



Primary Science Education in Australian Universities: An Overview of Context and Practice

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Abstract

Stagnating test scores, underwhelming student scientific literacy and declines in post-compulsory science enrolment are major issues in Australian science education. Universities are central in improving science education, as a relatively small group of 33 higher education providers can directly influence generations of primary teachers responsible for foundational science learning. Since this is a major review of primary science practice at Australian universities, factors including, but not limited to, changing employment conditions, shifts in study modes and an ever-expanding research literature base need to be considered in a more contemporary review. This paper aims to describe the reported primary science practices, challenges and strengths of Australian teacher education programs through semi-structured interviews and online surveys with 17 academics and analyses of public materials on university websites. Thematic analyses reveal noteworthy diversity in approaches, united by authenticity and student-centred learning. Key strengths included robustness of educational approaches, relevance and teaching team compositions. Key challenges included time, external pressures, resources and student capacity. These nuanced findings will be discussed as they relate to teaching and research.

Keywords Primary · Science · University · Initial teacher education

Introduction and Background Literature

It can be argued that primary education is failing to fulfil its role in the development of scientifically literate citizens who possess the capacity for critical, nuanced application of scientific knowledge and skills to novel contexts (Bybee, 1997; Roberts & Bybee, 2014). This encompasses an understanding of science as it advances human knowledge (scientific literacy) and influences societies (science literacy). With economies shifting due to the influences of technological advancement and globalisation (Cahill & Toner, 2018), a scientifically literate populace is a necessity. The Trends in International Mathematics and Science Study (TIMSS) provides a comprehensive overview of the science achievement of year 4 students across the Organisation for Economic Cooperation and Development

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(OECD) countries. Table 1 summarises some of the international primary science TIMSS trends between 1995 and 2019 (Martin et al., 1997; Thomson et al., 2020). The mean scores and rankings of these nations have slipped over the past quarter of a century. The most concerning trend is that 90% of participating OECD nations are falling below the High International Benchmark of 550, the level at which a primary student is generally able to apply their scientific knowledge to novel contexts. A possible interpretation is that the scientific literacy of primary students remains largely inadequate. However, caution must be taken when interpreting large international assessments, as they are mired by exclusionary sampling, cultural bias and latent assumptions about the equivalence of syllabi across jurisdictions (Baker, 1997; Bracey, 2000; Schuelka, 2013; Wang, 2001; Zhao, 2020).

Science disengagement can be considered an inter-generational problem (e.g. Breakwell & Beardsell, 1992; Howitt, 2007). Primary teachers have long struggled with low science interest and knowledge (Appleton, 1992, 2003). Preservice primary teachers (PPTs) are also concerned by their limited science content knowledge (Murphy & Smith, 2012). Even areas of science more prominent in public discourse are poorly understood by PPTs. Boon (2010) found that an overwhelming majority (88.6%) of a sample of 88 primary and early childhood PPTs did not hold an accurate conceptualisation of the greenhouse effect. Societal disengagement can now be seen in long-term declines in post-compulsory secondary science education in nations such as Australia (Kennedy et al., 2014; Norton et al., 2018).

Unsurprisingly, broader issues with science appear to be reflected in the science teaching practices reported in primary schools. Goodrum et al., 2001 surveyed 1221 primary-aged students in their evaluation of Australian science education. A quarter of the students were dismissive of science because they found it boring, whilst 27% were frustrated by the content heavy, note-taking focus of science. A concerning finding was that students could only “sometimes” relate their science lessons to the outside world: a sign of limited scientific literacy. Subsequent reviews of Australian science education practice have expanded upon these findings with themes such as poor student engagement, negative teacher attitudes and limited real-world relevance of science learning experiences (Goodrum & Rennie, 2007; Tytler et al., 2008). Perhaps more concerning is the marginalisation of science in the primary curriculum, with a consistent range of 40–60 min of reported science education per week in primary classrooms (Angus, 2003; Goodrum et al., 2001; Office of the Chief Scientist, 2012; Tytler & Griffiths, 2003; Tytler et al., 2008), which would be well below the 1.5 to 2.5 h per week mandated by the Australian curriculum (ACARA, 2017). Research from the USA highlights similar themes of poor quality and marginalised science teaching (Carlone et al., 2011; Osborne & Dillon, 2008; Roth, 2014; Weiss et al., 2003). The challenge of breaking this cycle through initial teacher education (ITE) is heightened when preservice teachers do not experience student-centred science learning during their university studies (Skamp & Mueller, 2001) or engage in or observe science teaching in their professional experience placements (Treagust et al., 2015; Wellcome Trust, 2017).

Table 1 Global trends in year 4 students’ science achievement in TIMSS (1995–2019)

Nation	1995 mean score (rank)	2019 mean score (rank)
Australia	562 (5)	533 (14)
England	551 (8)	537 (11)
Japan	574 (2)	562 (4)
New Zealand	531 (15)	503 (34)
USA	565 (3)	539 (8)

Australia (ACARA, 2017), the USA (NGSS, 2013) and other nations (Eggleston, 2018; Kim et al., 2013) have implemented inquiry-focused science curricula to improve primary science education. However, many current primary teachers lack the requisite pedagogical repertoires, scientific content knowledge and resources to successfully enact an inquiry-based curriculum (Kidman, 2012). ITE programs are well positioned to affect long-term change, but their effectiveness is threatened by perceived disconnections with school teaching practices, reductions in funding and lack of available science curriculum time (Fitzgerald & Knipe, 2016; McKenzie et al., 2011; NESA, 2018; Treagust et al., 2015). In recent decades, ITE has been politicised through cycles of policy change, ongoing reviews, the separation of pedagogy from discipline content and accountability measures (NESA, 2018; Mayer, 2014). Such issues serve to constrain primary science academics' capacity to teach preservice teachers the big ideas of science (Harlen, 2015) through extended argumentation (Roth, 2014), potentially resulting in disjointed science teaching similar to that reported in primary schools (Roth, 2014). The Wellcome Trust (2017) found that science content was often minimised explicitly in favour of science education pedagogy due to limited science curriculum time in UK ITE programs. Furthermore, preservice primary science teacher education (PPSTE) is mired by a lack of opportunities for PPTs to teach science and observe teaching on their professional experience placements (Treagust, 2015; Skamp & Mueller, 2001; Wellcome Trust, 2017).

