immediate workplace, but with positive repercussions for the work place, as new science PCK is shared among staff.

Primary teachers in this study had obviously different current priorities, levels of expertise and need, personal and school aligned goals, for their professional development. A self-identified PLN caters to these individual differences and self- regulation appeals to a teacher's sense of independence, agency, timing and purpose. Participants' PLNs and their development as science teachers evolved over time with reprioritising as they made changes to their PCK&S, often based on activities learned through their PLN. Employers if aware of these benefits may appreciate the value of this dynamic form of professional development: more immediately responsive to teachers' needs and recent research, than formally provided TPD might allow. At the very least, primary teachers' PLN activities offer a complement to provided sessions at a professional development juncture, implementation, where formal programs are known to be limited in effect without longer-term post program support. Teacher participants also engaged in PLN activities that preceded formal TPD such as webinars, face to face conferences, workshops and informal but organised professional development like TeachMeets. PLN activities were perceived by teacher participants as useful and complementary to other forms of TPD and could be encouraged and formally recognised by employers and formal TPD providers for this purpose.

For some teachers, the process of building and using a PLN at all could be professional development, as zones of proximal development are highly personalised. For others, evolving their PLN will be a necessary extension of already proficient and prolific activity characterised by frequent wider professional engagement. PLNs offer spaces for professional commitment activities like mentoring early career teachers. Some employers in Australia have shown immensely progressive and future-focused thinking in recognising the value of online formal and informal PLNs as contributing to the self-directed, teacher identified component of required professional development for maintenance of accreditation as found in the national teaching professional standards documentation (NESA, NSW Education Standards Authority, Australia). There is the limitation that quality of PLN interactions may indicate differences in professional development value that needs to be recognised by employers' documentation. The wording of professional standards documents and logging time spent online could be clearer for employees and more indicative of its value to employers.

Autonomy was highly valued when using PLNs to develop professionally by primary teacher participants in this study. This high value of autonomy for educators learning professionally using PLNs is not unique to this study (Pataraia et al., 2015; Tour, 2017) so employers need to be mindful that while their acknowledgment and support of PLN and online complementary PD activities are important, so is the self- directed nature, selectivity and choice retained by an individual teacher. In this study, participants' PLN activities were meeting many of the criteria usually expected of provided programs (Darling-Hammond et al., 2017). Perhaps the definition of teacher professional development needs to be extended to encompass self-directed activity as well as formally provided programs, since regardless of what is provided it is the teacher who is actively doing the relevant development of professional knowledge and practice (CK & PCK).

6.5 Suggested Future Directions of Research

Refining their PLN to ensure a quality of advice and information with which they were satisfied was a priority achieved by participants in this study. However, a further research direction is to investigate the current diversity of primary science education commentary online in PLNs and ways this could be improved, perhaps with more Indigenous science knowledge expert presence, if needed, to boost professional development in primary science education. Science and technology PCK exemplar activities from different international experts and associations were available online according to primary teachers in this study.

Development of content knowledge (CK), subject matter or discipline knowledge (SMK) has been suggested for decades as being crucial and requiring greater attention amongst primary teachers. So while the use of a PLN has yet under actualised possibilities to support these outcomes as discussed in section 6.1, it would be useful to further explore when and how primary teachers develop their existing science CK within PLN spaces. While this study found some similarities and few differences, there could be useful things to be learned and shared of specifically different ways that generalist and specialist teachers of science use their PLN, to develop professionally that could inform future teacher development.

The value that multimodal posts provide within these online PLN interactions and platforms is worthy of further exploration as teachers in this study reported that use of imagery could have motivating and inhibiting effects on their development. Taking up ideas suggested or dismissing them as unrealistic, unattainable or impractical for their own classrooms depended on these multi-modal communications. Teacher participants were exercising some important professional critique in evaluating these visual representations of science teaching practice. However detailed analysis, and understanding, of the multimodal posts, would be beneficial to understand the nature and extent of their impact on teachers' professional development.

Documentary evidence of primary teachers' changed practices, shifts in planning lessons and implemented approaches along with student work samples, would be valuable considerations for future research. This includes exploring the aspects of science education that general PK best supports through PLN activities but also the aspects of science education learning that can be generalised to other key primary subject curricula. This could enhance value for primary teachers who not only need to improve science CK and PCK but are responsible for integrated teaching of other curricula when working as generalist classroom teachers.

More studies could be conducted to account for the detail in student learning outcomes. Primary teachers in this study perceived their PLN inspired practices often increased students' interest and engagement. Possible longer-term effects could be investigated into later subject and career uptake in science and technology. Several teachers in this study perceived *academic* science learning outcomes being positively impacted as a result of their own PLN activities, substantiated with examples of extending content knowledge and understanding beyond primary curricula outcomes.

Employers in meeting the request, from some primary teachers in this study, for acknowledgment of their time spent professionally engaging with a broader network of colleagues and experts, may need to explore ways to make explicit which PLN activities are worth documenting as accreditation-worthy professional development beyond formally provided PDPs. Participants in this study were selective and reflective of the PCK learned through active sharing of new ideas within their PLN informal contexts. The wording in professional teaching and development standards documentation needs clarity as to the ways that primary teachers' PLN activities within informal contexts (such as social media platform supported science educational chats) can be logged in terms of hours that build towards required TPD.

6.6 Conclusion

Knowledge and experience of PLN construction and management would seem to have value as pre-employment preparation for teachers. Describing the potential of PLN activities for practising teachers' development in primary science education requires an understanding of the complexity of teachers' background knowledge. Shulman (1987) outlined, the importance of knowledge of: students, curriculum, content, purpose for the education, general pedagogical knowledge, understanding learning contexts and culture as well as pedagogical content knowledge "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of understanding" (p. 8). Subsequent academic work in this field, has expanded an understanding of PCK to include the development of skills in implementation of that content knowledge (PCK&S) (Gess-Newsome, 2015) or, personal to each individual teacher (pPCK), at a topic specific level (TSPK) (Gess-Newsome, 2015). More recent versions describe enacted PCK (ePCK) (Carlson & Daehler, 2019). In offering a revised version these authors remarked, "It is important to note that this model does not specify the mechanisms and pathways by which teachers strengthen their PCK for teaching science, change their teaching, or connect various knowledge bases" (p. 91).

Value assertions in this study are made in considering the criteria for effective teacher professional development as outlined by Darling-Hammond et al (2019) and the aspects of required science teacher background knowledge as described within the PCK consensus model (Gess-Newsome et al, 2015). Evidence from this study demonstrates that primary teachers' successfully used their online, informal and blended context PLN activities as an effective mechanism for promoting and supporting professional growth in aspects of science teaching knowledge and practice.

To address the research questions of this study primary teachers perceived their PLN activities had considerable value in more emergent PCK&S as well as general PK, sometimes adapted and repurposed for science from other disciplines. Primary teachers sharing progressive teaching ideas and advice online amongst numerous experts and teacher colleagues, at times co-teaching online with science experts. These PLN activities, participants asserted, contributed to more in-depth CK and affective value for themselves and their students. These represent aspects of individual teacher's PCK for science through using their PLN. Affinities of PLN activities with the nature of science, another aspect of CK (Anderson & Clark, 2012; Gess-Newsome et al, 2017) allowed primary teacher participants to refresh and refine their epistemic knowledge of the nature of science from scientists and others. PLN activities were amplifiers of reflective practice, allowing for later consideration of newly learned knowledge of ways to teach content and refine their teaching skills. In this study were participants accessing latest educational research which also extended their content knowledge; developing ways to focus their goals for inquiry-based and future-relevant student learning; and co-constructing their own science teacher identity. In light of these findings, this study defends the definition of a PLN that pays tribute to Shulman's understanding of the complexity of teacher knowledge to include "complex amalgums" (Trust et al., 2018, p. 1).

This study presents evidence with thick description showing the capacity of PLNs for promoting and supporting teachers' professional growth. PLN activities are complementary to other forms of TPD but primary teachers in this study also perceived value from their PLN interactions which was distinctive in facilitating self-directed, sustained, personalised, contextually relevant, practical ways of developing professionally (see previous chapter, section 5.3.4).

Multiple kinds of practical and aspirational value in taking up further professional opportunities, due to the range of activities within multiple blended contexts characteristic of their PLN were noted by participants. However value was somewhat constrained by primary teacher perceptions of low employer recognition of PLNs for professional development.

