# Relations Between Australian Primary Teachers' Reported Professional Development Engagement and Their Science Teaching Practices and Efficacy Beliefs

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*Abstract: Professional development has long been viewed as crucial to sustained improvement in the quality of primary science education. This paper considers professional development beyond the context of a specific program by examining how the science teaching efficacy beliefs and practices vary between teachers who both have and have not engaged with science professional development. This paper reports on a primarily quantitative study wherein a sample of 206 Australian public primary educators responded to an online survey capturing demographic, science teaching efficacy and science teaching practice data. Quantitative data were analysed via descriptive, ANOVA and Chi Square analyses. The supplementary qualitative data were analysed thematically. More participants reportedly not participating in science professional development (n=128) than those that did (n=78), with teachers based in non-metropolitan and disadvantaged schools being proportionally overrepresented in the "No PD" group. The results showed that teachers who reportedly engaged with science professional development showed significantly higher scores on measures of science teaching efficacy, science teaching approaches and curriculum coverage. Professional development attendees were also more likely to use science teaching approaches aligned with the broader goal of improving students' scientific literacy. This research has implications for increasing access to science professional development opportunities for primary educators. It also shows that the benefits commonly associated with specific professional development programs cannot be solely attributed to the characteristics of teachers willing to pursue such opportunities because the non-attendees in this study were still engaged and confident enough to participate in this research project.*

**Keywords**: science education; primary education; professional development; teacher efficacy; teacher beliefs; quality improvement

## Introduction and Literature Review

Quality science education must be emphasised in our increasingly complex and tumultuous world. It is imperative that our future generations become scientifically literate citizens who are able to flexibly apply their science knowledge and skills to real world contexts as informed global citizens (Akerson & Bartels, 2023; Bybee, 1997; Roberts & Bybee, 2014). Scientific literacy is about understanding the way scientific evidence and insights can benefit people in their everyday lives (Goodrum et al., 2001; Rennie, 2005). Australian national (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2013; 2019; 2024) and international (Martin et al., 1997; Thomson et al., 2020) assessments offer compelling, albeit flawed insights into the scientific literacy of primary learners (Baker, 1997; Bracey, 2000; Schuelka, 2013; Wang, 2001; Zhao, 2020). The Trends in International Mathematics and Science Study (TIMSS) is the preeminent assessment of Year 4 (i.e., 10 year old) learners across Organisation for Economic Cooperation and Development (OECD) nations; the triennial assessment shows that 90% of participating nations, including Australia, are falling below the high international threshold denoting age appropriate science and scientific literacy (Thomson et al., 2020). This is not to say that science education systems are in decline, rather that international assessments are signalling stagnation amidst inconsistent findings (Georgiou, 2023). A recent assessment of the scientific literacy of 6089 Australian students indicated that 57% reached the proficiency threshold which denotes their emerging abilities to construct and explain scientific concepts, with reference to evidence, in familiar contexts (ACARA, 2024). For the sake of equity, it is imperative that the proportion of Year 6 students reaching proficiency increase. However, despite this evidence of suboptimal scientific literacy, young people still reported positive views of science and science learning (ACARA, 2013; 2019; 2024). It is important for these early positive dispositions to be encouraged because they can dissipate in later years without high quality science education and engagement (Ali et al., 2013; Denessen, et al., 2015; DeWitt & Archer, 2015; Said et al., 2016).

Teachers are the agents of change for primary science education (Deehan et al., 2020) but they are often overburdened by the role of bridging the theory-praxis divide whilst dealing with the practical restraints of primary teaching, including, but not limited to: high rates of burnout (Kokkinos, 2007), work-life balance deficiencies (Johari et al., 2018), resourcing issues (Gonski, 2011; Rowe & Perry, 2020) and crowded curricula (Crump, 2005). The challenges are compounded for teaching inquiry-focused science curricula (ACARA, 2017; Bybee, 2014; Eggleston, 2018; Kim et al., 2013; Next Generation Science Standards [NGSS], 2013) as inquiry learning is fraught with impediments at the planning, implementation and summative evaluation phases (Akuma & Callaghan, 2019). Further, primary teachers often report limited interest and content knowledge in science (Appleton, 1992; 2003; Murphy & Smith, 2012) that may have inhibited their own preservice teacher education (Deehan, 2022). Indeed, teacher science content knowledge is considered to be one of the critical obstacles to improving science education (Goodrum & Rennie, 2007; Watters, 2014). Limited content knowledge directly impacts primary science teaching practices with passive approaches (e.g., note taking, teacher-controlled investigations and lectures) becoming more dominant and therefore adversely impacting student engagement (Goodrum, et al., 2001, Goodrum & Rennie, 2007, Tytler et al., 2008). Teachers may also be reduced in their capacity to help their students to fully realise the benefits of hands-on learning due to their own limited pedagogical understandings (Kleickmann et al., 2016). Most concerning is that science is often taught for less than one hour per week in primary settings, falling well below minimum recommended classroom time allocations (Angus, 2003; Goodrum et al., 2001; Office of the Chief Scientist, 2012; Tytler & Griffiths, 2003; Tytler et al., 2008). Regardless of the challenges, many primary learners hold favourable views of science and want to be taught more science (ACARA, 2013; 2019; 2024). This means that primary science is the ideal intervention point to avoid potential declines in secondary (Ali et al., 2013; Denessen et al., 2015; DeWitt & Archer, 2015; Said et al., 2016) and post-secondary science engagement (Kennedy et al., 2014; Norton et al., 2018).

Despite an historically limited evidence base (Scher & O'Reilly, 2009), recent research has shown the positive influence professional development (PD) can have on immediate outcomes, such as improved teacher beliefs and knowledge (e.g. Deehan, 2017), intermediate outcomes, such as changes in practice (e.g. Kleickmann et al., 2016), and long-term outcomes, such as improvements in students' achievement and knowledge (Lynch et al., 2019; Scher & O'Reilly, 2009; Yoon et al., 2007), in science education. Depending on the structure of the PD program, proximal and/or distal outcomes can be influenced to improve the quality of science education (Desimone, 2009). The delivery of PD can range from traditional, if often ineffective, one-shot workshops (Barber & Mourshed, 2007; Borko, 2004; Darling-Hammond et al., 2009; Lumpe, 2007; Lumpe et al., 2012) to extended and flexible professional learning networks (PLNs) (Greenhalgh et al., 2020; Fentie, 2019; 2021). Focus on Pedagogical Content Knowledge (PCK) development (Lynch et al., 2019; Scher & O'Reilly, 2009), active face-to-face programs (Fishman et al., 2013), expert scaffolding/ mentoring (Kleickmann, et al., 2016), teacher collaboration (Blank et al., 2008), exploring science in society (Ackay & Yager, 2010), addressing student conceptualisations (Kleickmann et l., 2016; Lynch et al., 2019), inquiry learning (Ketelhut et al., 2020) and meaningful follow-up after classroom implementation (Lynch et al., 2019) have all been reported in academic literature. However, despite the advances in knowledge afforded by the more robust measures (e.g., Ackay & Yager, 2010; Kleickmann et al., 2016) and methodologies (e.g., Heller et al., 2012; Fishman et al., 2013), principles of effective PD practice remain relatively vague as different forms of science PD have shown to be effective (Desimone, 2009; Lynch et al., 2019; Yoon et al., 2007). Furthermore, the positive outcomes reported in the science PD literature are somewhat incongruous with the broader problems experienced by teachers and the suboptimal student science learning outcomes.