One of the last comprehensive reviews of science teacher education practices in Australia was published by David Palmer in 2008 based on an earlier report into Australian preservice science teacher education broadly (Lawrance & Palmer, 2003). During this time, approximately 15 years ago, Australian university educators were beginning to incorporate many innovative, student-centred pedagogies as they moved away from more traditional practices, such as lectures and note-taking. Approaches such as problem-based learning, cross-curricular integration, student-centred investigations and in-school science teaching experiences were noted innovations (Lawrance & Palmer, 2003; Palmer, 2008). Due to a recent mandate requiring science content be taught prior to science education pedagogy (NESA, 2018), this paper will focus on primary science education subjects, offered within ITE degree structures, rather than distinct science content subjects. This means that this paper will focus on the science pedagogy subjects designed to prepare PPTs for primary science education practice. A subject shall refer to a single, discreet unit of study contributing to a broader course or degree. In the context of Australian PPSTE, a subject would constitute an intensive period of 10–14 study weeks, where PPTs are required to engage in set and/or emergent learning activities (e.g. lectures, tutorials, readings, school experiences) to assist them in the successful completion of pre-defined assessment tasks (e.g. reports, essays, lesson plans) to achieve subject outcomes.

In more recent years, the range of practices adopted in PPSTE has been investigated further (Deehan, 2017). The left-hand column of Table 2 presents a selection of guiding principles, science approaches and broad education approaches relevant to PPSTE in Australia and overseas that were initially established via a meta-analysis of 257 PPSTE articles and dissertations (Deehan, 2017). The meta-analysis applied many of the principles and approaches outlined in Table 2 to group and compare PPSTE research based on science teaching efficacy data. The guiding principles of constructivism, scientific literacy and reflection are broader framing elements that are likely to permeate ITE programs and cannot be limited to single events or practices. The science approaches and broad education approaches can be seen as more concrete strategies for enacting the guiding principles. For example, the *Primary Connections* (<https://primaryconnections.org.au/>) 5Es' framework functions as a constructivist model. This means that when educators refer to Primary

Table 2 Guiding principles, science approaches and broad education approaches in PPSTE*

Groupings	Guiding principle or approach	Description
Guiding principles (more general orientations in PPSTE that are typically expressed through the selection of more specific approaches)	Constructivism (e.g. 5Es)	Learning that occurs when an individual constructs their knowledge through active participation (e.g. discussion). This also includes the 5Es' framework underpinning the <i>Primary Connections</i> resources that are frequently used in Australian primary schools (e.g. Hume, 2012)
	Scientific literacy	Scientific literacy is multifaceted. While 'nature of science' instruction focuses on understanding science epistemology, scientific literacy is an individual's capacity to relate scientific knowledge to the world beyond academic settings (e.g. Bybee, 1997; Collins, 1997; Mesci & Renee S, 2017). It also encompasses the societal focus of science literacy (Roberts & Bybee, 2014)
Science approaches (specific approaches commonly associated with science education practice)	Reflective practices	Reflective practices occur through discussion or written reflections about PPTs' past and current and future practices. Such reflection is commonly linked to other approaches (e.g. Dalvi & Wendell, 2017) in order to consolidate pedagogical content knowledge (PCK) (Loughran et al., 2001)
	Alternative conceptions	Learners' alternative conceptions can inform the design and delivery of science learning experiences (e.g. McKinnon et al., 2017). Alternative conceptions can be sourced directly from learners or through scholarly material
	Problem-based learning	Problem-based learning uses real-world problems as a starting point for the acquisition and integration of new knowledge into existing schemas (e.g. Etherington, 2011). This approach helps students to develop transferrable skills which can be used in novel situations
	Inquiry learning	Inquiry learning is characterised by a focus on a specific outcome. It allows participants to apply skills and knowledge to seek the information needed to achieve the outcome. Learners can be afforded partial (guided) or complete (open) control of the inquiry process (e.g. Fitzgerald et al., 2019)
	Student-centred investigations	Student-centred investigations are characterised by affording agency to learners through hands on learning or simulations. In ITE, the academic staff would act as supporting facilitators (e.g. McKinnon et al., 2017; Palmer, 2006). Student-centred investigations can be more contained experiences where knowledge and skills can be developed for more extended inquiry sequences
	'Nature of science'	The understanding that scientific knowledge is fluid and always subject to reasonable debate. Instruction in this area may orient the learner to the variety of scientific approaches beyond an experimental research design. Essentially, 'nature of science' instruction orients learners to science epistemology (e.g. Demirdöğen et al., 2016)

Table 2 (continued)

Groupings	Guiding principle or approach	Description
Broad education approaches (specific approaches commonly associated with ITE broadly)	Cross-curricular integration	An approach to teaching where two discreet disciplines are integrated to create deep learning outcomes. For example, allowing students to collect and graph data is an example of a deep integrative link between mathematics and science (e.g. Kim & Bolger, 2017)
	Teaching tasks	This term broadly encompasses ITE learning that accurately reflects the responsibilities and actions of inservice teachers. An example would be allowing preservice teachers to create science units of work for classroom use (e.g. Lewis, 2019)
	Internal** practical teaching experience	This occurs when a subject (or other educational intervention) is designed with imbedded opportunities to teach; preferably to students of the intended year levels (e.g. Deehan et al., 2019; Flores, 2015; Kahn & VanWynsberghe, 2020)
	Links to professional experience placements/partnerships	This occurs when preservice teachers receive opportunities to teach that are not formally connected to a subject via lectures, tutorials, workshops or assessments. Such links often occur at the course level through professional experience placements or through other institutional connections to schools. Links to professional experience placements and external partnerships are more likely to afford preservice teachers opportunities for multiple science teaching experiences (e.g. Hobbs et al., 2018)
	Cooperative learning	Cooperative learning occurs when preservice teachers work together to complete a task that would otherwise be impossible or unreasonable to complete individually (e.g. Deehan et al., 2017)
	Modelling	This approach entails the academic modelling desirable educational practices, such as reflection, student-centred teaching and investigations (e.g. Menon & Sadler, 2018; Watters & Diezmann, 2007)

* Adapted from Deehan (2017).