Future research directions could include investigating the impacts of multimodal science posts on value for teachers in developing their science PCK. Perhaps the ethical considerations in sharing pictures of students at work needs closer consideration. It could be useful to understand whether explicit information about strategies for leveraging PLN value, for inspiration and support in learning about science education, and opportunities for teacher development throughout a career, is effective for PSTs. Another area of study is to explore if moderating, by more teachers of varied career stages and diverse experts (scientists, STEM, industry, teacher educators and teachers at different career stages) has an improved professional development value in terms of scope and quality of interactions. It would be helpful to understand the ways in which the facilities in different emerging online platforms might improve aggregating and archiving processes so that teachers can better reflect on their PLN sourced ideas and improve collective and/or personal PCK.-It is important to investigate ways that quality of PLN interactions can be verified to employers' satisfaction for documentation. With the main limitations of this exploratory study being a small sample, and teacher self- reported measures, future research with differing methodology mapping teachers changed practice, perhaps lesson planning, pedagogical reasoning and PLN activity as well as student work artefacts, is recommended with a larger and wider international representative sample.

The evidence from answering this study's research questions makes a contribution to understanding the value possible from primary teachers' PLN interactions; the detailed nature of their activities, and ways participants perceived they are developing as science teachers. Participants offered numerous examples of changes in their professional knowledge and practice; some reported noticeable impacts on student learning. Primary teachers' informal, but intentional, self-directed activities within their PLN inspired reflection on and learning of science PCK in ways that satisfied many criteria for effective TPD usually expected of formal programs. This study acknowledges the scant discussion of science subject matter knowledge. Greater scope and depth of primary science topic specific content in online PLN multiple contexts could add value for primary teachers developing science pedagogical knowledge. There was an evident lack of SMK based discussions within primary science teacher PLNs during this study which could be addressed to extend value. Participants perceived that their personally selective construction of a poly-contextual PLN and subsequent participation in online activities contributed considerable value. Value was perceived by participants in developing as more confident and inspired primary teachers, at the forefront of pedagogical advances, and for the benefit of their students' learning. Primary teachers in this study described in detail the nature and extent of their PLN activities, as having considerable professional development value across subjects, crucial for a generalist, and contributed to their own and others' development of knowledge and skills in science education.

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Appendices

Appendix A: Approvals, Participant Information and Consent Forms.

This appendix contains study approval from the University Ethics Committee, participant information and consent forms for each of the three study phases. The text has been reduced to fit pages.

Document A1: University Ethics Committee Approval Granted Email

Document A2: Phase 1 Participant Information and Consent Form

Document A3: Phase 2 Participant Information and Consent Form

Document A4: Phase 3 Participant Information and Consent Form

Document A1: University Ethics Committee Approval Granted Email

This letter of University approval was received via email 17/07/2018.

Dear Applicant

Your local research office has reviewed your application titled, "Exploring Primary teachers' Professional Learning Network (PLN) activity for potential value as professional development in science
education.", and agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application, subject to any conditions detailed in this document.
You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy (http://www.gsu.uts.edu.au/policies/research-management-policy.html).
Your approval number is UTS HREC REF NO. ETH18-2569.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.
The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat (Research.Ethics@uts.edu.au).
- The Principal Investigator will notify the UTS HREC of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions can be found athttps://staff.uts.edu.au/topichub/Pages/Researching/Research%20Ethics%20and%20Integrity/Human% 20research%20ethics/Post-approval/post-approval.aspx#tab2.
- The Principal Investigator will promptly report adverse events to the Ethics Secretariat (Research.Ethics@uts.edu.au). An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.
- The Principal Investigator will report to the UTS HREC annually and notify the HREC when the project is completed at all sites. The Principal Investigator will notify the UTS HREC of any plan to extend the duration of the project past the approval period listed above through the progress report.
- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).
- The Principal Investigator will notify the UTS HREC of his or her inability to

continue as Principal Investigator including the name of and contact information for a replacement. Letter of permission continued.

We also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

You should consider this your official letter of approval.

If you have any queries about this approval, or require any amendments to your approval in future, please do not hesitate to contact your local research office or Research.Ethics@uts.edu.au.

--------------------------------------- REF: 12a

Document A2: Phase 1 Participant Information and Consent Form

PHASE 1 SURVEY PARTICIPANT INFORMATION & CONSENT SHEET

"Exploring primary teacher's Professional Learning Network (PLN) activity for potential value as professional development in science education

UTS HREC APPROVAL NUMBER ETH18-2569

WHO IS DOING THE RESEARCH?

My name is Ruth Fentie and I am a PhD student at UTS. My supervisor is Assoc. Prof.
Matthew Kearney (email : Matthew.Kearney@uts.edu.au Phone +612 9514 5165).

WHAT IS THIS RESEARCH ABOUT?

This research is about exploring the ways primary teachers select and construct Professional Learning Networks (PLN). It aims to understand the detail of online interactions within primary teachers' PLNs for ways that using a PLN contributes to their science teaching. A further focus is on primary teachers' perceptions of different ways they are developing professionally through PLN activity.

WHY HAVE I BEEN ASKED?

You have been invited to participate in this study because you are a primary (elementary) teacher of science.

Whether you are a K-6 classroom teacher of science or specialist science primary teacher, you have a strong interest in science education, an online Professional Learning Network (PLN) and so meet the criteria for this project sample..

PLN is defined in this study refers to all of your social media links, digital tools, resources and people that you interact with for teaching purposes on a regular basis. **This is not focusing on networks used for personal purposes.**

Your important contribution to this research will be appreciated and could help inform professional development in science for primary teachers.

IF I SAY YES, WHAT WILL IT INVOLVE?

If you decide to participate, you are invited to complete this international online survey.

Phase 1 - Survey

You will be asked to answer an online questionnaire about your PLN activity with a focus on science based content or aspects of your PLN. Question types include some demographics, closed response items, rating style items, and a few open –ended items.

Your time taken approx. 20 mins.

Your time contributing to this research will be appreciated.

On the last page of the questionnaire you will be invited to join another phase of the study. You can choose if you want to participate further or not.

ARE THERE ANY RISKS/INCONVENIENCE?

DO I HAVE TO SAY YES?

This is a low risk study and your confidentiality will be maintained.

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part.

WHAT WILL HAPPEN IF I SAY NO?

If you decide not to participate in this survey, it will not affect your relationship with the researchers or the University of Technology Sydney**. If you wish to withdraw from the study once it has started, you can do so at any time without having to give a reason,** by contacting Ruth Fentie, email: Ruth.Fentie@uts.edu.au or Matthew.Kearney@uts.edu.au

If you withdraw from the study, we understand you will not be completing the further phases. If you decide to leave the research project, we will not collect additional information from you, although information already collected will be retained to ensure that the results of the research project can be measured properly and to comply with law. You should be aware that data collected up to the time you withdraw will form part of the research project results.

CONFIDENTIALITY & CONSENT

By completing this survey you consent to the researcher collecting and using information provided about you for the research project. All this information will be treated confidentially.

The researcher will only collect your name and email contact details if you wish to participate in further phases after the survey or go into the draw for a chance to win one of 4 book vouchers each one valued at $50 USD. All data collected will be de-identified, coded numerically and stored securely in UTS facility for use only by this research team, so risk to confidentiality is very low.

Your contact details will not be linked to this survey. Your information will only be used for the purpose of this research project and it will only be disclosed with your permission, except as required by law.

We plan to discuss and publish the results for completion of this doctoral thesis and as part of the expectations for the degree, at conferences. Research design and results may also be published in relevant educational journals. In any publication, information will be provided in such a way that you cannot be identified.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact us on email: Ruth.Fentie@uts.edu.au or Matthew.Kearney@uts.edu.au You can print a copy of this document to keep. If you wish to be kept up to date with the results once analysed please email me.

NOTE: This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

Document A3: Phase 2 Participant Information and Consent Form

PHASE 2 ONLINE VIDEO CONFERENCE PARTICIPANT INFORMATION & CONSENT FORM

"Exploring primary teacher's Professional Learning Network (PLN) activity for potential value as professional development in science education"
UTS HREC APPROVAL NUMBER ETH 18-2569

WHO IS DOING THE RESEARCH?

My name is Ruth Fentie and I am a PhD student at UTS. My supervisor is Associate Professor Matthew Kearney (email : Matthew.Kearney@uts.edu.au Phone +612 9514 5165).