A vast array of effective and accessible science PD opportunities has emerged in Australia over the past few decades. The most well-established program is Primary Connections; an initiative from the Australian Academy of Science (AAS) that provides professional development, curriculum support and resource packs to Australian primary teachers (https://primaryconnections.org.au/). A recent review of 63 research articles has shown the strong influence that Primary Connections has had on teachers and students (Aubusson et al., 2019). Primary Connections has expanded its influence through the provision of flexible, online professional development opportunities (Walker et al., 2020). Similar programs, such as "Science by Doing" have maintained this positive science momentum in early secondary classrooms (Ng et al., 2018). In recent years, integrated STEM PD and Professional Learning Networks (PLNs) have expanded the scope and accessibility of science PD for primary educators (Ralls et al., 2020; Stevenson et al., 2019). The key challenge for stakeholders now is to ensure that as many primary educators as possible engage with strong, evidence-based science PD for the sake of system-wide science education improvement.

In Australia there are some systemic factors that can unintentionally limit primary teachers' engagement with the available science PD opportunities. Across all public Australian educational jurisdictions, there is no specific requirement for primary educators to engage in science PD as part of their 20-50 hours of annual PD required for ongoing accreditation (Australian Capital Territory Teacher Quality Institute [ACTTQI], 2022; Australian Institute for Teaching and School Leadership [AITSL], 2017; NSW Education Standards Authority [NESA, 2017]; Queensland College of Teachers [QCT, 2022]; Teacher Registration Board of the Northern Territory [TRBNT, 2022]; Teachers Registration Board of Tasmania [TRBT], 2022; Teachers Registration Board of South Australia [TRBSA], 2022; Teacher Registration Board of Western Australia [TRBWA, 2022]; Victoria Institute of Teaching [VIT], 2022). Ostensibly, the relatively broad requirements are designed to account for the varying needs across different schools and sectors. Indeed, primary science in Australian can be taught by generalist classroom teachers or science specialists. Although many Australian principals prefer science to be taught by specialists (Ardzejewska et al., 2010), the number of available specialist science teachers will likely never satisfy demand (Fraser et al., 2019; Hobbs, 2013). Interestingly, the current evidence base suggests that there is no inherent difference in the quality of specialist and generalist primary science teaching (Levy et al., 2016; Mills et al., 2020). Many accredited and committed Australian primary educators experience inconsistency in both their role as science educators and their engagement with science PD; creating a group of science educators whose experiences, practices and attitudes are not yet fully represented in the science PD or general science education literature. A macro perspective extending beyond specific programs to consider broader issues of PD engagement is necessary to ensure a full understanding of the science teaching efficacy beliefs and science teaching practices of Australian primary teachers.

All reviewed studies drew upon primary science teacher populations engaged in PD whereas the current study expands this perspective to include teachers who have not engaged in science PD which allows for the "silent voice" of non-attendees be heard. Therefore, this paper does not seek to comment on the structure or style of science PD, but rather examine how those educators with access to PD differ to those have not engaged with PD on measures of science teaching efficacy and practices. Due to the proliferation of science PD opportunities, including more traditional programs and PLNs, such as science teachers' associations, this paper focuses on teacher engagement with PD in general, rather than on a specific program. Indeed, most of the science education PD literature only considers PD participants, and does not consider the educators who, whether due to attitude or opportunity, have not participated in science PD. By examining science PD beyond the context of a program, issues of social desirability bias and the "silent voice" of non-attendees can be mitigated. Research participants are likely to be more engaged and confident than the general target population regardless of previous PD experience, meaning that between group comparisons are less likely to be impacted by unknowable characteristics. Therefore, this paper makes a broader, macro contribution to primary science education and PD research by collecting data from primary science teachers both with and without science PD experiences. Furthermore, this project is a timely contribution as much of the existing literature in Australian primary science education is now over a decade old (e.g., Goodrum et al., 2001; Goodrum & Rennie, 2007). The following research question will be answered in this paper:

- What are the relationships between a sample of Australian primary teachers' reported professional development engagement and their science teaching efficacy beliefs, reported teaching approaches, and reported curriculum coverage?

As science PD opportunities have been shown to enhance teachers' science teaching efficacy beliefs (Deehan, 2017) and science teaching practices (Aubusson et al., 2019), it is hypothesised that primary science teachers who have engaged with science PD will report higher science teaching efficacy beliefs, broader teaching repertoires and wider science curriculum coverage than their counterparts who have not engaged with science PD.

## Methodology

Efficacy beliefs are based on judgements about the capability of the self and/ or others to successfully complete a valued task (Bandura, 1977; 1986), and have shown to be strong predictors of motivation and behaviour (Bandura, 1977). This paper will explore Teacher Efficacy (TE) (Berman et al., 1977) in the context of primary science education. The two related concepts that underpin TE are an educator's personal beliefs about his/her ability to assist student learning, known as Personal Teaching Efficacy (PTE) (Coladarci, 1992; Gordon & Debus, 2002) and his/her general beliefs about the capacity of education to override external factors to enhance student outcomes, known as General Teaching Efficacy (GTE) (Tschannen-Moran & Hoy 2001). A corpus of research has established TE as more closely associated with desirable educational outcomes than other traditional measures, such as teacher content knowledge (e.g., Lui & Bonner, 2016; Pajares, 1997; Zee & Koomen, 2016). Over the past half century, research has shown that teacher efficacy is positively associated with a myriad of positive educational outcomes, including greater professional commitment and teacher performance (Chesnut & Burley, 2015; Høigaard et al. 2012; Klassen & Tze, 2014; Nie et al., 2013), and improved student learning (Cantrell et al., 2013; Goddard et al., 2000; Çoğaltay, & Karadağ, 2017).

A parallel explanatory mixed methods methodology was employed wherein quantitative data were prioritised with supplementary insights afforded by qualitative data (Creswell & Creswell, 2018). The research was also a Type III case study (Yin, 2014) where mixed methods data were collected from teachers across multiple sites in a broader primary education jurisdiction (Yin, 2014). This methodology was enacted as it enabled the benefits of cross triangulation in mixed methods research whilst ensuring parsimony for a time-poor target population that is challenging to recruit. Data were collected through the cross-sectional administration of an online quantitative survey supplemented by an open qualitative option. An interpretivist approach is also employed as the research seeks to describe the perspectives of an important stakeholder group in science education, primary teachers (Bryman, 2016; Clarke et al., 2021). The interpretivist lens reflects a positive approach to education research wherein the views and experiences of teachers are prioritised. Ethics clearance for this project was received from both the university (H21071) and the educational jurisdiction of the target population of primary educators (2021178).

## Context and Sampling

Participants were a sample drawn from a jurisdiction of over 46,000 Australian primary teachers (ACARA, 2023) working within and across over 1600 primary schools (ACARA, 2024). A combination of non-probabilistic purposive and convenience sampling approaches was used for recruitment in this project. Probabilistic sampling was not possible as direct access to the contact details of the entire target population was not made available to the research team. From July to November 2021, a series of recruitment strategies were employed. Two direct email invitations were sent to each school in the target population, approximately three months apart, in the first week of both the third and fourth terms of the 2021 school year. A physical printed mailout campaign was also conducted with invitations and flyers sent to each of the schools in the target population. Snowball sampling was invoked as participants were asked to share the invitation with others. Social media and professional networks were also used for wider dissemination. Prospective participants were also incentivised through prize draws for gift cards and science teaching resource vouchers.