** Internal refers to experiences delivered within the delivery of a PPSTE subject.

Connections they may also be referring to science approaches, such as student-centred investigations, and broad education approaches, such as cross-curricular integration. As another example, cooperative learning (broad education approach) could be seen as integral to constructivist learning (guiding principle). In practice, many of these approaches would occur simultaneously, such as a problem-based learning (science approach) scenario establishing a context for “nature of science” (science approach) instruction, with scientific literacy as a key guiding principle underpinning the learning and teaching cycle. While representative, the framework is not exhaustive and is certainly contestable. The framework is limited by available sources of data because of variance in how and where guiding principles and approaches will be expressed. This means that without access to subject delivery materials and observations, commentary on the absence of guiding principles and approaches cannot be offered. At best, we can see which principles and approaches are prioritised.

The aforementioned trends in science education, highlighted by an ever-expanding body of research literature (e.g. Skamp, 2020), in conjunction with dramatic changes in university working conditions (Hitch et al., 2018), such as increasing uptake of online education and a more casualised academic workforce (Norton & Cakitaki, 2016), build a compelling argument for a more contemporary review of PPSTE in Australia. This paper aims to answer the following research questions:

1. How is primary science teacher education reportedly taught in preservice primary initial teacher education programs in Australian universities?
2. What are the perceived strengths of, and challenges to, reported primary science teacher education practice in Australian preservice primary initial teacher education programs?

Methodology

This research project utilised a type IV case study approach (Yin, 2014), with two data sources over multiple sites, to examine the PPSTE practices within Australian universities. The first source of data was science education subject information presented publically on university websites. The second form of data was insights offered directly by academics through either semi-structured interviews or asynchronous online surveys. A multi-method, convergent parallel design was used (Creswell, 2013), meaning that the data collection processes were separate before converging during data analyses. Interview and survey data were collected from late 2018 through to the middle of 2019. Ethics approval was obtained for this research project.

Sampling and Participants

The public webpages of 33 Australian ITE providers were searched for PPSTE subjects. A total of 58 relevant PPSTE subjects were identified across 32 (97%) universities, for an average of 1.8 PPSTE subjects per institution. The overwhelming majority of institutions offered one (11) or two (19) PPSTE subjects, with two outliers offering 4 PPSTE subjects. One university did not provide sufficient public information for this part of the project. A targeted, purposive sampling approach was used to identify and recruit academic staff based on web profiles. Snowball recruiting and requests to other university staff were used when appropriate staff members could not be otherwise identified. However, this approach

does diminish the quality of the research through issues such as silent voices and self-selection bias (O’Toole & Beckett, 2013). From October 2018 through to July 2019, 141 emails were sent to contacts from all 33 targeted institutions. A total of 17 academic staff members agreed to participate via recorded phone interview (13) or online survey (4). All but one participant provided demographic data. There were 14 full-time academics and two casuals. Fifteen of the 16 academics held a doctoral qualification. The majority of participants (9) had between 10 and 20 years of university teaching experience. Three participants reported over 20 years of university teaching experience, and four had less than a decade of experience in higher education. The response rate (11.8%) is below the 30–35% response rate expected in social science research (Nulty, 2008). This may be related to impersonal sampling strategies and/or the lack of available time for the target population. Despite this sampling issue, nearly half (45%) of the identified primary ITE providers in Australia were represented through interview or survey.

Data Sources

The first data sources were publically available PPSTE subject information presented on university websites, including subject descriptions and subject outcomes. Each institution presented subject information with different levels of detail, ranging from a few sentences to several pages. As full subject outlines were only publically available for 8 subjects (14%), these artefacts were excluded from the project for the sake of consistency and fairness. Initial analysis (of these eight) showed that the tutorials, lectures and assessments generally reflected the principles and approaches promised in the broader website descriptors. Thus, as the more detailed subject outlines did not provide new information related to the research questions, they were excluded because they would only serve to distort the dataset by artificially enhancing the prominence of the 8 subjects within the dataset. This means that the only the shorter website descriptors (typically brief outlines and subject outcomes) for 58 PPSTE subjects across 32 institutions were included in the dataset.

The second data source was a series of semi-structured interviews and online surveys. The 13 semi-structured interviews were conducted over the phone and took approximately 30–40 min to complete. To increase the sample, invitees were afforded the option to respond through an online survey. It must be noted that this removed the option for immediate clarification and follow-up, meaning that generally the qualitative survey data were not as detailed as the interview data. All verbal interviews were recorded and transcribed by the author. Respondents were given the opportunity to review their transcripts prior to data analysis. No changes occurred as a result of this process.

Data Analyses

The public documents, in the form of website descriptors, were analysed using the framework presented in Table 2. Available information was manually reviewed for the presence of words and phrases indicating the inclusion of different principles and approaches. For example, the phrase “embedding literacy and numeracy” would signal cross-curricular integration. “You will work collaboratively” signals cooperative learning, and “inquiry-based perspectives” signals “inquiry learning”. All subjects were coded dichotomously as either including or not including each approach. As subject descriptions show variance in language and differing degrees of explicitness, it is important to note that the author’s interpretation diminishes the objectivity of the research. Indeed, it was found that the website descriptors did not contain

sufficient information to consistently apply all guiding principles and approaches outlined within the framework. A research assistant worked with the author to ensure inter-rater reliability. Initially, the author and the research assistant independently coded 10 example subjects. Miles and Huberman's (1994) method of dividing the number of agreements by the number of agreements plus disagreements produced an inter-rater reliability score of 0.8, which is widely deemed to be acceptable (Lavrakas, 2008) or substantial (Landis & Koch, 1977). The coded samples were then discussed and critiqued to ensure a common understanding, which then informed the description of the principles and approaches outlined in Table 2. The inter-rater reliability was then confirmed through separate coding of further 5 examples, resulting in consensus between the author and research assistant (1.0). The frequency of each approach was used to determine prevalence. Neither the author nor the research assistant was able to identify reflective practices (guiding principle) or alternative conceptions (science approach) in website descriptor analyses. The decision was taken to omit these elements from the findings as this may be related to the limited nature of the data source and the prioritisation of other principles and approaches on university websites rather than absence from practice entirely.