WHAT IS THIS RESEARCH ABOUT?

This research is about exploring the ways primary teachers select and construct Professional Learning Networks (PLN). It aims to understand the detail of online interactions within primary teachers' PLNs in terms of potentially contributing value to their science teaching. A further focus is on primary teachers' perceptions of different ways they are developing professionally through PLN activity.

WHY HAVE I BEEN ASKED?

You have been invited to participate in this study because you are an in-service (employed), primary K-6 teacher of science, and so meet the criteria for this project sample.

You have a strong interest in science education and a Professional Learning Network (PLN) described here as collectively all of your online social media interactions, links, digital tools, resources and people that are part of your professional learning.

Your important contribution to this research will be appreciated and could help inform professional development in science for primary teachers.

IF I SAY YES, WHAT WILL IT INVOLVE?

If you decide to participate in the second phase of this research:

- You will be asked to participate in one online videoconference (with the researcher via Zoom). You are invited to share your thoughts and answer questions about PLN activity with focus on science education (semi-structured interview). This discussion will be recorded (can be just audio if requested, only for purposes of transcribing accurately). Your time taken approx. 20-30 minutes.

At the end of this time I would like to invite you to continue (totally optional) to:

- collect 3 significant interactions (conversation threads) via screen shots & reflect on your choices using a template (provided by researcher, 1 pg grid per interaction) giving a 1 school term (9-10 week) time frame for collection of the 3 interactions and 3 reflection grids. Your time taken 1 and ½ hours spread over 1 school term and I would be keen if you want to discuss your selections later.

ARE THERE ANY RISKS/INCONVENIENCE?

Yes, there are some risks/inconvenience. The main inconvenience is the time commitment to participating when teachers are already very busy. Online videoconference via Zoom is to avoid participants having to travel and will happen at a time that is mutually convenient (negotiated by researcher & participant).

Agreement to participate in this and optional further phases will mean the researcher retains your name, email and contact details but all data gathered will be de-identified and stored securely in UTS facility so risk to confidentiality is very low, however anonymity is not possible. Discussion will be recorded, which may cause some embarrassment or discomfort to participants but this is only for purposes of accurately transcribing interactions and will be de-identified with pseudonyms given for any publication.

Data collected is self-selected and sent by you to researcher via email and stored in university data storage to maintain confidentiality.

DO I HAVE TO SAY YES?

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part. You can choose at completion of this phase whether you can participate in the next phase or not

WHAT WILL HAPPEN IF I SAY NO?

If you decide not to participate, it will not affect your relationship with the researchers or the University of Technology Sydney. If you wish to withdraw from the study once it has started, you can do so at any time without having to give a reason, by contacting Ruth Fentie, email: Ruth.Fentie@uts.edu.au or Matthew.Kearney@uts.edu.au

If you withdraw from the study, we understand you will not be completing the further phases. If you decide to leave the research project, we will not collect additional information from you, although information already collected will be retained to ensure that the results of the research project can be measured properly and to comply with law. You should be aware that data collected up to the time you withdraw will form part of the research project results.

CONFIDENTIALITY

By signing the consent form you consent to the research team collecting and using information about you for the research project. All this information will be treated confidentially. The researcher will retain your name and email contact but all data collected will be de-identified & coded numerically and stored securely in UTS facility for use only by this research team, so risk to confidentiality is very low. Your information will only be used for the purpose of this research project and it will only be disclosed with your permission, except as required by law.

We plan to discuss and publish the results for completion of this doctoral thesis and as part of the expectations for the degree, at conferences. Research design and results may also be published in relevant educational journals. In any publication, information will be provided in such a way that you cannot be identified.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact us on email: Ruth.A.Fentie@student.uts.edu.au or Matthew.Kearney@uts.edu.au

You can retain a copy of this form to keep. You will also be provided with a copy of the results once data has been analysed.

X

STUDY PHASE 2 CONSENT FORM

"Exploring primary teacher's Professional Learning Network (PLN) activity for potential value as professional development in science education" *UTS HREC APPROVAL NUMBER ETH 18-2569*

I________________*[participant's name]* agree to participate in the research project "Exploring primary teacher's Professional Learning Network (PLN) activity for potential value as professional development in science education" *UTS HREC APPROVAL NUMBER ETH 18-2569* being conducted by Ruth Fentie UTS Sydney, Australia, supervised by Assoc. Professor Matthew Kearney ph: 612XXXXXXX.

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney.

I understand that I can download and print a signed copy of this document to keep

I understand and agree that this Phase 2 online discussion will be recorded.

I understand and agree that the research data gathered from this project may be published in a form that does not identify me in any way and may be used for future research purposes.

I am aware that I can contact Ruth Fentie (student researcher) or Matthew Kearney (supervisor) if I have any concerns about the research.

________________________ ________________

Signature of Participant. Date

__Ruth Fentie______________________ ________/2019______

Signature of Researcher Date

This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

Document A4: Phase 3 Participant Information and Consent Form

PHASE 3 INTERVIEW PARTICIPANT INFORMATION SHEET

"Exploring primary teacher's Professional Learning Network (PLN) activity for potential value as professional development in science education"

UTS HREC APPROVAL NUMBER 18-2569

WHO IS DOING THE RESEARCH?

My name is Ruth Fentie and I am a PhD student at UTS. My supervisor is Assoc. Prof. Matthew Kearney (email : Matthew.Kearney@uts.edu.au Phone +612XXXXXXX).

WHAT IS THIS RESEARCH ABOUT?

This research is about exploring the ways primary teachers select and construct Professional Learning Networks (PLN). It aims to understand the detail of online interactions within primary teachers' PLNs in terms of contributing value to developing their science teaching. A further focus is on primary teachers' perceptions of different ways they are developing professionally through PLN activity.

WHY HAVE I BEEN ASKED?

You have been invited to participate in this study because you are an in-service (employed), primary (elementary) teacher of science, and so meet the criteria for this project sample.

Whether you are a primary school classroom teacher or specialist science primary teacher, you have a strong interest in science education and an online Professional Learning Network (PLN). Your PLN is described here as collectively all of your online social media interactions, links, digital tools, resources and people that are part of your professional learning.

Your important contribution to this research will be appreciated and help inform professional development in science for primary teachers.

IF I SAY YES, WHAT WILL IT INVOLVE?

If you decide to participate, welcome to phase 3 of this research. You will be asked **to take 4 weeks t**o:

Please make screenshots **from 3 conversations** that you feel were of **value to you in developing professionally as a teacher of science** (any social media, online platform/s, multiple is fine).

This is a focus on your own professional learning, rather than e-learning for students.

You can **screen shot, copy & paste a conversation thread, or screen**

videorecord (e.g. QuickTime) however is most convenient for you. If you are concerned about others' names in your chat history please contact me to discuss a solution.

1. Please **evaluate ONE of these conversations** you selected for its value to you in developing professionally as a teacher of science **by completing the attached template.**
2. **Please send me by email items from STEPS 1& 2:**
   3 x significant interactions/conversations as documents or video-recordings
   1 x filled in evaluation template for 1 significant interaction.

3. Finally, a **quick (15 minute) follow-up audio interview** to address any other questions.
   Your time contributing to this research will be appreciated and it will hopefully inform your practice and could be used towards your own documented professional development activities.

ARE THERE ANY RISKS/INCONVENIENCE?

This is a low risk study. The main inconvenience is the time commitment to participating when teachers are already very busy. The interview will be conducted at a time that is mutually convenient (participant choice of before or after school, weekday or weekend).

Agreement to participate in this phase will mean the researcher retains your name, email contact details but all data collected will be de-identified and stored securely in UTS facility so risk to confidentiality is very low.

Interviews will be recorded (audio only) but this is only for purposes of accurately transcribing interactions and will be de-identified with pseudonyms given for any publication.

DO I HAVE TO SAY YES?

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part.

WHAT WILL HAPPEN IF I SAY NO?

If you decide not to participate, it will not affect your relationship with the researchers or the University of Technology Sydney. If you wish to withdraw from the study once it has started, you can do so at any time without having to give a reason, by contacting Ruth Fentie, email: Ruth.Fentie@uts.edu.au or Matthew.Kearney@uts.edu.au

If you withdraw from the study, we understand you will not be completing this phase. If you decide to leave the research project, we will not collect additional information from you, although information already collected will be retained to ensure that the results of the research project can be measured properly and to comply with law.