A total of 206 Australian primary educators from 173 different schools completed the online survey. Table 1 presents the demographic data obtained from the participants, including their school's broad geographic location, according to the Australian Statistical Geographical Standard (ASGS) (ABS, 2016). The Index of Community Socio-Educational Advantage (ICSEA) (ACARA, 2016) scores were below average with a mean of 983.80 (41.6 %). There was also a reported average of 15.4 years of teaching experience in this sample.

| | | Number | Percentage |
|---|---|---|---|
| **Gender** | | | |
| | Female | 163 | 79.13% |
| | Male | 43 | 20.87% |
| **Age** | | | |
| | 18-24 | 3 | 1.46% |
| | 25-34 | 60 | 29.13% |
| | 35-44 | 53 | 25.73% |
| | 45-54 | 57 | 27.67% |
| | 55-64 | 28 | 13.59% |
| | 65+ | 5 | 2.43% |
| **Role** | | | |
| | Classroom Teacher | 173 | 83.98% |
| | Administrator | 13 | 6.31% |
| | Both | 20 | 9.71% |
| **Employment Status** | | | |
| | Full Time | 133 | 64.56% |
| | Fixed Term Contract | 66 | 32.04% |
| | Casual | 7 | 3.40% |
| **School Location** | | | |
| | Metropolitan | 91 | 44.17% |
| | Non-metropolitan | 109 | 52.91% |
| | Unspecified | 6 | 2.91% |

**Table 1: Participant Demographic Data (N=206)**

The percentages of primary educators (0.45%) and schools (10.79%) sampled from the target population fall well below the 30-35% sampling rates often reported in survey-based research (Nulty, 2008). However, the teacher sample to population ratio of primary educators (1:150) is better than a previous survey ratio of science educators (1:400) reported in an admittedly broader and more technological limited national review of Australian science education (Goodrum, Rennie & Hackling, 2001). The average participant in this project graduated in 2004 and thus was not part of the target population for Goodrum, Rennie and Hackling's (2001) project, meaning that the data presented in this paper captures the perspectives of a different generation of educators. An independent T-test on the ICSEA data for both included (M=981.14, SD=94.56) and non-included (M=987.08, SD=90.69) schools shows that the sample is generally reflective of the target population in terms of location, diversity of learners and socioeconomic status $t(1594)=1.85$, $p=.42$). It should also be noted that males were slightly overrepresented in this sample (21%) relative to the target population (17.9%). Clearly, there is evidence that the sample is, in some ways, a reflection of the targeted jurisdiction of Australian primary educators and schools despite the lack of generalisability associated with the non-probabilistic sampling strategies.

## Data Collection Instruments

The data for this project were collected through a mixed methods survey that was delivered to participants digitally through hyperlinks and QR codes. The first section of the 20-minute survey captured participants' demographic information, including their schools, years of experience, genders, employment statuses (full time, fixed contract or casual) and graduation years. The second section captured respondents' science teaching efficacy beliefs through a condensed version of the Science Teaching Efficacy Belief Instrument-A STEBI-A (Riggs & Enochs, 1990) comprised of two five-point Likert scales ranging from '*strongly agree*' to '*strongly disagree*'. The first PSTE subscale measures respondents' beliefs about their personal ability to assist students to achieve science learning outcomes through their responses to eight items, such as '*I know the steps necessary to teach science concepts effectively*'. The remaining eight items comprise the STOE subscale which measure respondents' beliefs about the capacity of science teaching to guide learners to the achievement of science outcomes. An example STOE item is '*Students' achievement is directly related to their teacher's effectiveness in science teaching*'. Since its publication, over three decades ago, the PSTE and STOE subscales have consistently proven to be reliable measures across different contexts (Deehan, 2017; Deehan et al., 2020; Riggs & Enochs, 1990). In this study, both the PSTE ($\alpha$=0.89) and STOE ($\alpha$=0.74) subscales were proven reliable (Chandrasegaran et al., 2007; Pallant, 2020).

The third section of the survey focused on participants' science teaching practices. Participants were required to identify their science teaching practices from a list of 38 approaches through a series of dichotomous prompts, wherein participants were asked to identify science teaching approaches they had employed in the previous 12-months. The detailed, but contestable framework of science teaching approaches, capturing an array of teacher-centred and student-centred approaches can be seen in appendix one. The framework presented in appendix one reflects a considerable pedagogical evidence base in primary science education (Aubusson et al., 2015; 2019; Deehan et al., 2024; Skamp & Preston, 2021). Respondents were also able to identify other approaches via an open question prompt. Total Approaches scores for each participant were calculated by adding together all selected and identified teaching approaches.

Steps were taken by the research team to confirm the validity of the science teaching approaches framework (appendix one). The initial development of the framework was informed by existing science teaching pedagogical literature in the field (Aubusson et al., 2015; Deehan, 2017; Deehan et al., 2024; McComas, 2013; Skamp & Preston, 2021). In accordance with established research norms (e.g. Cruickshank et al., 2021), content validity was established through consultation with a panel of three science education academics and four current primary school teachers that was convened to provide feedback on the framework. There was consensus that the framework was exhaustive and reflected the approaches commonly used in contemporary primary science teaching. One panellist recommended including an "open response" option, which was subsequently included in the survey. An academic suggested offering definitions as part of the research materials to enable consistent interpretation of the approaches. Participants were afforded the opportunity to read the framework via a weblink prior to identifying their science teaching approaches. Engagement with the more detailed framework was made optional to avoid disruption and minimise attrition. Furthermore, the online survey approach prevented any bias that may have occurred through an interviewer's description of the framework.

Social desirability bias (Clark et al., 2021) was also mitigated throughout the project. The project was framed as exploratory rather than evaluative throughout the recruitment process. Care was also taken to prevent respondents from misinterpreting the science teaching approaches as a hierarchy of quality. The optional explanatory framework was presented in alphabetical order and the teaching approaches were presented in a random order in the online survey. The asynchronous nature of data collection removed the risk of social desirability bias associated with direct personal communication.

Participants were also asked to identify which areas of the Australian Science Curriculum they have taught in the previous 12-months through simple "tick box" items (ACARA, 2021). A Curriculum Coverage score was calculated for each participant by counting how many of the 11 curriculum sub-strands under Science Understanding, Science as a Human Endeavour and Science Inquiry Skills had been selected.

Participants were asked whether they have undertaken any PD relevant to their science teaching and to describe their experiences of science PD. Respondents were asked to answer “yes” or “no” to a question about their science PD engagement: “*Have you received any professional development in science education?*”. The respondents who answered “yes” received an additional open-ended prompt: “*If yes, what professional development program(s) did you participate in?*”.

## Data Analyses

Qualitative data were collected on open teaching approaches and PD items on the digital survey. A standard open, axial and selective coding scheme was employed for the initial manual analyses (O’Toole & Beckett, 2013). Data were first organised based on the survey question structure. QSR NVIVO 12 software was then used for a reflective, iterative process wherein the researchers organised the qualitative responses based on emergent themes relevant to both the research questions and the existing literature. Due to the concise and organised nature of the responses, initially coding occurred collaboratively until consensus was reached to ensure interrater reliability. The researchers worked on the initial coding processes. The authors cooperatively coded each response in online meetings and a research assistant was employed to check the coding for consistency and coherence. These analyses were supplemented by Jaccard’s Similarity Coefficient Cluster Analysis (Krebs, 2014); a form of cluster analysis where the similarity/ overlap of codes into NVIVO nodes is calculated on a 0 (no similarity) to 1 (replication) scale. None of the themes identified reached the duplication threshold (1).

Descriptive analyses, Analysis of Variance (ANOVA) and Chi Squares were computed for the quantitative data. Initially, means and standard deviations were calculated for the PSTE, STOE, Total Approaches and Curriculum Coverage scores of the respondents in both the No Professional Development Attendance (No PD) and Professional Development Attendance (PD) groups. A One-way ANOVA between the No PD and PD groups (independent variables) on the PSTE, STOE, Total Approaches and Curriculum Coverage measures (dependent variables) was calculated to investigate between group differences (Coleman & Pulford, 2008; Pallant, 2020). The magnitude of between group differences on the dependent variables was assessed through Hedges’ G effect size calculations due the differences in group sample sizes. The assumptions of data level (i.e., metric dependent variables and a single independent grouping), independence of cases (No PD and PD groups) and homogeneity of variance (no between group differences) for MANOVA were all met (Algina & Olejnik, 2003). The large sample size also ensures sufficient power and resilience to normality threats (VanVoorhis & Morgan, 2007). Chi Square tests were also calculated to investigate differences between the No PD and PD groups on reported use of the 38 science teaching approaches presented appendix one. The risk of Type 1 error was reduced via the application of Bonferroni corrections; meaning that the accepted p values were adjusted in SPSS based on the number of tests calculated.