Due to the open nature of the second research question, the framework (Table 2) was not employed directly. Rather, emergent themes were coded through multiple readings. Interview and survey data were analysed via an iterative process based on inductive open, axial and selective coding procedures (Glaser & Strauss, 1967; O'Toole & Beckett, 2013; Williams & Moser, 2019). Full transcripts were considered in the open coding phase, with segments of text being grouped into themes under the core interview questions in the axial coding phase. The most representative themes (selective coding) were expanded upon in the findings. All identifiable information, including names and institutions, were either redacted or replaced with pseudonyms. The qualitative data were transferred to QSR NVIVO 12 (Jackson & Bazely, 2019) for the analyses. Participant responses were grouped based on the research questions. The open-ended nature of the interview and survey data allowed for emergent themes to be considered, as participants described educational elements that were not readily identified in the aforementioned website descriptors or had otherwise not been considered by the researcher. PCK development, digital technologies and flexibility of delivery were emergent themes that related more to academics' functioning within subjects rather than the design of subjects themselves. Footnotes in Table 3 describe these themes. Alongside the informed reading of the author, the relative prominence of each theme was determined by the source and mention counts to mitigate bias and enhance objectivity. The source count refers to the number of participants who contributed to each theme. Mention counts refer to the number of times each theme was discussed uninterrupted by new questions or interviewer prompts. In essence, source counts are a measure of thematic coverage across the sample, and mention counts are a measure of the relative prevalence of each theme to some of the participants. To address the potential for duplication, as many interview and survey responses were coded across multiple themes, Jaccard's similarity coefficients (Krebs, 2014) were calculated to evaluate the overlapping of codes within themes on a 0 (no overlap) to 1 (duplication) scale. None of the inter-code coefficients reached the duplication threshold.

Findings

The research questions will be answered in sequence. First, the approaches to Australian PPSTE will be described and discussed. Second, academics' perspectives on the relative strengths and weaknesses of their PPSTE practices will be presented.

Table 3 Self-reported guiding principles and approaches to Australian preservice primary science teacher education (academic perspectives) (N = 17)

Theme	Number of contributing sources (percentage)	Number of total mentions	Example quote
Teaching tasks	15 (88%)	64	“...actually implementing the unit of work with children. You have to go out and work with children” (Helen)
PCK development*	12 (71%)	42	“I pose some sort of question about, you know, what’s happened that the teachers need to be considering or being mindful of. And so they’re constantly switching hats.” (Faye)
Reflective practices	11 (65%)	39	“But they come in and have to do one of these activities and they really have to reflect on it from the point of view of their students” (Brian)
Internal practical teaching experience	11 (65%)	26	“So our very last day of class is this science fair at a local school. And usually 300 or 400 kids and 200 or 300 of our students in groups of three. It’s a very exciting day for the school. It’s all a really good thing” (Isabel)
Digital technologies**	10 (59%)	35	“Now we’re also bringing in the digital technologies components as well, so they learn to code robots and do some things with ‘Scratch Junior [ScratchJr]’ and so on” (Grace)
Student-centred investigations	10 (59%)	32	“So they will be then provided, here are your materials, um, you have to figure out your question, but basically here’s the gist of what you’re doing” (Faye)
‘Nature of science’	9 (53%)	23	“So that last week is sort of to look at that pseudoscience but also look at climate, is it pseudoscience, where’s the evidence? We look at different perspectives” (Connor)
Basis in research	9 (53%)	18	I’ll send you a couple of articles I’ve written... I wrote one about this particular assignment” (Douglas)
Constructivism (e.g. 5Es)	8 (47%)	15	“...running across the unit is a focus on constructivist theory” (Bianca)
Modelling	8 (47%)	13	“There’s also a lot of teacher modelling from my part” (Grace)
Cooperative learning	7 (41%)	25	“They get a four-week collaborative space to generate a response to their tasks that they’ve got to do” (Franklin)
Alternative conceptions	7 (41%)	16	“Many of these children like their ideas and it’s difficult to change them, and we are trying to change them to the scientific view” (Douglas)
Cross-curricular integration	7 (41%)	13	“...you can’t just teach science. You’ve got to be able to integrate the science with your writing and your reading and your speaking and listening” (Edward)
Scientific literacy	6 (35%)	18	“Students are taught to support their reasoning and the labs are designed so students can practice supporting their reasoning each week” (Elizabeth)

Table 3 (continued)

Theme	Number of contributing sources (percentage)	Number of total mentions	Example quote
Problem-based learning	6 (35%)	14	“This is a problem, let’s design something. These are our parameters and this is how much time you’ve got” (Edward)
Flexibility of delivery ^{***}	4 (24%)	8	I still urge the other coordinators and tutors to make decisions in their particular classes to take advantage of their strengths and to cater for their particular students” (Andrew)
Links to professional experience placements and partnerships	2 (12%)	5	“...always had that 2-week, school based experience” (Bianca)

*PCK development refers to academics’ self-reported means of guiding students to deeper, more cohesive understandings of the complex learning experiences. This extends beyond more focused reflective practices, to consolidation of learning through extended discussions, feedback and probing questions for extended abstract professional cognition about scenarios that have not occurred.

**Digital technologies broadly refer to PPTs engaging with technological resources during their PPSTE subjects (e.g. communication, design).

***Flexibility of delivery refers to the different choices; PPTs and lecturers may be afforded in the delivery of a PPSTE subject.

Approaches to Preservice Primary Science Teacher Education in Australia: Research Question One

The web-based descriptor analyses will first be presented for a wide-ranging overview, followed by the more in-depth academic perspectives.

Website Descriptors

Authentic, student-centred approaches are widespread in Australian PPSTE. Figure 1 indicates the number of PPSTE subjects and universities whose website descriptions implied particular intended student-centred principles and approaches. The three approaches with counts over 40 highlight the broad focus on preparing PPTs for professional practice. The dominant theme of scientific literacy suggests a strong focus (94% of institutions) on assisting PPTs to understand how scientific skills and knowledge apply to the world beyond the classroom. Internal practical teaching experiences were featured in the descriptions of a substantial minority (36%) of subjects within half of the included institutions (50%). Perhaps such experiences could be later consolidated into more to professional experience blocks and partnerships, which is an area for future development in PPSTE programs. The inconsistency in the number of PPSTE subjects offered by each university was striking, ranging from one (34%) to four (6%). While these data provide useful insights into Australian PPSTE, it should be noted that guiding principles (e.g. constructivism) can encompass a variety of different approaches and thus are inherently more likely to be cited with more frequency than specific pedagogical approaches (e.g. cooperative learning). Reflective practices (guiding principle) and alternative conceptions (science approach) were omitted from Fig. 1 as these were not presented clearly in the website descriptors. This decision