You should be aware that data collected up to the time you withdraw will from part of the research project results.

CONFIDENTIALITY

By signing the consent form you consent to the research team collecting and using information for the research project. **All this information will be treated confidentially**. The researcher will retain your name and email contact detail from phases 2 & 3 but **all data collected will be de-identified**, coded numerically and stored securely in UTS facility for use only by this research team, so risk to confidentiality is very low. Your information will only be used for the purpose of this research project and it will only be disclosed with your permission, except as required by law.

We plan to discuss and publish the results for completion of this doctoral thesis and as part of the expectations for the degree, at conferences. Research design and results may also be published in relevant educational journals. In any publication, **information will be provided in such a way that you cannot be identified.**

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact us on email: Ruth.Fentie@uts.edu.au or Matthew.Kearney@uts.edu.au

You will be given a copy of this form to keep. You will also be provided with a copy of the results once data has been analysed.

NOTE: This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

PHASE 3 STUDY CONSENT FORM

"Exploring primary teacher's Professional Learning Network (PLN) activity for potential value as professional development in science education"
UTS HREC APPROVAL NUMBER 18-2569

I______________*[participant's name]* agree to participate in the research project "Exploring primary teacher's Professional Learning Network (PLN) activity for potential value as professional development in science education" ***UTS HREC APPROVAL NUMBER 18- 2569*** being conducted by Ruth Fentie, University of Technology Sydney, 9514-2000.

I have read and I understand the Participant Information Sheet.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney.

I understand that I can keep a signed copy of this document.

☐ I agree to collect and share my self-selected online artefacts from my professional online networks with the researcher, sending these via email
I agree to also send 1 completed written evaluation using provided template to the researcher I agree that the research data gathered from this project may be published in a form that: Does not identify me in any way

I agree to be:

☐ Audio recorded in the interview (This data will only be accessible to the researcher and will only be used for research analysis by the researcher).

I am aware that I can contact Ruth Fentie or Matthew Kearney, if I have any concerns about the research.

______________________________ __________

Name and Signature [participant] Date

______Ruth Fentie________________________ __________/2019____

Name and Signature [researcher] Date

Appendix B: Phase 1 Survey Instrument Development

This appendix contains documents of the Design Features of the Survey Instrument and also the survey document before being put into Qualtrics.

Appendix B1: Design and Content features of the survey instrument

Design features	Survey Instrument content
Landing Page	The first page invited participants by offering title and details of the study; offered an incentive; provided a link to study information and ethical consent document; projected estimate of completion time; gave required instructions for completing the survey
Screening question	This was introduced to ensure that only primary teachers of science with an active PLN answered the survey (excluding high school science teachers for example). A piped response meant if interested prospective participants clicked on "yes" they entered the survey, if an answer of "no" they were piped to end message 1
End Message 1	If participants answered "no" for the screening question, a polite end message thanked them for their interest but informed them of their ineligibility to continue with the survey
Part B A few questions about your PLN	A definition of PLN was provided for clarity, relating to work (professional focus) rather than for socialising on a personal level **Items 8-12** (Item 8 removed in second campaign) Items asked: ways into building a PLN; purpose for doing so; criteria for basis of adding to initial, preferred platforms used; and what was being sought from their participation in these chosen platforms. The multiple platforms matrix item is informed by Nielsen, Moll, Farrell, McDaid & Hoban (2013) Social Media and Science Learning Survey for social media use amongst primary PSTs. * **Item 12** contains inconsistency- should have said 'Rarely' instead of 'Not often' (already explained in design features).t often' (already explained in design features).

Part C Some questions about your PLN related to science education	**Item 13** An open-ended crucial question to the survey in terms of its' content. It asked teachers how their PLN activities are contributing to their development as a teacher of science**.** **Item 14** This item has branching logic. It asks if participants have any science/focused links in their PLN, in other words, science specific groups, followers/ing , blogs, etc. If no they were piped to question 17 as they would not be able items 15&16 meaningfully. Items 15 & 16 (items removed "hidden" in second wave/campaign) **Item 15** was open-ended and asked favourite science groups, tools sites asking for specific names, hashtags etc**.** **Item 16** was frequency scale from never to always to establish usual participation and contribution roles e.g. moderate or read posts. **Item 17** Likert style item related to general behaviours of using PLN based on literature with reference to usefulness of PLN use for TPD; reflection; problem-solving teaching challenges and overall perception of quality of interactions in online spaces.

Part D Some questions about your PLN related to science	**Item 18** This Likert type item is designed to address SMK or SCK, ways teachers build their content knowledge or professional substantive knowledge of science. **Items 19 & 20** These Likert items could be considered as a scale related to PCK for science so addressed topic specific content knowledge and skills and general PCK related to science teaching practices **Item 21** Likert type item from strongly Disagree to Strongly Agree is to ascertain whether teachers perceive PLN activity as self-directed professional development (includes 3 questions). One question addressed if teachers' employers consider PLN use as professional development. **Item 22** Frequency scale 1-5 of whether teacher access latest science education research findings. **Item 23** Categorical yes/no item asked if teachers log their hours of PLN use for their job.
End Message 2	Thanked participants for their contribution and invited them to join a further phase; be entered into draw for a book voucher; and be kept informed of study results when analysed.

Appendix B2: The Survey Instrument (online in Qualtrics)

Restart Survey | Place Bookmark | Mobile view on | Tools

Using Your Online Professional Learning Network (PLN) for Professional Development in (K-6) Science Education

Please complete this international survey to give your opinions as an elementary or primary school teacher, (even if you are new to using PLNs).

I am a doctoral research student from the University of Technology, Sydney (UTS), Australia. My study is approved by UTS ethics (ETH18-2569) and explores **online** activities with social media, digital tools, resources, and people that contribute to **your professional learning**. My focus is the ways these PLN activities contribute value to your professional development as a teacher of science. Examples are use of: Facebook, Twitter, Pinterest, Wechat, etc.

The **survey takes approximately 15 minutes** to finish. **Your responses will be confidential and de-identified**. If you consent to your survey responses being used for this study as outlined in the participant information sheet (if opened, pls use your browser's Back button to return to this survey.), please complete the survey by clicking on the arrow at the bottom of this page.

At the end of the survey there is an option to join a further research phase of this study and you can go into the draw for **a chance to win one of 4 book vouchers, valued at $50 USD each.**

If you have any questions about the research, please see contacts on the participant information sheet.

Thank you for your participation. **Please click on the arrow at the bottom of this page to do the survey.**

Using Your Online Professional Learning Network (PLN) for Professional Development in (K-6) Science Education

Please complete this international survey to give your opinions as an elementary or primary school teacher, (even if you are new to using PLNs).

I am a doctoral research student from the University of Technology, Sydney (UTS), Australia. My study is approved by UTS ethics (ETH18-2569) and explores **online** activities with social media, digital tools, resources, and people that contribute to **your professional learning**. My focus is the ways these PLN activities contribute

0% — 100%

Do you use online professional learning networks (PLNs) AND teach science for elementary or primary (K-6) school students?

- YES
- NO

In which country do you teach?

How many years have you taught **science** for elementary/primary school students?

- 0-5 yrs
- 5-10 yrs
- 10-20yrs
- 20+ yrs

Do you identify as : Female? Male? Other? Prefer not to say?

What degree(s), qualification(s) or tertiary level certifications do you hold?

	Graduate	Postgraduate
Education		
Science		
other		

To what level of education did you study a science subject? Please select category of best fit for you.

- ◯ Secondary/high school
- ◯ Tertiary/university

In what role do you teach science for elementary/primary school students?

- ◯ General classroom teacher
- ◯ Specialist science teacher -*across one or multiple elementary/primary grades*
- ◯ Specialist science teacher- *across secondary/high school grades and elementary/primary grades?*

→

Please indicate the agreement level you have for these statements:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am interested in teaching elementary/primary science	◯	◯	◯	◯	◯
I am confident in my elementary/primary science teaching skills	◯	◯	◯	◯	◯
I am confident that I can promote elementary/primary school students' interest in science	◯	◯	◯	◯	◯
I am confident in my elementary/primary science content knowledge	◯	◯	◯	◯	◯
I am personally interested in science	◯	◯	◯	◯	◯

→

PART B - A few questions about your PLN

In this study, **PLN** refers to all of your **online** activities with social media, digital tools, resources, and people that contribute to **your professional learning.**

Why did you start building your online PLN ? Please select **all** that are applicable.