## Results

In a possible reflection of the aforementioned lack of science PD mandates and inconsistency in school science teaching roles, there were far more educators who had not engaged with science PD (n=128) than those who had engaged with science PD (n=78). This alone is a particularly curious finding as the sampled participants are likely to represent the most confident and engaged science teachers in the target population. The demographic data for the PD and No PD groups are presented in Table 2. The groups were similar in terms of gender, age, employment status and years of teaching experience. Of note is that educators from non-metropolitan and more socio-economically disadvantaged schools were proportionally overrepresented in the No PD group.

| | | No PD | | PD | |
|---|---|---|---|---|---|
| | | **Number** | **Percentage** | **Number** | **Percentage** |
| **Gender** | | | | | |
| | Female | 102 | 79.69% | 61 | 78.2% |
| | Male | 26 | 20.31% | 17 | 21.79% |
| **Age** | | | | | |
| | 18-24 | 3 | 2.34% | 0 | - |
| | 25-34 | 41 | 32.03% | 19 | 24.36% |
| | 35-44 | 32 | 25.00% | 21 | 26.92% |
| | 45-54 | 33 | 25.78% | 24 | 30.77% |
| | 55-64 | 18 | 14.06% | 10 | 12.82% |
| | 65+ | 1 | 0.78% | 4 | 5.31% |
| **Role** | | | | | |
| | Classroom Teacher | 107 | 83.59% | 66 | 84.62% |
| | Administrator | 7 | 5.75% | 6 | 7.69% |
| | Both | 14 | 10.94% | 6 | 7.69% |
| **Employment Status** | | | | | |
| | Full Time | 79 | 61.72% | 54 | 69.23% |
| | Fixed Term Contract | 43 | 33.59% | 23 | 29.49% |
| | Casual | 6 | 4.69% | 1 | 1.28% |
| **School Location** | | | | | |
| | Metropolitan | 51 | 40.80% | 40 | 53.33% |
| | Non-metropolitan | 74 | 59.20% | 35 | 46.67% |
| | Unspecified | 3 | 2.34% | 3 | 2.34% |

**Table 2: Participant Demographic Data by Science PD Status (No PD=128 and PD=78)**

The PD group reported higher PSTE, STOE, Total Approaches and Curriculum Coverage means than their peers who has not engaged in science PD. Table 3 provides the means and standard deviations of PSTE, STOE, Total Approaches and Curriculum Coverage Scores by PD engagement group. The PD group reported a mean PSTE score 5.46 points higher than the no PD group, which means the average science PD attendee in this sample is comfortably efficacious ($\geq$32) whereas those with no PD experience are only somewhat efficacious (>24 and <32). The difference between the groups on the STOE scale was more marginal (1.54), with both groups falling into the somewhat efficacious category. The broader nature of the STOE subscale means that it is impacted by other educators and contexts in ways that could explain the lower growth rates and scores. On average, the PD attendees listed nearly four (3.76) additional science teaching approaches more than their counterparts (No PD). Perhaps appropriately, given the curricular coverage requirements for Australian primary teachers, the difference between the two groups on curriculum coverage was quite small (1.03).

| Variable | Group | N | M | SD |
|---|---|---|---|---|
| PSTE | No PD | 128 | 28.30 | 5.18 |
| | PD | 78 | 33.76 | 4.70 |
| STOE | No PD | 128 | 28.82 | 3.46 |
| | PD | 78 | 30.36 | 3.59 |
| Total Approaches | No PD | 128 | 15.93 | 6.32 |
| | PD | 78 | 19.69 | 6.38 |
| Curriculum Coverage | No PD | 128 | 8.23 | 2.09 |
| | PD | 78 | 9.26 | 1.83 |

**Table 3: Descriptive Statistics for the STEBs, Total Approaches and Curriculum Coverage of Primary Teachers by Reported Science Professional Development (PD) Engagement**

There was some variation in the PD experiences described by the educators in the PD group. A total of 72 (92.31%) of the participants in this PD group chose to elaborate on the PD they had received. Table 4 summarises these participants' open responses to the supplementary question, "*what professional development program(s) did you participate in?*", under broad themes: Science based, STEM based and Other. The most common professional development themes were both science and STEM based: General STEM PD (32%), Curriculum Training (22%) and Primary Connections (19%). General STEM education was delivered to educators through "*STEM symposiums*", "*Industry Partnerships*", "*Scholarships*", "*STEAM programs*" and "*STEMx*"; a clear indication of how current science support is framed in Australian science education. "*Curriculum Training*" for "*Implementation of K-6 Syllabus*" is a theme that is likely to reflect the 2017-2018 rollout of the most recent iteration of the Australian K-10 Science Curriculum (ACARA, 2021), and thus may not represent any ongoing, systemic commitment to science education development. "*Primary Connections*" was cited directly by 14 teachers, a relatively unsurprising finding given that this program has been effective and widely adopted across school and university sectors alike for nearly 20 years (Aubusson et al., 2019; Deehan, 2021). Primary Connections is typically delivered through either online modules or 4-day intensive workshops. Conversely, the curriculum training workshops were frequently delivered in a single day. It should be noted that despite our focus on PD engagement as a key independent variable, there is still considerable variation in the structure and quality of science PD that is beyond the scope of this paper. Technology focused PD (e.g., "*first robotics*") (11%) and engagement with the university sector (e.g., "*university science project*") (11%) were noteworthy, albeit far less prominent, themes. Amongst this sample, School Specific (e.g., "*a school science day*") (7%), Unspecific/ Minor Areas (e.g., "*I did a PL on Critical Creative Thinking and used Science as my focus KLA*") (3%), Online Delivery (e.g., "*online*") (3%), and High School Partnerships (e.g., "*with HS teacher*") PD engagements were limited; which may indicate room for diversification in the science PD opportunities offered to Australian primary teachers.

| Themes and Sub-Themes | Number of Contributing Respondents (%) | Illustrative Quote |
|---|---|---|
| Science based | | |
| Curriculum Training | 16 (22%) | *"PL about the new science syllabus when it was introduced."* |
| Primary Connections* | 14 (19%) | *"Primary Connections PD courses."* |
| Science Organisation | 6 (8%) | *"CSIRO, Questacon."* |
| STEM based | | |
| General STEM PD | 23 (32%) | *"STEM Training Course."* |
| Technology PD | 8 (11%) | *"Technology based ones using makey makey and ozabot."* |
| Other | | |
| University Connection (inc. degrees and partnerships) | 8 (11%) | *"I studied a Post-Graduate Certificate in Primary Science Education in 2018."* |
| School Specific | 5 (7%) | *"School based TPL."* |
| Unspecified/ Minor Areas | 3 (4%) | *"A program to include indigenous perspectives for astronomy."* |
| Online Delivery | 3 (4%) | *"I have attended many STEM PL's both online and conference."* |
| High School Partnership | 2 (3%) | *"STEM support through our feeder High School."* |

*Note: Six of the respondents who reported attending relevant professional development chose not to provide any specific examples.*
**Primary Connections is a longstanding science program that provides professional development and curriculum resources to Australian primary teachers (https://primaryconnections.org.au/). It has a particular emphasis on active science learning and literacy development*