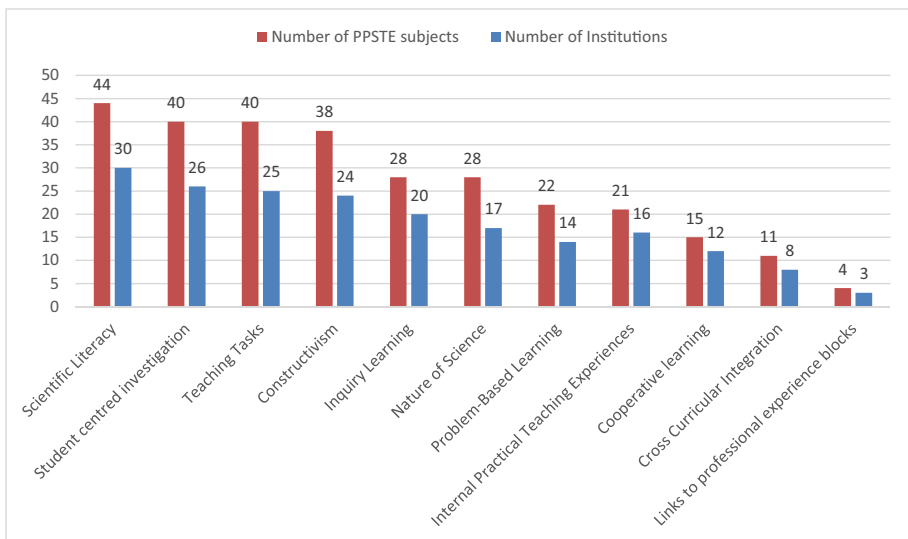


Fig. 1 Guiding principles and approaches to Australian preservice primary science teacher education (university website descriptors)

was made to avoid a misleading interpretation regarding their absence from Australian PPSTE.

The average number of approaches and principles per PPSTE subject per university was 5.125, with 14 institutions reporting an average of 6 or more and 4 institutions incorporating an average of 9 and above. These trends were calculated by dividing the number of guiding principles and themes identified within each institution by the number of PPSTE subjects offered by each institution. A curious trend was the focus on problem-based learning, with 8 universities including it in all of their PPSTE subjects. Similar institutional commitments were made to cross-curricular integration and inquiry learning, as these approaches were shown in all PPSTE subjects in 6 and 10 universities, respectively. Conversely, cooperative learning appeared to be a more supplementary approach as it was reported only once within 9 institutions.

Academic Perspectives

The 17 academics echoed the broader themes of professionally authentic and student-centred practice in Australian PPSTE (Table 3). Teaching tasks were commonly supplemented by PCK development cues and reflective practices. The prominent theme of internal practical teaching experiences was more common amongst academic respondents (65%) than the website descriptors (50%), referring to 16 out of 32 institutions. While Isabel felt the internal practical teaching experience offered to her preservice teachers to be beneficial, she lamented the scarcity of such experiences in ITE, “they never get enough”. When discussing the challenges to facilitating in-school teaching experiences, Helen believed more direct connections with primary schools to be the solution, “The trick would be to have it school based”. Indeed, only two interviewees described such direct connections. Bianca described a rare instance of a school-based PPSTE subject, “We have a unit that is solely school based, where our students plan and deliver a unit of work”.

Strengths of and Challenges to Preservice Primary Science Teacher Education in Australia: Research Question Two

The participants’ perceived strengths of Australian PPSTE practices (Table 4) were similar to the approaches outlined in the prior section. Authenticity was viewed as a strength by the majority of participants (71%). Faye’s views are indicative of a desire to bridge the gap between schools and universities through her practice, “everything that we do is something that they can do in a classroom”.

Many respondents looked beyond themselves when describing the strengths of practice, with team (11 sources), resources (9), internal practical teaching experience (8) and school-external relationships (7) emerging as key themes. Bianca described the benefit of bringing practicing teachers into her teaching teams, “It can be good to have people who have had really recent teaching experience”. Diversity can also emerge through collaboration with science faculties, as Grace noted, “The chemists can show what they love about chemistry, and physicists can show what they love about physics”.

The perceived challenges (Table 5) were important to the responding academics.

Negative Views About Students These issues were raised by the overwhelming majority of respondents (94%), including issues related to engagement (15), science content knowledge (11), life circumstances (9) and pedagogical knowledge (5). Phrases such as

Table 4 Perceived strengths of Australian preservice primary science teacher education ($N=17$)

Theme	Number of contributing sources (percentage)	Number of total mentions	Example quote
Authenticity	12 (71%)	22	"...the assessment's practical, it gives them something they can draw on when they're on their professional experience and then later on when they're teaching" (Connor)
Team	11 (65%)	27	"Yeah, just really diverse and we have a very strong team. We have a lovely team" (Josephine)
Resources	9 (53%)	13	"...we also have a room that's a dedicated room for science and art in the education building. So that's helpful as well..." (Edward)
Internal practical teaching experience	8 (47%)	10	"That opportunity to work out in the schools, that's a definite positive of the subject" (Isabel)
School-external relationships	7 (41%)	10	"...we've always had a relationship with the demonstration school and worked with them, it's just much more integrated now" (Josephine)
Science content	7 (41%)	9	"...it's quite rigorous in terms of the expectation that the students understand the science content" (Bianca)
Student-centred learning (including hands on learning)	6 (35%)	9	"Very, very hands on. Very, very practical" (Grace)
Reflective practices	6 (35%)	8	"So that kind of tension between the theory and the practice is really important for them. And we reflect on that in class afterwards as well" (Andrew)
Cohesion between science subjects	5 (29%)	9	"...we co-design subjects and that we know what each other is doing, even if we take different subjects..." (Isabel)
Cooperative learning	5 (29%)	6	The fact that we got them working with each other. So it was very much a collaborative process and I think that was a key strength" (Abigail)
<i>Primary Connections</i> (5Es, constructivism)	4 (24%)	6	"I think having the <i>Primary Connections</i> as a resource for students is a strength" (Edward)
Cross-curricular integration	3 (18%)	5	"...the collaboration that you need to trigger between curriculum areas, distinct areas of math, science, and different areas" (Franklin)
Accessibility–flexibility	3 (18%)	8	"...it's more accessible to many more students..." (Douglas)
Cohesion within Science subjects	3 (18%)	4	"...the tutorials are connected. So things they do in week two brought back in week three, week four, week five" (Andrew)
Students	2 (12%)	5	"Our students are quite amazing..." (Grace)