- ☐ Job requirement
- ☐ Tertiary level studies requirement
- ☐ Self-initiated professional learning
- ☐ Other . Please specify

What platforms did you use **when you started** your PLN connections? Please select all that are applicable.

- ☐ Google+
- ☐ FaceBook
- ☐ Linked In
- ☐ Pinterest
- ☐ Twitter
- ☐ Edmodo
- ☐ Wechat
- ☐ QQ
- ☐ Wikis
- ☐ Blogs
- ☐ You Tube
- ☐ Instagram
- ☐ Other. Please specify

What were you seeking from your PLN activities **when you started** to build your PLN?

Please indicate the level of importance to you for each of the following:

	Not at all important	Unimportant	Neutral	Important	Very important
Expert advice	○	○	○	○	○
Supportive professionals	○	○	○	○	○
New teaching ideas	○	○	○	○	○
Improved content knowledge	○	○	○	○	○

other. Please specify

On what basis did you decide to **add to your PLN** (e.g. adding new connections, groups, people to follow) ?

	Never	Not often	Sometimes	Often	Always
Recommendations from colleagues	○	○	○	○	○
Recommendations or requirements of my employer	○	○	○	○	○
Quality of my previous interactions	○	○	○	○	○
Serendipitous (lucky) finds	○	○	○	○	○
Evaluation of expertise & credibility of other members/followers	○	○	○	○	○
Notices/suggestions from platform (feeds)	○	○	○	○	○

Other. Please specify

PART C – Some questions about your PLN activities related to SCIENCE education

How do your PLN activities contribute to you developing as a teacher of science?
Please give an example.

Do you have any science-focused connections/links in your PLN eg. sciene-specific Fb groups, Twitter #s?

- ○ YES
- ○ NO

How often do you participate in **your science PLN activities** in the following ways?
Please select all that are applicable.

	Never	Rarely	Sometimes	Often	Always
I use my PLN as ongoing development for my science teaching	○	○	○	○	○
I am an observer (peripheral/reader)	○	○	○	○	○
I am a contributor (comment, share or produce content)	○	○	○	○	○
I am a moderator (organize or moderate a group)	○	○	○	○	○

Please indicate the extent to which you agree with the following statements in relation to your PLN.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
My PLN interactions are ***as useful*** as offline (face to face) professional development for learning how to teach elementary/primary science	○	○	○	○	○
My PLN activities *promote reflection* on my elementary/primary science teaching practice	○	○	○	○	○
I use my PLN to *problem-solve* challenges experienced in teaching elementary/primary science	○	○	○	○	○
I am satisfied with the *quality of my PLN interactions* about elementary/primary science education	○	○	○	○	○

Part D Some questions about your PLN related to science teaching and learning development

Please indicate extent to which you agree with the following statements in relation to your PLN.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I build my science **knowledge base** using my PLN	○	○	○	○	○
I use *science-focused association sites* e.g. RSC, ACS, ASE (UK), ASTA (Aust.), NSTA (USA) to develop my science knowledge	○	○	○	○	○
I improve my *understanding of science concepts* by asking questions to content experts e.g. "ask an expert", "ask a scientist"	○	○	○	○	○
I use my PLN activities to build my science content *knowledge specific* to K-6 science curriculum topics	○	○	○	○	○

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Using my PLN challenges my understanding of ***ways elementary/primary school children learn science effectively***	○	○	○	○	○
I improve my understanding of elementary/primary students' *science misconceptions* using my PLN	○	○	○	○	○
I build my understanding of *diverse learners' needs for differentiated science learning* opportunities by using my PLN	○	○	○	○	○
I learn *ways to improve student interest* in science lessons through my PLN activities	○	○	○	○	○

→

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
My PLN activities ***promote changes in my elementary/primary science teaching practice***	○	○	○	○	○
I *learn about planning* more effectively for science lessons using my PLN	○	○	○	○	○
I learn how to *implement new learning tools* (e.g. apps) in science lessons through my PLN activities	○	○	○	○	○
I learn about other possible *assessment strategies suited to K-6 science students* using my PLN	○	○	○	○	○
I *evaluate my science teaching* practice during my PLN activities	○	○	○	○	○
My PLN activities *promote opportunities to teach students science beyond the classroom* (e.g. class joins citizen science project; takes excursion or field trip)	○	○	○	○	○

Please indicate extent to which you agree with the following statements in relation to your PLN.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Self-directing my PLN activities is important for my professional development as a teacher	○	○	○	○	○
When I need to learn something new for my science teaching *I take the initiative to learn it* using my PLN	○	○	○	○	○
When I learn something new from my PLN activities I *feel more confident about teaching science*	○	○	○	○	○
My employer recognizes self-directed PLN activities as teacher professional development	○	○	○	○	○

	Never	Rarely	Sometimes	Often	Always
How often do you access the *latest elementary/primary science educational research findings* using your PLN ?	○	○	○	○	○

Do you record your time spent in PLN activities as professional development for your job?

- ○ YES
- ○ NO

Thank you very much for your participation in this international study.
Please email me at Ruth.A.Fentie@student.uts.edu.au if:

* you could spare **10-15 mins for a Skype or Zoom call at a time convenient for you.** I would be most interested to hear more from you to strengthen the findings for this important study; and/or
* you would like to be kept up to date with the study results; and/or
* you wish to go into the draw **for a chance to win one of 4 book vouchers valued at $50 USD** each

NB. emails cannot be linked to your survey responses
Thanks,
Ruth Fentie (UTS doctoral candidate)

Appendix C: Communications with participants

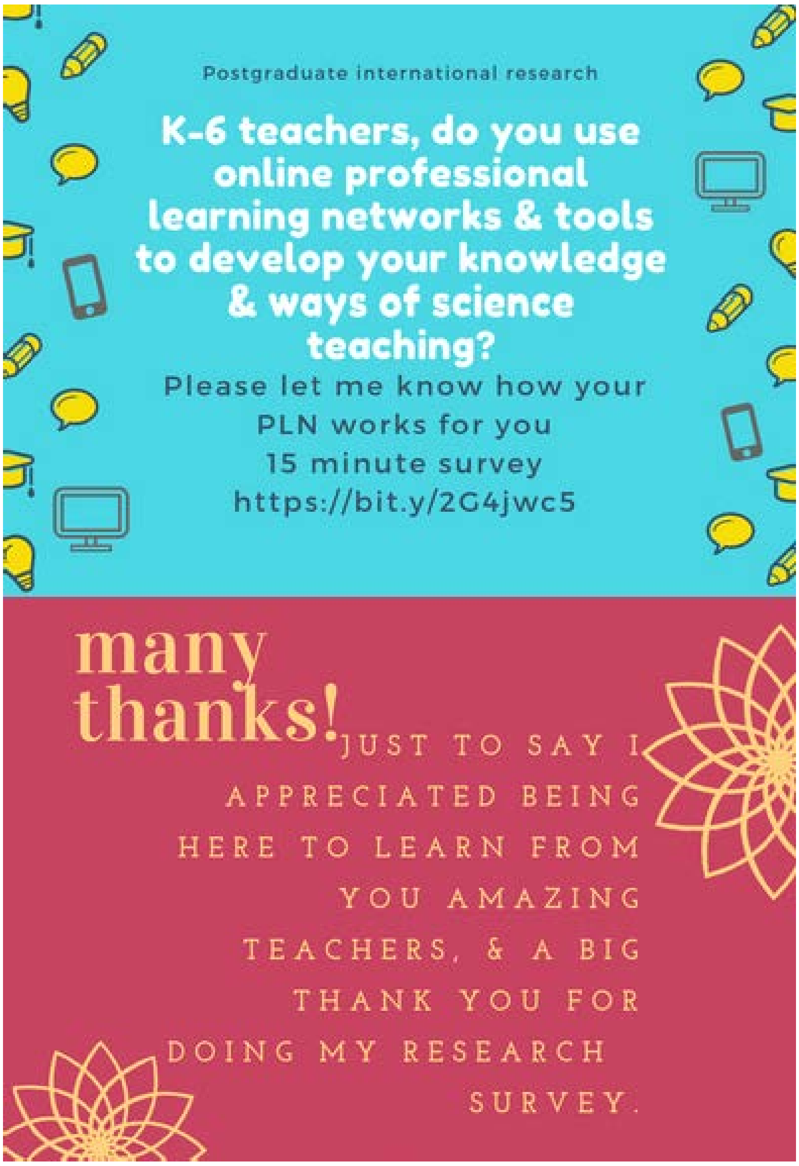
This appendix contains the international online survey advertisements posted to distribute survey and other communications with participants such as email invitations to be join ongoing phases of the study.