**Table 4 Professional Development Activities Reported by the PD group (n=72)**

The participants who reportedly engaged with science PD held significantly higher PSTE scores, STOE Scores, Total Approaches and Curriculum Coverage scores than the educators who reported to not have accessed science PD. Table 5 presents the output for a One-Way ANOVA on the four dependent variables by the two groups. There was a statistically significant different difference between the PD group's PSTE scores and those of the No PD group, $F(1,204)=57.73$, $p<.01$, with a large effect size calculated ($g=1.09$). The STOE differences were still statistically significant, $F(1,204)= 9.32$, $p=<.01$, but were of a lesser, moderate magnitude ($g=0.44$). The nearly four approach difference between the two groups was both statistically significant, $F(1,204)= 17.06$, $p<0.01$, and of a moderate-to-large effect size ($g=0.59$). Interestingly, there was also a statistically significant, moderate ($g=0.52$) difference in favour of the PD group on the measure of Curriculum Coverage, $F(1,204)= 17.06$, $p<.01$.

| Variable | SS | MS | F | p | g |
| --- | --- | --- | --- | --- | --- |
| PSTE | 1444.60 | 1444.60 | 57.73 | <.01** | 1.09 |
| | 5105.09 | 25.03 | | | |
| STOE | 114.74 | 114.74 | 9.32 | <.01** | 0.44 |
| | 2510.82 | 12.31 | | | |
| Total Approaches | 686.15 | 686.15 | 17.06 | <.01** | 0.59 |
| | 8204.98 | 40.22 | | | |
| Curriculum Coverage | 51.40 | 51.40 | 12.89 | <.01** | 0.52 |
| | 813.30 | 3.99 | | | |

*** Denotes results highly significant at the 0.01 level.*

**Table 5: One Way ANOVA for STEBs, Total Approaches and Curriculum Coverage of Primary Teachers by Science Professional Development (PD) Attendance**

Chi Square analyses on each of the 38 dichotomous teaching approach items afford deeper insight into the nature of the statistically significant difference in the reported science pedagogical repertoires between the PD and No PD groups. Table 6 presents the statistical output for the teaching approach Chi Square analyses between the PD and No PD groups. It is important to note that for 22 of the approaches there were no significant differences in reported usage between the two groups. Indeed, it appears that a base repertoire of Hands-on Tasks (p=.23), Group Work/ Cooperative Learning (p=.34) and Class Discussions (p=0.69) is evident with over 90% selection rates for each of these approaches across both the PD and No PD groups. In a broad sense, this may suggest that constructivist, student-centred approaches are now mainstream in primary science education. Further to this point, there were no significant between group differences for Diagnostic Assessment for Alternative Conceptions (p=.12), Open/ Guided Discovery (p=.19), Peer Tutoring (p=.15), Cross Curricular Integration (p=.25) and Excursions (p=.37). There was also some evidence of more complex pedagogical conceptualisation as propensities for more traditional, teacher-centred practices, such as Watching Videos (p=.62), Worksheets (p=.49), Direct Instruction/ Transmission (p=.80), Teacher Lead Investigation (p=.41), Note Taking (p=.86) and Lectures (p=.14), were similar between the groups. Such findings could suggest that teachers are aware that student-centred practice are not necessarily undermined by the inclusion teacher-directed strategies in their professional and pedagogical experience repertoires (Loughran et al., 2001).

| Approach | No PD Count (%) | PD Count (%) | $\chi^2$ | Sig. | g |
|---|---|---|---|---|---|
| Hands On Tasks | 120 (94%) | 76 (97%) | 1.43 | .23 | 0.08 |
| Group Work/ Cooperative Learning | 119 (93%) | 75 (96%) | 0.90 | .34 | 0.07 |
| Class Discussions | 117 (91%) | 70 (90%) | 0.16 | .69 | 0.03 |
| Teacher Demonstration | 111 (88%) | 75 (96%) | 4.92 | .03* | 0.16 |
| Watching Videos | 116 (91%) | 69 (88%) | 0.25 | .62 | 0.04 |
| Big Ideas/ Inquiry Questions | 97 (76%) | 70 (90%) | 6.16 | .01* | 0.17 |
| Inquiry Learning | 90 (70%) | 69 (88%) | 9.07 | <.01** | 0.21 |
| Joint Construction | 90 (70%) | 58 (74%) | 0.39 | .53 | 0.05 |
| Student Centred Investigations | 82 (64%) | 65 (83%) | 8.81 | <.01** | 0.21 |
| Modelling | 83 (65%) | 56 (72%) | 1.07 | .30 | 0.07 |
| Outdoor Science | 72 (56%) | 60 (77%) | 9.00 | <.01** | 0.21 |
| Open/ Higher Order Questioning | 67 (52%) | 60 (77%) | 12.39 | <.01** | 0.25 |
| Worksheets | 80 (63%) | 45 (58%) | 0.47 | .49 | 0.05 |
| Project/ Problem-Based Learning | 65 (51%) | 54 (69%) | 6.76 | <.01** | 0.18 |
| Teacher Lead Investigations | 68 (53%) | 46 (59%) | 0.67 | .41 | 0.06 |
| Open/ Guided Discovery | 65 (51%) | 47 (60%) | 1.75 | .19 | 0.09 |
| Digital Technology/ Simulations | 57 (45%) | 51 (65%) | 8.45 | <.01** | 0.20 |
| Direct Instruction/ Transmission | 65 (51%) | 41 (53%) | 0.06 | .80 | 0.02 |
| Cross Curricular Integration | 55 (43%) | 40 (51%) | 1.35 | .25 | 0.08 |
| Note Taking | 59 (46%) | 35 (45%) | 0.03 | .86 | 0.12 |
| Excursions | 51 (40%) | 36 (46%) | 0.79 | .37 | 0.06 |
| Predict-Observe-Explain (POE) Cues | 38 (30%) | 36 (46%) | 5.71 | .020* | 0.17 |
| Diagnostic Assessment for Alternative Conceptions | 33 (26%) | 28 (36%) | 2.38 | .12 | 0.11 |
| Station Rotation | 26 (20%) | 30 (38%) | 8.07 | <.01** | 0.20 |
| The 5Es Framework | 23 (18%) | 32 (41%) | 13.17 | <.01** | 0.25 |
| Other | 27 (21%) | 19 (24%) | 2.15 | .34 | 0.10 |
| Science in the Media | 21 (16%) | 29 (37%) | 11.36 | <.01** | 0.24 |
| Individual Reading | 27 (21%) | 16 (21%) | 0.01 | .92 | 0.01 |
| Deep Reflection | 15 (12%) | 20 (26%) | 6.66 | .01** | 0.18 |
| Guest Speakers | 14 (11%) | 21 (27%) | 8.78 | <.01** | 0.21 |
| Community Projects | 13 (10%) | 21 (27%) | 9.89 | <.01** | 0.22 |
| Peer Tutoring | 14 (11%) | 14 (18%) | 2.03 | .15 | 0.10 |
| Debate | 13 (10%) | 14 (18%) | 2.58 | .11 | 0.11 |
| Nature of Science Teaching | 15 (12%) | 12 (15%) | 0.57 | .45 | 0.05 |
| Constructivism | 8 (6%) | 14 (18%) | 6.95 | .01** | 0.18 |
| Claim-Evidence-Reasoning (CER) Cues | 7 (5%) | 7 (9%) | 0.94 | .33 | 0.07 |
| Second Hand Research | 8 (6%) | 5 (6%) | <0.01 | .96 | <0.01 |
| Analogies (Content Representations) | 2 (2%) | 10 (13%) | 11.20 | <.01** | 0.23 |
| Lectures | 3 (2%) | 5 (6%) | 2.147 | .14 | 0.10 |

*Notes: df=1 for all analyses, *Denotes results significant at the 0.05 level, ** Denotes results highly significant at the 0.01 level.*