Table 4 (continued)

Theme	Number of contributing sources (percentage)	Number of total mentions	Example quote
None	2 (12%)	2	“None so far” (Kylie)
Administrative support	1 (6%)	2	“And that’s a definite strength, that we’ve got this strong administrative support” (Isabel)

Table 5 Perceived challenges to Australian preservice primary science teacher education (*N* = 17)

Theme	Number of contributing sources (percentage)	Number of total mentions	Example quote
Students (attitudes & capacity)	16 (94%)	70	“...students say that they do not like science, and avoid science” (Elizabeth)
Curriculum issues (narrow or broad)	14 (82%)	30	“There’s only so much you can fit in a four-year degree, so things have been squeezed” (Edward)
School–university disconnection (professional placements)	12 (71%)	16	“In general, the most difficult challenge is that students do not see teachers teaching primary science in the classroom when they go to the schools to complete their practical (professional) experiences” (Elizabeth)
External pressure	11 (65%)	48	“Over time there’s generally a push to bump up completion rates of subjects by watering down the assessment somewhat” (Connor)
Time	11 (65%)	27	“I quite like what I do obviously. But I would just like to do more of it” (Douglas)
Resources	10 (59%)	19	“I was squashed in a little room, shared with the art teacher, and the storage space was just pathetic” (Helen)
Team-colleagues	9 (53%)	24	“We do have some difficulty in terms of our casual people” (Josephine)
Inconsistency, lack of clarity (delivery & design)	7 (41%)	16	“We do have issues of consistency across tutorials” (Isabel)
Lecturer-driven teaching (passive learning)	6 (35%)	10	“So, it’s still predominantly lecturer driven” (Connor)
Online education	4 (24%)	11	“...the online guys generally want to get through the degree with a minimal disruption to their world...” (Franklin)

“not keen”, “intimidated”, “not confident”, “never liked science”, “don’t want to be there”, “horrible experiences” and “weak” were used by the academics to describe PPTs’ initial attitudes towards science teaching and science content knowledge. Faye said that phrases such as “antennas, antlers and legs” were used by PPTs to label ants, highlighting sub-optimal science content knowledge. Additional reported issues included the lack of post-compulsory science education, increasing reliance on online education, life responsibilities and the absence of science during practical placements. Regardless, Bianca’s comment captured a sense of hope that was echoed by at least three other participants, despite not being the focus of this project:

By the end the students say “Ah, I love science”, it’s just very exciting because you know you’ve provided the type of experience where you’ve given them a feeling of success.

Time and Curriculum Issues These were raised by 11 and 14 participants, respectively. Many seemed resigned to the relative lack of curriculum time dedicated to PPSTE, as can be seen through phrases like “limited”, “jam packed” and “not enough”. Grace described an extreme example of reduced teaching time, “We can’t fit everything in to that nine weeks”. Narrowing of available science time in the broader degree structure was seen as problematic, often taking the form of merging science disciplines with other disciplines, such as physical education, into single subjects. Others believed more integrated learning to be beneficial; Helen believes that stronger themes throughout ITE science programs could be worth pursuing, “I’d also like to see a sustainability overlay, but you just don’t have the time”. Brian felt that the emerging focus on STEM afforded a worthwhile, but challenging, opportunity for integration, “But I guess with the focus on STEM, if we could incorporate science in other units as well that would be great, but obviously we have a limited curriculum with which to do that with”. Bianca was firm in her view that there was “no possible way” to include discreet, meaningful coverage of chemistry, physics, earth science and biology in a degree structure. One suggestion would be to view the linked themes of curriculum issues and time in PPSTE through a STEM lens.

School–University Disconnection and External Pressure These were raised by the majority of academics, with 12 and 11 sources, respectively. Elizabeth viewed the disconnection between schools and universities as the biggest issue in the sector, “The most difficult challenge is that students do not see teachers teaching primary science in the classroom”. Other sources of external pressures included high stakes testing in schools, changes in the Australian curriculum, budget restraints, conflicting accreditations agendas, lack of agency and more diverse degree structures. Connor humorously referred to Australia’s National Assessment Program (NAPLAN), a high-stake national assessment focuses primarily on literacy and numeracy, as “NAPLAN” for primary science education.

Resources Limited access to physical materials, adequate storage, professional development and appropriate learning technologies were issues raised by 10 academics. Increased tutorial sizes and reduced operational budgets forced lecturers to adapt more teacher-centred approaches, as Connor notes, “You think you get better results working in small groups and then the budget says that you have to do it the way you do it”. An institutional push for standardisation left Isabel feeling that she was being “forced into a box” rather than “letting the pedagogy drive (her) choices”.

Discussion

Research Question One: Reported Teaching Practices in Australian PPSTE

The PPSTE subjects investigated in this paper were unified in their focus on providing student-centred and professionally relevant experiences to PPTs yet displayed variance in the specific principles and approaches employed. Many of the “innovative practices” initially identified by Palmer (2008) could now be considered mainstream “student-centred” approaches. Authenticity was the central pedagogical theme, with the development of scientific literacy, teaching tasks, student-centred investigations and constructivism (e.g. 5Es) featuring prominently. This suggests that the sector is attuned to the core issue of generationally low scientific literacy (Martin et al., 1997; Thomson et al., 2020). The relative prominence of internal practical teaching experiences was a positive trend that could serve as basis for the development of more formal partnerships with primary schools in the future (Hobbs et al., 2018).

While Palmer’s (2008) investigation in PPSTE relates more directly to the research presented in this paper, some speculative discussion attributes of effective primary science practice are warranted. For example, the relative prominence of themes such as scientific literacy, student-centred investigations, and “Nature of science” provides some indication that Australian PPSTE broadly incorporates attributes of effective primary science teaching (Roth, 2014). However, the distal nature of the data presented in this paper does not allow for anything more than speculation because these deeper concepts are interrelated, complex and reliant on the actions of teachers in the moment. A logical next step would be to collect more proximal data (e.g. subject resources, observations, student learning artefacts) to investigate these deeper concepts in PPSTE. Furthermore, future research into the science teaching practices of recent graduate primary teachers could be contextualised within primary science models, such as Harlen’s (2015) “14 big ideas about and of science” and Roth’s (2014) “attributes of effective primary science teaching”.