Appendix C1: Invitation advertisements and thank you posted online for Phase 1 survey recruitment

Appendix C2: Email invitation phase 2 template Appendix C3: Email invitation

Phase 3 template

Document C1: Invitation advertisements and thank you posted online for Phase 1 survey recruitment



Document C2: Email invitation to participate in Phase 2 of study

Email Invitation to participate in Interview via VideoConference (Zoom or Skype)

Dear................. ,

Thank you for recently completing the online survey for my international research study "Exploring primary teacher's Professional Learning Network (PLN) activity for potential value as professional development in science education" *UTS HREC APPROVAL NUMBER ETH 18-2569*.

My apologies for the delay in contacting you again.

I trust that you are still *interested in a brief online discussion* with me (1:1), regarding your PLN use, for professional teacher development. This will be an opportunity for you to share your thoughts in a semi-structured interview of 20 minutes via Zoom or Skype (whatever platform you prefer).

Your contribution to this international research is very important because it will progress global understandings of primary teacher professional development in science.

Could you please let me know a time that would be convenient for you in the coming weeks? (Please note that I live in Australia, GMT+11, daytime & evening hours are fine).

Please also find attached a participant information sheet and consent form that the university requires you to sign before we talk. Once signed (electronic signature), please send it back to me via email and I will send you the details for our online interview.

Many thanks and I look forward to hearing from you soon, Regards,

Ruth Fentie (UTS student)

Document C3: Email invitation to participate in Phase 3 of study

Dear ,

Thank you for being part of this international research. You indicated an interest in completing the last phase of data collection, please find attached the Phase 3 consent form to sign and email back to me. I hope you find this phase adds to your professional learning.

Phase Outline (4 weeks collection time please):

STEP 1. Please take screenshots of your online chat from 3 conversations that you feel were of value to you in developing professionally as a teacher of science (any social media, online platform/s, multiple is fine).

This is a focus on your own professional learning, rather than e-learning for students.

You can screen shot, copy & paste sections of chat, or screen videorecord (e.g. QuickTime) however is most convenient for you. If you are concerned about others' names in your chat history please contact me to discuss a solution.

STEP 2. Please evaluate ONE of these conversations you selected for its value to you in developing professionally as a teacher of science by completing the attached template.

STEP 3. Please send me by email items from STEPS 1& 2:

3 x chat histories from conversations as screenshots, documents or video- recordings

1 x filled in evaluation template for 1 selected conversation.

Just a reminder, after step 3, I will organise a quick (15 minute) follow-up audio interview.

Thank you in advance for contributing to this study. If I can answer any questions please feel free to call me on____or email.

Regards, Ruth Fentie

REMINDER email sent if required:

I was very grateful for your contribution to the research so far and hope you can join this last phase. The information and consent form is attached for you to sign and email back to me please.

Details are as follows:

(4 weeks collection time please but negotiable)……..

Appendix D: Interview Schedules for Phases 2 & 3

This Appendix contains the interview questions for Phase 2 and Phase 3 Online interviews (conducted via Zoom for most participants)

Document D1: Interview Schedule Phase 2 Document D2: Interview Schedule Phase 3

Document D1: Interview Questions Phase 2

Reminder about project i.e. professional and for science education. In the survey I found this…….

1. Can you please tell me how & when you use your online PLN?

2. Why do you use your online PLN ?

Now for some questions about your science focused PLN

3. What is it about some links/follows etc that make them your favourites ?

4. Can you please describe the kinds of online interactions/discussions you find most beneficial for your learning about science teaching?

5. Are there any PLN interactions or other educators' questions that challenge or contradict your science teaching beliefs/approaches ? If so, do you answer those ones or avoid them?

6. Do you notice any limitations when people share content, approaches or strategies for teaching and learning science in a PLN ?

7. Do you have ways to manage your PLN effectively?

8. What influences your decision to participate as moderator (run the group chat), observer (read only), critic (offer a counterview), contributor (share or add to discussion)?

9. In your opinion, is there anything about using PLNs, that makes them particularly suited to **science** education professional development?

10. Do you participate in synchronous "real time" science ed. text-based

'chats'? Follow up: What do you find is the value of these chat times

11. Do you find that general PLN activities focused on other subjects, (eg English, Mathematics) or areas of interest (eg hobbies) have benefits for your science teaching? What are these?

12. I am keen to hear if you think or have noticed that your activities in your PLN affect your student's learning and in what ways?

If time (ask this one too, need it for fixing placement of survey question which had it just in content knowledge section)

13. If you look to science association and science teacher association sites – is it for content knowledge or ways to teach science or both?

14. Do you have any questions or thoughts arising from the survey that you would like to tell me about?

Document D2: Interview Questions Phase 3

1. Looking at your selections not represented on the evaluation template, what made these significant for you developing professionally ?

2. What are your current **professional development** goals in primary science education?

3. To what extent do you feel your PLN contributes to meeting those goals?

4. From phases 1 & 2 could you tell me more about improvements in your science teaching as a result of using your PLN?

5. In what ways have you noticed your PLN evolving

6. Do you find you use your PLN to meet professional accreditation standards, eg
7.0 ?

7. Do you think that your employer should value your PLN activity as professional teacher development? As paid work? What proportion of TIPD would be reasonable?

8. What would improve the value of a PLN for you as a primary teacher of science?

9. Did you have anything else that you wanted to share or ask about the research?

Appendix E: Phase 3 Data Collection Tool – an evaluation template

This template was provided to participants in landscape format, to provide room for their responses.

Modified from template in Wenger, Trayner & DeLaat (2011), p.45.

File name or screenshot title or video file name of this selected conversation sent to the researcher	
Name of network / person/ site/ group	
Reasons for participation in this online interaction (eg. Quick Q&A, discuss teaching strategies, inspiration, etc)	
Activities around this interaction (eg. prior chats, question posted, sharing (lesson material, advice, links), webinars, direct messaging, conferences, etc)	
VALUE for developing your SCIENCE TEACHING (e.g. developing knowledge of topic specific content, strategies suited to science curriculum outcomes, children's misconceptions, assessment of learning, evaluating, etc) **&/Or** **VALUE for developing your TEACHING** (e.g. goal setting, planning, implementing, differentiating for student needs, learning environment, reflecting, etc) **&/Or** **VALUE for YOU professionally** (e.g. developing confidence, competence, identity, meeting school or professional goals, etc)	

Appendix F: Samples of Coding Themes

This appendix contains documents discussed and referenced in Chapter 4 which show key theme summaries from coding; and comparison of coding between participants to indicate personalisation of PLNs.