**Table 7: Chi Square Analyses of Teaching Approaches by Professional Development Engagement (No PD = 128 & PD = 78)**

There were 17 approaches that the PD recipients were more likely to report using than the educators who had not engaged with science PD. The highly significant results for Inquiry Learning ($p<.01$) and the 5Es Framework ($p<.01$) could be related to the relative prominence of the aforementioned Curriculum Training and Primary Connections themes respectively; indeed, the current Australian Science Syllabus is explicitly framed around inquiry learning (ACARA, 2021) and Primary Connections programs employ the 5Es framework (Aubusson et al., 2019). Many of the approaches that were more commonly reported amongst the PD attendees, such as Student-centred Investigations ($p<.01$), Open/ Higher Order Questioning ($p<.01$), Station Rotation ($p<.01$), Deep Reflection ($p=.01$), Constructivism ($p<.01$), and Analogies (Content Representations) ($p<.01$) appear to represent a richer conceptual extension of the base repertoire of student-centred approaches reportedly adopted similarly across both groups. These teaching strategy analyses also provide some tentative evidence that the sample of PD attendees are more focused on extending their students' science learning beyond the confines of their classrooms because they are more likely to use teaching strategies such as: Outdoor Science ($p<.01$), Project/Problem-Based learning ($p<.01$), Digital Technologies/ Simulations ($p<.01$), Science in the Media ($p<.01$), Guest Speakers ($p<.01$) and Community Projects ($p<.01$). Not only are many of these approaches well-supported by scholarly literature (e.g., Deehan et al., 2024), they explicitly address the long-standing, global deficiencies of primary learners' science and scientific literacy levels (Martin et al., 1997; Thomson et al., 2020).

## Discussion

A strong majority of the sample of Australian primary educators (62%) had not received any science PD. This is of concern as the educators in the No PD group had been teaching for over 15 years on average, suggesting the lack of discipline specific PD requirements for primary science educators may be resulting in science education practice not progressing in accordance with Australian teacher accreditation standards (ACTTQI, 2022; AITSL, 2017; NESA, 2017; QCT, 2022; TRBNT, 2022; TRBT, 2022; TRBSA, 2022 TRBWA, 2022; VIT, 2022). The demographic traits of the No PD and PD groups were generally quite similar, except for the overrepresentation of teachers from non-metropolitan and low ICSEA schools in the No PD group. This finding aligns with the well-established literature on the educational disadvantages for non-metropolitan and low socio-economic learners (Cardak et al., 2017; Cooper et al., 2018; Cuervo & Acquaro, 2018; Halsey, 2018; OECD, 2013). While these data should not be taken as a commentary on the quality of teachers in non-metropolitan and lower ICSEA schools, it does suggest that access to high quality science PD for teachers in these schools should be emphasised by all stakeholders. The fact that 128 educators willingly participated in this project despite never having engaged with science PD may be an indication that the PD needs of all engaged science educators are not being met. Alongside increased proliferation of science PD opportunities for primary educators, it may also be worthwhile for policy makers to consider discipline specific PD requirements to create the conditions necessary for greater engagement with science PD opportunities. Put simply, it should not be the norm for primary teachers to not receive any PD in any key discipline, including science, for 15 years.

The hypothesis was confirmed as the findings showed that participants who purportedly engaged in science PD held significantly higher science teaching efficacy beliefs, on both the PSTE and STOE subscales, and reported broader science teaching repertoires and curriculum coverage. In practical terms, the highly significant ($p<.01$), large ($g=1.10$) difference between the groups on the PSTE measure means that approximately 85% of the educators in the No PD group scored below the average of the PD group. This is a particularly noteworthy finding given that higher personal efficacy beliefs have been linked to better teacher performance (Chesnut & Burley, 2015; Høigaard et al. 2012; Klassen & Tze, 2014; Nie et al., 2013) and improve student learning (Angle & Mosely, 2009; Cantrell et al., 2013; Goddard et al., 2000; Çoğaltay, & Karadağ, 2017). In fact, the highly significant findings for both Total Approaches (p<.01) and Curriculum Coverage (p<.01) does suggest that the PD attendees report a wider selection of science teaching approaches (g=0.59), and broader coverage of the science curriculum strands (g=0.52) than the non-attendees; both of which are possible distal indicators of more expansive practice. Even the small-to-moderate STOE difference in favour of PD attendees (g=0.44) is worth remarking upon, as growth on this measure is historically difficult to achieve (Deehan, 2017; Unfried et al., 2022), and has shown, in some cases, to actually decline significantly after inservice teachers have completed specific science PD programs (Haney et al., 2007; Lockman, 2006; Saka et al., 2009). Although establishing causality or even directionality amongst these variables is beyond the scope of this research, it is clear that primary educators who reportedly engaged in some form of science PD were more efficacious, reported more expansive science teaching repertoires, and indicated greater science syllabus coverage than those participants who had not participated in science PD. This further contextualises many much of the science PD literature as it shows mainstream benefits for PD attendees, beyond a specific program, relative to educators who have not engaged with science PD.

The similarities and differences in the reported use of specific pedagogies by PD engagement help to illuminate the wider progression of teaching practices and signal current trajectories in primary science education respectively. For most of the specified science teaching approaches, there were no differences between the groups. PD and Non-PD attendees were both equally likely to report student-centred approaches, such as Hands-on Tasks, Group Work/ Cooperative Learning, Class Discussions, Diagnostic Assessment for Alternative Conceptions, Open/ Guided Discovery, Peer Tutoring, Cross Curricular Integration, and Excursions. An interpretation of the evidence could be that the authentic, student-centred practices that nearly universally underpin primary science initial teacher education programs (Deehan, 2022; Fitzgerald et al., 2021) have become mainstream in primary science education practice. At the very least, it seems the historical reliance on teacher-centred practices in primary science education may be dissipating (e.g., Goodrum et al., 2001; Goodrum & Rennie, 2007); a claim given further credence by the recent improvements in Australian Year 4 Students' science achievement and scientific literacy in the TIMSS (Thomson et al., 2020). Curiously, it does not seem to be the case that traditional teacher-centred practices are eschewed by PD attendees, with reported incorporation of Watching Videos, Worksheets, Direct Instruction/ Transmission, Teacher Lead Investigation, Note Taking, and Lectures not differing significantly between the groups. A possible interpretation may be that these primary educators' conceptualisation of science teaching practice may be more sophisticated than a simple student-centred, teacher-centred dichotomy, but this is beyond the bounds of this project. Perhaps the more cohesive narrative between the reported practice of the sampled educators and the science education research literature may be a sign that the theory-praxis divide is being bridged (Anagnostopoulos et al., 2007; Deehan et al., 2020; Holbert et al., 2011).

Beyond the signifiers of the commonly cited Primary Connections (i.e., the 5Es framework) and Curriculum Training (i.e., Big Ideas/ Inquiry Questions and Inquiry Learning) PD programs, much of the differences in pedagogical choices between the groups appeared to indicate that the educators with access to PD were providing opportunities for high level student cognition. This can be seen in the highly significant differences for Student-centred Investigations, Open/ Higher Order Questioning, Station Rotation and Deep Reflection. It could be argued that these approaches are conceptual extensions of approaches common to both groups (PD and No PD), such as Group Work/ Cooperative Learning and Class Discussions. Additionally, the increased prevalence of Outdoor Science, Project/Problem-Based learning, Digital Technologies/ Simulations, Science in the Media, Guest Speakers, and Community Projects, all of which are time and resource intensive to varying degrees, within the PD group could suggest that they are more focused on extending their science teaching beyond the classroom. Alternatively, the uptake of these more demanding approaches may be related to the relative socio-economic advantage of the PD group's school contexts. Nonetheless, the incorporation of such outwardly-oriented primary science teaching practices does align with the overarching goal of improving learners' science and scientific literacy (Bybee, 1997; Martin et al., 1997; Roberts & Bybee, 2014; Thomson et al., 2020). This promising indicator that primary science PD attendees are reportedly using outwardly focused pedagogies with more frequency than non-attendees must be considered in context. It cannot be known whether PD attendance influences pedagogical selection or whether PD attendance is a result of other factors such as teacher traits or positive science cultures within schools. Regardless, it is doubtful that the differences between PD and No PD primary science educators described in this paper could be attributed to a lack of interest and/or engagement by non-attendees, as they still willingly opted to participate in this research project. If anything, the difference between PD attendees and non-attendees presented in this paper is likely to be an underestimation as many disengaged primary science educators are unlikely to have provided data for this project.