Research Question Two: Perceived Strengths of and Challenges to Australian PPSTE

The participating academics described an array of strengths for the PPSTE subjects delivered within their institutions, including authenticity, teaching teams, internal teaching experiences, external partnerships and resources. Many of these themes can be traced back to Palmer’s (2008) earlier work, which may be a possible indication of a degree of consistency and resilience in Australian PPSTE. Further to this point, the identification of resources as a point of strength appears, at least at face value, to contradict broader themes of resource scarcity more commonly associated with higher education (Norton and Cakitaki, 2016). The key perceived challenges to the provision of PPSTE in Australian ITE were the characteristics of PPTs, time and curriculum issues and school–university disconnection. In line with existing literature (e.g. Appleton, 1992, 2003; Boon, 2010; Murphy & Smith, 2012), attitudes, capacities and circumstances of PPTs were recognised as a core challenges by 94% of the contributing academics, a possible indicator that the long-established science disengagement reported by preservice and inservice teachers continues unabated. Time and curriculum issues may be related to factors beyond PPSTE academics’ control, such as requirements to show impact on student learning (AITSL, 2015), for which academics have little to no direct control, and the complex demands associated with

ITE accreditation processes (Ell et al., 2019; Ingvarson & Kleinhenz, 2006). A comprehensive discourse analysis of the AITSL ITE accreditation document highlighted themes of accreditation, impact and evidence that serve to position ITE academics in managerial roles within a highly regulated environment (Bourke, 2019), which could have contributed to the time and curriculum issues identified in this paper. If unaddressed, such issues may threaten academics' professional identities (Clegg, 2008).

Almost all participants (14) felt that their science education subjects covered too many concepts with limited depth or simply omitted important areas, such as indigenous perspectives and sustainability (ACARA, 2017). The relative lack of science, technology, engineering and mathematics (STEM) coverage in the findings warrants some discussion. For the majority of the participating academics, the move towards STEM may have the potential to further exacerbate existing time and curriculum issues if individual PPSTE subjects are merged. STEM in Australian PPSTE was not an explicit focus of this research project, but it did emerge indirectly through STEM aligned practices, such as problem-based learning and cross-curricular integration. Yet, dissent emerged from Helen, "I'm criticizing STEM actually because STEM is just basically around neoliberal economic policy". Indeed, the increasing prominence of STEM education has been critiqued for its potential to marginalise other important aspects of science, such as education for sustainability (Smith & Watson, 2018, 2019). Still, the benefits of more integrated, authentic and higher order STEM education must be considered. Indeed, the UK's National STEM Learning Centre (<https://www.stem.org.uk/finding-us>) provides direct teaching and professional development support for STEM educators. To complement such initiatives, academics' perspectives on how STEM is being incorporated into ITE programs appear to be fertile ground for future research. As generalists, primary teachers are uniquely positioned to teach integrated STEM programs equitably across jurisdictions where access to external support is not consistent.

The Relationship Between Schools and Universities

The relationship between universities and schools was a major theme throughout the data. The broad inclusion of internal practical teaching experiences and other authentic practices indicates a sector-wide alignment with the needs of primary school stakeholders. This was reiterated by positive reports of in-school teaching experiences and the inclusion of primary teachers in teaching teams. Indeed, the benefits of in-school teaching experiences have long been established in science education research literature (Flores, 2015; Kahn & VanWynsberghe, 2020; Lewis, 2019). Longitudinal research into PPTs' science teaching efficacy beliefs showed that the single largest 1-week increase to participants' personal science teaching efficacy beliefs occurred after the completion of an in-school teaching experience (Deehan et al., 2017). However, it must be stated that the quality of extended in-school experiences is often related to the modelling provided by mentor teachers (Skamp & Mueller, 2001). Aside from some early leaders in establishing more formal, institutional links between schools and universities (Hobbs et al., 2018), it seems that many of the school–university connections are built on the relationships between individuals rather than formal institutional programs.

From the academics' perspectives, school–university relationships were both challenging and rewarding. A core issue raised was that the science teaching narrative established in universities is not necessarily consolidated when PPTs enter schools without direct university relationships. In fact, preservice teachers seem to seldom observe science teaching

on their formative professional experience placements (Deehan et al., 2017; Deehan et al., 2020; Treagust et al., 2015; Wellcome Trust, 2017). Formal, institution level connections between schools and universities are undeniably beneficial (Hobbs et al., 2018) and should be actively fostered by ITE providers; certainly the necessary time and effort needed to build such relationships are already being spent by dedicated academics, teachers and school administrators. Such relationships clearly function well with a stable workforce and may be fundamentally threatened by the steadily increasing reliance on non-tenured staff in higher education (Norton & Cakitaki, 2016; 2018), likely worsened by the economic devastation wrought by COVID-19 in 2020 (Ferguson & Love, 2020). Post COVID-19 research into PPSTE is clearly needed. Regardless, university administrators need to actively consider how all staff should be supported to safeguard student-centred, authentic practice.

Limitations

There are five main limitations to the research presented in this paper. First, the data are descriptive and do not allow for the effectiveness of different approaches to be evaluated without reference to external research. This means that definitive statements about effectiveness of practice cannot be made. Second, the data and coding are interpreted through the author's research-informed perspectives on student-centred practice that are unlikely to capture the full nature of Australian PPSTE. This is further exacerbated by the cross-sectional and second-hand data's limited ecological validity as they do not capture complex teaching and learning dynamics. Third, the low academic response rate (11.8%) and reliance on self-selection are likely to have biased the findings as individuals with more extreme views were more likely to voluntarily participate. It should be noted that impersonal email approaches and the heavy working burden of the target population are likely contributing factors. Fourth, the distal nature of the data do not allow for more complex elements of effective PPSTE, such as Harlen's (2015) big ideas and Roth's (2014) attributes of effective primary science teaching, to be addressed beyond light speculation. Fifth, the selection and organisation of the guiding principles, science approaches and broad education approaches in the framework (Table 2) are contestable, despite being defensible. The framework offers a flawed, singular lens through which to investigate Australian PPSTE. For example, the frequency counts of website descriptors cannot account for differences and relationships between the principles and approaches presented in the framework. Additionally, an argument can be made that the science approaches and broad education approaches are not mutually exclusive. For example, project-based learning (e.g. Fitzgerald, 2020) and inquiry learning (Hwang et al., 2015) have been used in disciplines other than science. In addition, the framework could not be applied consistently to the different data sources presented in this paper (website descriptors, interviews and surveys). For example, while not readily apparent in the website descriptor findings, reflective practices were evident in the interview data. Clearly, this paper is far from definitive, and further research from different perspectives is warranted.