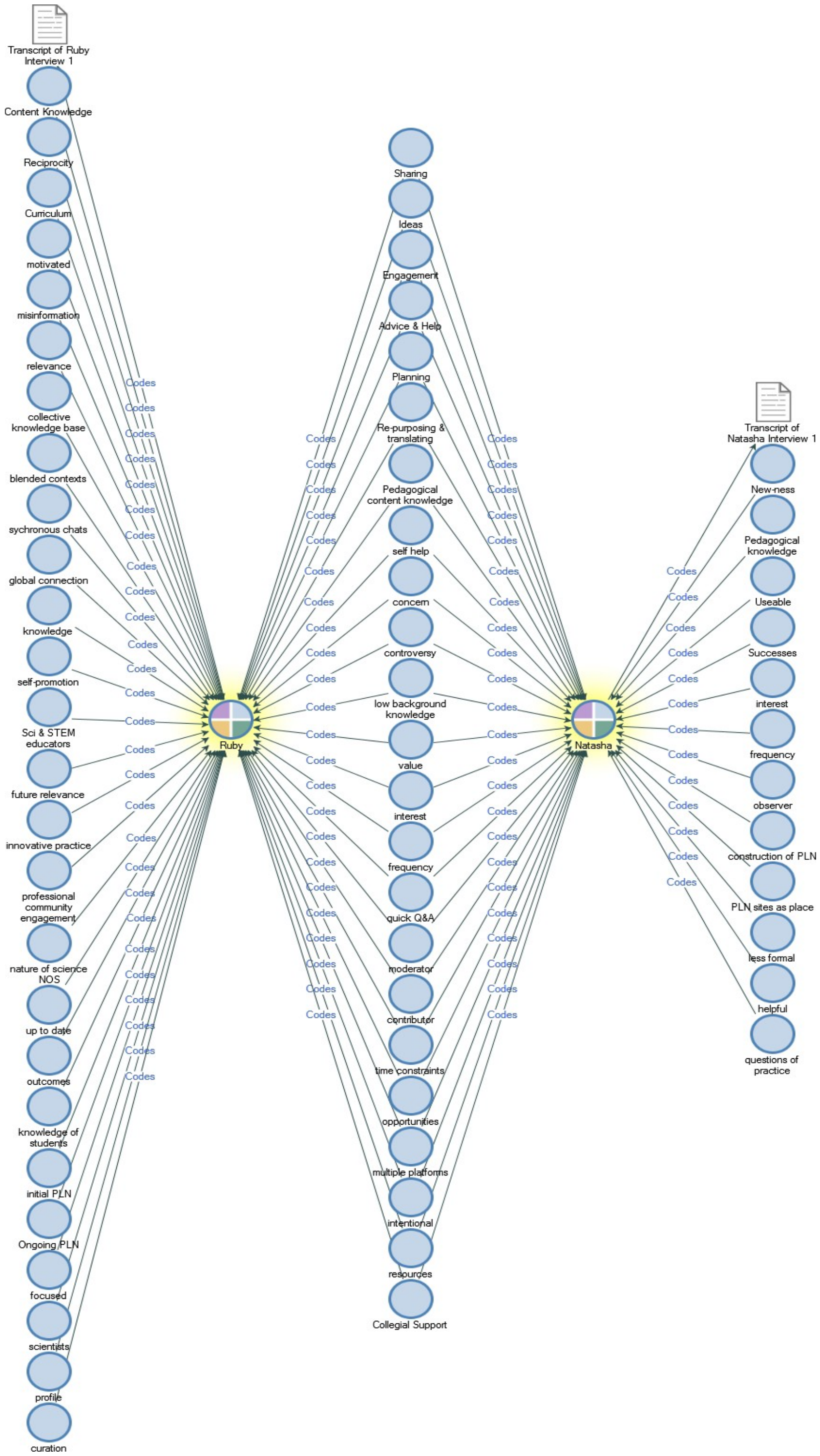
Document F1: Nodes aggregated from NVivo into major and nuanced themes from all phases for PLN construction and management using Excel

Nodes	Themes	Nuanced themes
Multiple contexts: Beyond immediate context	Multiple contexts for immediacy and availability	Beyond the classroom excursions, Hobbies and interests
Multiple contexts: Local		Prefer local
Multiple contexts: global		Prefer global
Multiple contexts: Blended contexts	Multiple blended contexts : offline and online, informal complements other forms of PD	Personal vs public, multimedia and multimodal,
Multiple contexts: less formal		Self-directed, non threatening, personalised compared to formal
Professional community engagement	Professional community engagement	Extends networks & views
Activity: Sharing: resources	Sharing	Collating collections of resources
Activity: Sharing: values		
Activity: sharing: Knowledge	Sharing knowledge, experience and resources for a collective PCK	Primary specific
Activity: inquiring: questions of practice		"best practice"
Activity: Reciprocity	Building reciprocal relationships over time	Give and take, time dependent
Professional knowledge: usable	Building professional knowledge with actionable knowledge	Immediately implementable, "takeaways"
Professional knowledge: CK: curriculum		
Professional knowledge: PK	Shifting focus of PK	Emergent curriculum, differentiation for students
Professional knowledge: PCK	Multidisciplinary PCK	
Professional knowledge: Lack		Lack of content knowledge
Newness: evolving and changing PK	New Ideas promoting shifts in PK	
Newness: up to date		
Newness: Innovative		STEM focus
Newness: planning: repurposing & translating		
Newness: ideas		
Collegial support: help & advice	Giving and receiving advice & help	Authentic representation of PCK from other teachers
Collegial support: help & advice: affirmation	Affirmation giving confidence	Confidence, validation
Collegial support: help & advice: mentoring	Building professional identity through Mentoring	
Collegial support: help & advice: expert	Reciprocity of expert advice	Latest research, expertise
Collegial support: help & advice: expert : Sci & STEM educators		Experts into classrooms
PLN management: multiple platforms: digital tools	Effective PLN management strategies	Meaningfully integrating technology
PLN management: construction: initial		Evolving from initial PLN
PLN management: ongoing Construction	Curation practices needed	
PLN management: multiple platforms	Multiple platforms fit for multiple purposes	
PLN management: Selectivity: relevance	Selectivity: Valid & reliable sources	Core groups
PLN management: Selectivity: like minded	PLN management: Selectivity for affirmation	
PLN management: selectivity: critical contrast	Selectivity for critical contrast and professional growth	
PLN management: selectivity: helpful		Blocking or unfollowing if unhelpful
PLN management: Time constraints	Time constraints and frequency of use	Convenience, beyond work hours
Self help	Self-initiated learning	
Professional identity	Building professional identity	Shared and co-constructed professional identity
Reflection	Reflective value	Delayed usefulness
Student learning: engagement & outcomes	Aiming for enhanced, future focused, relevant student learning for interest and engagement	Interest and benefits
Student learning: relevant		Future focused
Concern: misinformation	Concerns around science education misinformation	

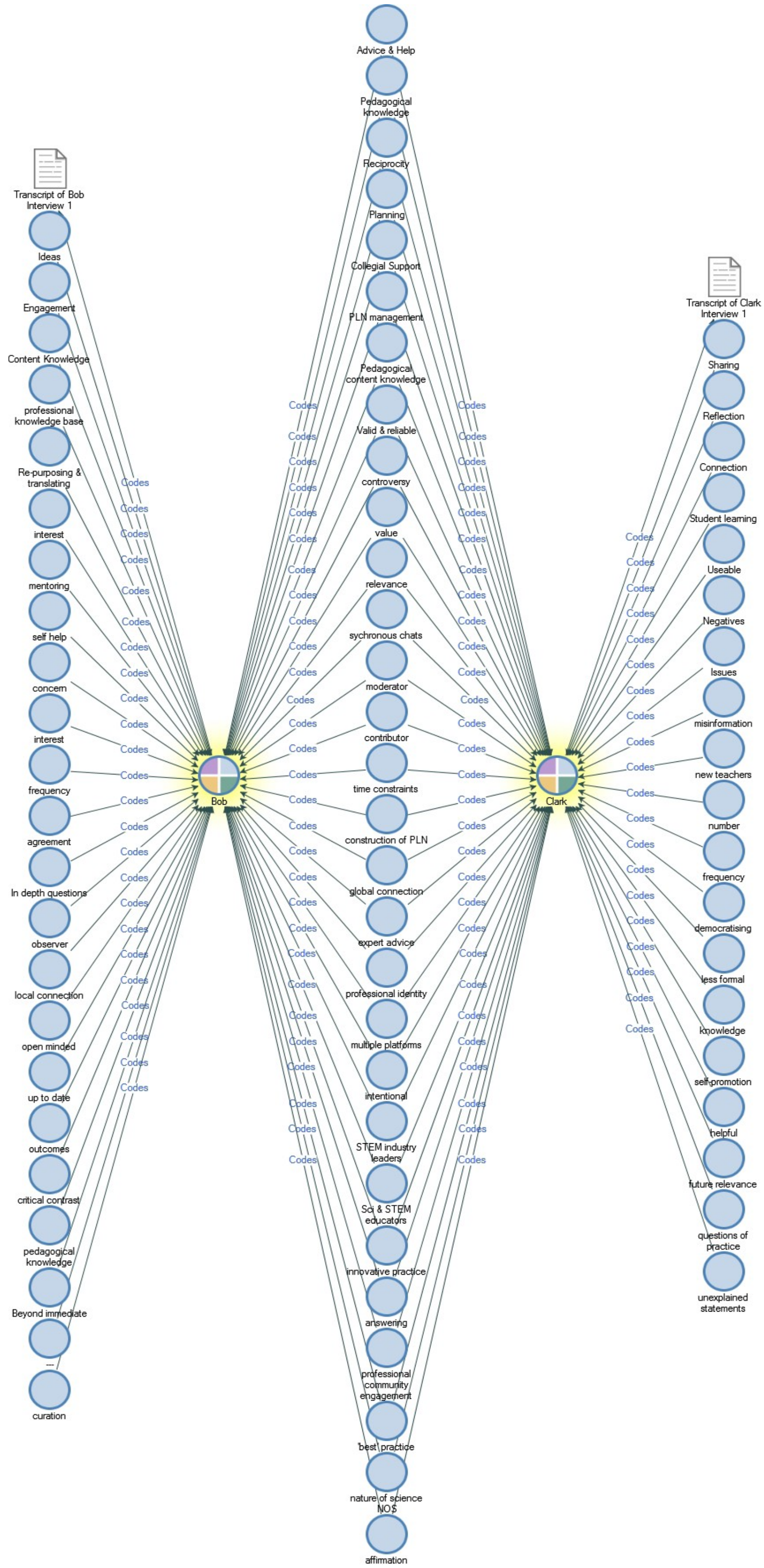
Document F2: Exemplar of summarised coding (second cycle) for Phase 2 interview responses to question of beneficial PLN interactions for learning about science teaching