## Limitations

There are limitations to this research project that should need to be considered. First, the reliance on non-probabilistic sampling methods hinders the generalisability of the findings despite the relatively strong teacher (1:150) and school (1:10) sample to population ratios. That is to say that there is a silent voice issue as there are primary educators from the target population who, whether due to personal choice or lack of awareness, did not provide data for this project. How the characteristics of non-participants compares to participants is unknowable. Second, the framework underpinning the presentation of science approaches in the survey cannot be exhaustive and thus cannot capture any primary science teacher's full professional and pedagogical experience repertoire. This limitation is exacerbated by the asynchronous mode of data collection that prevents a shared understanding of the survey and the teaching approaches from being developed. Although the framework was shared as an optional resource to develop a shared understanding, there is no way of knowing if this aim was achieved. Making engagement with the framework mandatory or delivering it synchronously would have exacerbated attrition and response bias risks respectively. Third, the reliance on distal data means that the practices of educators cannot be confirmed, and the impact of any approaches on primary students' science learning cannot be ascertained. Further to this point, the emphasis on quantitative data in this project does, to some extent, contradict the fluid, constructivist nature of education as practices are atomised in a way that does not reflect how practices can be synthesised, altered, and emphasised in a classroom environment. Fourth, the cross-sectional design prevents causality or even directionality amongst variables to be determined. For example, we cannot infer whether PD attendance, in a general sense, improves science teaching efficacy beliefs or whether more efficacious educators are more likely to seek out PD opportunities.

## Directions for Future Research

Despite the limitations of the project, there are some worthwhile directions for future research. As this pilot project was limited to a single Australian public primary jurisdiction, it would be worthwhile to extend similar research projects into other educational jurisdictions and nations. Further research should delve into the reasons why educators engage and do not engage with science PD, what informs these decisions, what benefits science PD attendees ascribe to their experiences and what educators desire in this space. For example, educators who attended a one-day curriculum workshop are likely to have different experiences and outcomes than those who attend a weeklong Primary Connections course. It is also advisable for PD providers to conduct follow-up research to determine if and how the experience has altered approaches to primary science education. Perhaps most importantly, proximal classroom level data is a necessary complement to the broad distal presented in this paper. Indeed, the quality of practice in primary science classrooms is beyond the scope of this research and can only be speculated upon through reference to prior research, other science education sectors (e.g., Deehan, 2021; Fitzgerald et al., 2021) and international assessments (Martin et al., 1997; Thomson et al., 2020). The STEBI data presented in this paper can also serve as a baseline for evaluating professional development programs as this research has occurred outside the context of a specific program. Also, it would be interesting to explore the decisions that educators take regarding PD opportunities, in science and other disciplines, on the basis of the current accreditation requirements in Australia.

Although the distal, cross-sectional nature of this project does not give rise clear implications for classroom practice, it does provide some insight into how quality primary science teaching can be fostered by educational stakeholders. A case can be made that primary educators who access some form of science PD have higher science teaching efficacy beliefs, and the possible benefits associated with such high beliefs (e.g., Deehan, 2017), report more expansive science teaching repertoires and purport to cover more areas of the science syllabus. Therefore, it would behove administrators and leaders to expand opportunities for primary teachers to access varied forms of science PD to suit their unique contexts and professional needs. Given the characteristics of the No PD group, a focus on expanding science PD opportunities for primary teachers in non-metropolitan and lower ICSEA schools is recommended. This would be a worthwhile direction for Initial Teacher Education (ITE) providers given their strong orientation towards authentic, student-centred practices (Deehan, 2021; Fitzgerald et al., 2021) and the need for higher education to adapt to the challenges wrought by Covid-19 (Ferguson & Love, 2020; Thatcher et al., 2020). It is important to note that any expansion to the provision of science PD to primary teachers would need to be accompanied by structural support, including ongoing guidance, time and financial resources, and grounded in a clear vision to improve primary students' science and scientific literacy. To this end, stakeholders should holistically consider both the positive and negative impacts of the flexible PD requirements on primary science PD engagement.

## Conclusion

This paper has highlighted the importance of professional development in primary science education on the basis of data collected from educators who have both participated in and not participated in science PD. The contribution is relatively unique as the research was conducted without a specific professional development context, lessening the impact of social desirability bias and short-term motivation boosts. Despite professional learning mandates that are fundamental to Australian teacher accreditation, the majority of participants had never engaged in science PD in their average of 15-years in the profession. Teachers based in non-metropolitan and lower ICSEA schools were less likely to have received science PD. The research hypothesis was confirmed by the higher PSTE, STOE, Total Approaches and Curricular Coverage scores of educators who had engaged with professional development. These findings suggest that PD, in a general sense, is associated with more positive science dispositions and reportedly more expansive science teaching practices. It is therefore recommended that the provision of diverse and accessible science PD opportunities should be a point of emphasis for all stakeholders striving to improve the quality of primary science education to ensure a scientifically literate citizenry.

## References

Akerson, V. L., & Bartels, S. L. (2023). Elementary science teaching: Toward the goal of scientific literacy. In Lederman, N.G., Zeidler, D.L., & Lederman, J.S. (Eds.), *The Handbook of Research on Science Education: Volume III (1st ed.*), (pp.528-558). Routledge. https://doi.org/10.4324/9780367855758

Akuma, F. V., & Callaghan, R. (2019). A systematic review characterizing and clarifying intrinsic teaching challenges linked to inquiry-based practical work. *Journal of Research in Science Teaching*, *56*(5), 619-648. https://doi.org/10.1002/tea.21516

Algina, J., & Olejnik, S. (2003). Conducting power analyses for ANOVA and ANCOVA in between-subjects designs. *Evaluation & the Health Professions, 26*(3), 288-314. https://doi.org/10.1177/0163278703255248

Ali, M. M., Yager, R. E., Hacieminoglu, E., & Caliskan, I. (2013). Changes in student attitudes regarding science when taught by teachers without experiences with a model professional development program. *School Science and Mathematics, 113*(3), 109-119. https://doi.org/10.1111/ssm.12008

Anagnostopoulos, D., Smith, E. R., & Basmadjian, K. G. (2007). Bridging the university–school divide: Horizontal expertise and the "Two-Worlds Pitfall". *Journal of Teacher Education*, *58*(2), 138-152. https://doi.org/10.1177/0022487106297841

Angle, J., & Moseley, C. (2009). Science teacher efficacy and outcome expectancy as predictors of students' End-of-Instruction (EOI) Biology I test scores. *School Science and Mathematics*, *109*(8), 473–483. https://doi.org/10.1111/j.1949-8594.2009.tb18294.x

Angus, M. (2003). School choice policies and their impact on public education in Australia. *Choosing Choice: School Choice in International Perspective*, 112-141.

Appleton, K. (1992). Discipline knowledge and confidence to teach science: Self-perceptions of primary teacher education students. *Research in Science Education, 22*, 11-19.

Appleton, K. (2003). How do beginning primary school teachers cope with science? Toward an understanding of science teaching practice. *Research in Science Education, 33*(1), 1-25. https://doi.org/10.1007/BF02356874

Ardzejewska, K., McMaugh, A., & Coutts, P. (2010). Delivering the primary curriculum: The use of subject specialist and generalist teachers in NSW. *Issues in Educational Research*, *20*(2), 203-219.