Tentative Implications for PPSTE

Some tentative suggestions for Australian PPSTE can be offered, despite the descriptive nature of the data presented in this paper. The prominence of more ad hoc internal teaching experiences and the relative scarcity of more formal links to professional experience

placements and school partnerships suggest that more work can be done in the consolidation of relationships between schools and universities. However, given the increasing reliance on non-tenured staff in higher education (Norton & Cakitaki, 2016), the expectations of and remuneration for university teaching roles could be adjusted to more directly align with institutional commitments to student-centred practice. Another potential mechanism for strengthening school–university relationships would be to focus PPTs’ transitions into their teaching careers through online professional learning networks, such as those associated with the Science Teachers Association of NSW (STANSW) and *Primary Connections*, to ensure the learning occurring within universities is consolidated into desirable science teaching practices.

Implications for Research

There are many important implications for future research that have arisen from this paper. The collection of more proximal data, such as subject outlines, PPT artefacts, observations and subject materials from Australian ITE providers, would be worthwhile to ensure a comprehensive and accurate understanding of the sector. Research into teaching team compositions and online teaching practices would be interesting contributions to the literature. Further research into PPSTE would also allow for Harlen’s (2015) big ideas of and about science and Roth’s (2014) attributes of effective primary science teaching to be investigated. Indeed, the emergence of themes such as scientific literacy, student-centred investigations and “nature of science” suggests it may be worthwhile to further investigate other elements of effective primary science teaching, such as science discourse, argumentation and scientific reasoning (e.g. Roth, 2014). Additionally, academics should conduct follow-up research with teaching graduates to explore how they relate PPSTE to their science teaching practice. Such research would enable initial teacher education programs to determine whether or not they are succeeding in producing agents of change (Deehan et al., 2020). The dearth of the necessary longitudinal research can likely be attributed to substantial commitments in terms of time and resources. More intra-university research in this space could be a means of overcoming barriers. Further to this point, the changes to ITE caused by the COVID-19 crisis also need to be understood. In particular, it would be prudent to investigate how rapid shifts to online education during the crisis impacted academics who construct their professional identities around face-to-face teaching practice. It would also be pertinent to investigate how existing school–university relationships could be used to ensure cohesive professional transitions for graduate teachers. Online professional learning networks are a promising avenue with an emerging evidence base (Greenhalgh et al., 2020) and a target group of educators with improving technological literacy fostered during the COVID-19 crisis. Finally, the delivery of more integrated STEM subjects in PPSTE needs overt research attention (Skamp, 2020). It would be interesting to see if and how existing STEM adjacent practices in PPSTE are being connected to or adapted within broader community- and/or university-based STEM initiatives. Furthermore, the perspectives of university lecturers, preservice teachers and inservice teachers on STEM education should also be investigated, given existing challenges with resources and crowded curriculums. Research could be extended into the state of primary science education practice more broadly given the recent release of the TIMSS data (Thomson et al., 2020) and the age of seminal work in this space (Goodrum et al., 2001). These suggestions align with similar themes raised in Skamp’s (2020) review of 262 RISE publications, wherein STEM and

primary science education were identified as areas of science education research warranting further attention.

Conclusion

Student-centred, authentic principles and approaches seem to be common within Australian PPSTE, where many academics are overtly striving to bridge school–university divides. Scientific literacy (guiding principle), student-centred investigations (science approach), teaching tasks (broad education approach), constructivism (guiding principle), inquiry learning (science approach) and nature of science (science approach) were the most common principles and approaches found in the website descriptor and interview/survey analyses. A complex array of strengths and challenges associated with the provision of PPSTE in Australian ITE were reported by the 17 contributing academics. Strengths were based around orientation to professional science teaching as a majority of respondents valued the authenticity of their PPSTE practice, the quality of their teams, opportunities for teaching experiences and relationships with external stakeholders. However, the academics' perceived challenges echoed wicked problems beyond their direct influence, such as the poor science views held by PPTs, institutional pressures (curriculum and time) and disconnections between universities and schools. Moving forward, it is imperative we expand the research base beyond universities to determine if and how graduate teachers are functioning as agents of change in the provision of primary science education. It is also necessary to consistently embed student-centred, evidence-based practices in the educational designs of PPSTE subjects and ITE programs to ensure consistency and reduce the reliance on individuals. However, we must also consider emerging factors, such as online education, casualisation, the STEM agenda and new science education research in order to ensure the continuation of the student-centred trajectory of the sector.

Appendix-Interview and survey questions

Question 1

“What is your name?”

- “Remember that your confidentiality will be ensured in all data reporting. Only the interviewer will know your identity”.

Question 2

“At what institution are you currently employed?”

Question 3

“Can you tell me a bit about your background?”

- “What are your qualifications?”
- “How long have you worked in preservice primary science teacher education?”
- “What is/has been your role in the preservice primary science education at your institution?”

Question 4

“How is primary science education taught to preservice primary teachers at your institution?”

- Can you describe the structure and approaches?
- What do you focus on in the primary science education subject(s)?

Question 5

“What are the biggest strengths of the preservice primary science education subjects(s) at your institution?”

Question 6

“What are the biggest challenges in the teaching of primary science education to preservice primary teachers at your institution?”

The interviews were delivered in a semi-structured fashion as interviewer discretion was used in follow-up questions after each of the six questions were asked. The essential questions are presented under each question number. Additionally, optional prompts are presented in dot points under questions 3 and 4, with the reviewer exercising discretion based on the interviewee’s responses to create a conversation tone.

Copies of the questions are available from the author.

Declarations

Ethics Approval The study was conducted under Ethics Protocol Number H18197 at Charles Sturt University, Bathurst, NSW, Australia.

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