QUESTION 4 Can you please describe the kinds of online interactions/discussions you find most beneficial for your learning about science teaching?											
Clustered Themes	Angela	Archie	Bob	Charles	Clark	Jane	Molly	Natasha	Ruby	Jess	Theme Strength
Inquiring (synchronous chats, quick Q&A, and in-depth discussion)			1	3	1	1	2	1		3	12
PLN Management (multiple platforms, time constraints, frequency,selectivity (relevance & interest), ongoing construction)			2			1	2	2		1	8
Collegial support: help & advice: expert (science & STEM educators, industry leaders and scientists)	1	1	1		2				2	1	8
Collegial support: help & advice (giving and seeking help)			1				2	2	1	1	7
Professional knowledge: PCK (usable, inquiry & advice takeaways)	3	2	1		1	1	1	1	1		7
Student learning (engagement, interest and future-focused, differentiation)	2				2		1		1	1	7
Multiple contexts (local, global, less formal, beyond immediate, primary specific)	1		1		1		1	1		2	7
Newness (innovative practice PK, authentic real world links)	2		1		1				2		6
Participation (reciprocity, democratising, relationship building process, professional community engagement)			2	2					1	1	6
Sharing (ideas, resources, 'best practice')	1	1			1	1		1			5
Nuanced themes (convenience of chat history, daily feeds keep connections, PLN as internet filter, concern)	1		2					1	1		5
adapting & repurposing PK, PK cross key learning area integration	2	1			1						4
Professional knowldge base: content knowledge (includes nature of science NOS)				1	1				1		3
Newness: motivation & inspiration	1	1							1		3
collegial support: affirmation							1				1
Newness: ideas	1										1
Participation: observer			1								1

Document F3: Comparing Coding Using NVivo for Two Primary Teachers (Ruby and Natasha, Phase 2 interview 1)



Document F4: Comparing Coding using NVivo For Two Primary Teachers (Bob and Clark, Phase 2 Interview 1)



Appendix G: Extracts from Reviewed Teacher Professional Standards Documents

Professional Teaching Document	Relevant Section	Theoretical support of PLN use to meet standard
Australian Institute for Teaching and School Leadership (2011, reprinted 2018) Australian Professional Standards for teachers. Standards at the proficient teacher level	Sections 6.2, 6.3,7.4	"6.2 Engage in professional learning and improve practice. Participate in learning to update knowledge and practice targeted to professional needs and school and/or system priorities." "6.3 Engage with colleagues and improve practice. Contribute to collegial discussions and apply constructive feedback from colleagues to improve professional knowledge" "7.4 Engage with professional teaching networks and broader communities. Participate in professional community networks and forums to broaden knowledge and improve practice" (no page ref, online pdf)
U.K. Department for Education. (2011, updated 2013) Teachers' Standards Guidance for school leaders, school staff and governing bodies	Progression and professional development, Section 8	"Appropriate self-evaluation, reflection and professional development activity is critical to improving teachers' practice at all career stages" (p.7) "8. Fulfil wider professional responsibilities. Make a positive contribution to the wider life and ethos of the school, develop effective professional relationships with colleagues, knowing how and when to draw on advice and specialist support, …take responsibility for improving teaching through appropriate professional development, responding to advice and feedback from colleagues" (p.13)

U.S.A. National Board for Teaching Standards: Middles Childhood Generalist Standards (for teachers of students age 7-12) (3rd Ed)	Standard 7	Advocating for the teaching Profession. “By reading professional journals, networking with teacher colleagues, and becoming members of professional organizations, teachers stay informed of policy initiatives that impact their profession” (p.54)
	Standard 8	Responsiveness to change. “Teachers utilize online learning environments as a resource for enhancing their professional development. They strive to advance their technological skills as they remain attuned to the use of technology by their students, the profession and the surrounding world. ” (p.56)

Appendix H: Quantitative Data from Survey Items Using SPSS Tables

Responses to survey items, have sample size (n=49) unless otherwise indicated.

Table H1: *Extent of Surveyed Primary Teacher's Agreement of Using Science- focused Association Sites e.g. RSC, ACS, ASE (UK),ASTA (Aust.), NSTA (USA) to develop my science knowledge*

Level of Agreement	Frequency	Percent
Strongly Agree	5	10.2
Agree	16	32.7
Neutral	14	28.6
Disagree	11	22.4
Strongly Disagree	3	6.1
Total	49	100

Table H2: *Extent of Surveyed Primary Teacher's Agreement of Learning about Planning More Effectively for Science Lessons Using a PLN*

Level of Agreement	Frequency	Percent
Strongly Agree	6	12.2
Agree	25	51.0
Neutral	12	24
Disagree	6	12.2
Strongly Disagree	0	0
Total	49	100

Table H3: *Extent of Surveyed Primary Teacher's Agreement of Learning Ways to Improve Student Interest in Science Lessons through PLN activities*

Level of Agreement	Frequency	Percent
Strongly Agree	19	38.8
Agree	21	42.9
Neutral	8	16.3
Disagree	1	2
Strongly Disagree	0	0
Total	49	100

Table H4: *Extent of Surveyed Primary Teacher's Agreement in Building Understanding of Diverse Learners' Needs for Differentiated Science Learning Opportunities by Using a PLN*

Level of Agreement	Frequency	Percent
Strongly Agree	8	16.3
Agree	24	49
Neutral	12	24.5
Disagree	6	12.2
Strongly Disagree	2	4.1
Total	49	100

Table H5: *Primary Teachers Agreement level for Using a PLN to Promote Learning Opportunities Beyond the Classroom (e.g. excursions, citizen science projects)*

Level of Agreement	Frequency	Percent
Strongly Agree	15	30.6
Agree	17	34.7
Neutral	10	20.4
Disagree	7	14.3
Strongly Disagree	0	0
Total	49	100

Table H6: Frequency of Primary Teachers' Participation in their PLN in roles of Moderator, Contributor and Observer (Phase 1 survey, n=38, piped question)

Level of Agreement	Moderator Frequency	Contributor Frequency	Observer Frequency
Always	1	1	4
Often	2	15	23
Sometimes	3	14	8
Rarely	9	6	3
Never	23	2	0
Total	38	38	38

Table H7: *Primary Teachers agreement with feeling greater confidence in teaching science when using their PLN to learn something new.*

Level of Agreement	Frequency	Percent
Strongly Agree	19	38.8
Agree	23	46.9
Neutral	7	14.3
Disagree	0	0
Strongly Disagree	0	0
Total	49	100

Table H8: *Surveyed Primary Teachers' Rating of Importance of Self-directed Learning Through Their PLN*

Level of Agreement	Frequency	Percent
Strongly Agree	19	38.8
Agree	23	46.9
Neutral	7	14.3
Disagree	0	0
Strongly Disagree	0	0
Total	49	100

Table H9: *Primary Teachers' Level of Agreement That PLN Activities Promoted Reflection on their Primary Science Teaching*

Level of Agreement	Frequency	Percent
Strongly Agree	8	16.3
Agree	34	69.4
Neutral	7	14.3
Disagree	0	0
Strongly Disagree	0	0
Total	49	100