Aubusson, P., Schuck, S., Ng, W., Burke, P., & Pressick-Kilborn, K. (2015). *Quality learning and teaching in primary science and technology literature review Sydney*: Association of Independent Schools, New South Wales.

Aubusson, P., Skamp, K., Burke, P. F., Pressick-Kilborn, K., Ng, W., Palmer, T. A., ... & Ferguson, J. (2019). *Primary connections: Linking science with literacy stage 6 research evaluation final report*. Prepared for Steering Committee of Primary Connections, Australian Academy of Science. Accessed 22 December 2021 https://opus.lib.uts.edu.au/bitstream/10453/134515/1/Primary%20Connections%20Stage%206%20Evaluation_redacted_report_FINAL.pdf.

Australian Bureau of Statistics (ABS). (2016). *Australian Statistical Geography Standard [ASGS] Remoteness Structure*. Retrieved from https://www.abs.gov.au/websitedbs/D3310114.nsf/home/remoteness+structure

Australian Capital Territory Teacher Quality Institute (ACTTQI). (2022). *Professional Learning*. Author. Retrieved from https://www.tqi.act.edu.au/professional-learning
Australian Curriculum, Assessment and Reporting Authority (ACARA). (2013). *National Assessment Program – Science Literacy Year 6 Report 2012* (pp. 1-118). Sydney: ACARA. Retrieved from http://www.nap.edu.au/verve/_resources/NAP-SL_2012_Public_Report.pdf
Australian Curriculum, Assessment and Reporting Authority (ACARA). (2019). *National Assessment Program – Science Literacy Year 6 Report 2018* (pp. 1-160). Sydney: ACARA. Retrieved from https://nap.edu.au/docs/default-source/resources/nap-sl-report-2018.pdf?sfvrsn=8737e5e_2
Australian Curriculum, Assessment and Reporting Authority (ACARA). (2024). *National Assessment Program – Science Literacy 2023 Public Report* (pp. 1-168). Sydney: ACARA. Retrieved from https://nap.edu.au/docs/default-source/nap-sample/nap-sl-2023-public-report.pdf
Australian Curriculum, Assessment and Reporting Authority (ACARA). (2017). *Cross-curriculum Priorities.* Australian Curriculum. https://www.australiancurriculum.edu.au/f-10-curriculum/cross-curriculum-priorities/
Australian Curriculum, Assessment and Reporting Authority (ACARA). (2016). *About ICSEA.* https://docs.acara.edu.au/resources/About_icsea_2014.pdf
Australian Curriculum, Assessment and Reporting Authority (ACARA). (2021). *Science: The Australian Curriculum*. https://www.australiancurriculum.edu.au/f-10-curriculum/science/
Australian Curriculum, Assessment and Reporting Authority (ACARA). (2023). *National Report on Schooling in Australia: Staff Numbers*. Author. https://www.acara.edu.au/reporting/national-report-on-schooling-in-australia/staff-numbers
Australian Curriculum, Assessment and Reporting Authority (ACARA). (2023). *Australian Schools List*. Author. https://asl.acara.edu.au/home
Australian Institute for Teaching and School Leadership (AITSL). (2017). *Australian Professional Standards for Teachers*. Author. Retrieved from https://www.aitsl.edu.au/standards
Baker, D. P. (1997). Surviving TIMSS. *Phi Delta Kappan*, *79*(4), 295.
Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, *84*, 191-215. https://doi.org/10.1037/0033-295X.84.2.191
Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice-Hall.
Barber, M., & Mourshed, M. (2007). *How the world's best-performing school systems come out on top*. London: McKinsey.
Berman, P., McLaughlin, M., Bass, G., Pauly, E., & Zellman, G. (1977). *Federal programs supporting educational change: Vol. VII. Factors affecting implementation and continuation (rep. No. R-1589/7- HEW).* Santa Monica: RAND (ERIC Document Reproduction Service No. 140 432).
Blank, R. K., de las Alas, N., & Smith, C. (2008). *Does teacher professional development have effects on teaching and learning? Analysis of evaluation finding from programs for mathematics and science teachers in 14 states.* Washington, DC: Council of Chief State School Officers.
Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*(8), 3–15. https://doi.org/10.3102/0013189X033008003
Bracey, G. W. (2000). The TIMSS "final year" study and report: A critique. *Educational Researcher*, *29*(4), 4-10. https://doi.org/10.3102/0013189X029004004

Bryman, A. (2016). *Social Research Methods (5th Edition)*. Oxford.
Bybee, R. (1997). *Achieving scientific literacy: From purposes to practices*. Westport: Heinemann.
Bybee, R. W. (2014). NGSS and the next generation of science teachers. *Journal of Science Teacher Education*, *25*(2), 211-221. https://doi.org/10.1007/s10972-014-9381-4
Cantrell, S. C., Almasi, J. F., Carter, J. C., & Rintamaa, M. (2013). Reading intervention in middle and high schools: implementation fidelity, teacher efficacy, and student achievement. *Reading Psychology, 34*(1), 26–58. https://doi.org/10.1080/02702711.2011.577695
Cardak, B., Brett, M., Bowden, M., Vecci, J., Barry, P., Bahtsevanoglou, J., & McAllister, R. (2017). *Regional student participation and migration: Analysis of factors influencing regional student participation and internal migration in Australian higher education*. Perth: National Centre for Student Equity in Higher Education. Curtin University.
Chandrasegaran, A. L., Treagust, D. F., & Mocerino, M. (2007). The development of a two-tier multiple-choice diagnostic instrument for evaluating secondary school students' ability to describe and explain chemical reactions using multiple levels of representation. *Chemistry Education Research and Practice, 8*(3), 293-307. https://doi.org/10.1039/B7RP90006F
Chesnut, S. R., & Burley, H. (2015). Self-efficacy as a predictor of commitment to the teaching profession: A meta-analysis. *Educational Research Review, 15*, 1-16. https://doi.org/10.1016/j.edurev.2015.02.001
Clark, T., Foster, L., Sloan, L., & Bryman, A. (2021). *Bryman's social research methods*. Oxford University Press.
Çoğaltay, N., & Karadağ, E. (2017). The effect of collective teacher efficacy on student achievement. In *The factors effecting student achievement* (pp. 215-226). Springer, Cham https://doi.org/10.1007/978-3-319-56083-0_13
Coladarci, T. (1992). Teachers' sense of efficacy and commitment to teaching. *The Journal of Experimental Education, 60*(4), 323–337. https://doi.org/10.1080/00220973.1992.9943869
Coleman, A., & Pulford, B. (2008). *A crash course in SPSS for windows (4th Ed.)*. Oxford: Blackwell Publishing.
Cooper, G., Strathdee, R., & Baglin, J. (2018). Examining geography as a predictor of students' university intentions: A logistic regression analysis. *Rural Society*, *27*(2), 83-93. https://doi.org/10.1080/10371656.2018.1472909
Cruickshank, V., Hyndman, B., Patterson, K., & Kebble, P. (2021). Encounters in a marginalised subject: The experiential challenges faced by Tasmanian Health and Physical Education teachers. *Australian Journal of Education*, *65*(1), 24-40. https://doi.org/10.1177/0004944120934964
Cuervo, H., & Acquaro, D. (2018). Exploring metropolitan university pre-service teacher motivations and barriers to teaching in rural schools. *Asia-Pacific Journal of Teacher Education*, *46*(4), 384-398. https://doi.org/10.1080/1359866X.2018.1438586
Creswell, J. W., & Creswell, J. D. (2018). Chapter 10 Mixed Methods Procedures. *In Research Design: Qualitative, Quantitative and Mixed Methods Approaches (5th Ed.)* (pp.213-256). Sage Publications.
Crump, S. (2005). Changing times in the classroom: teaching as a 'crowded profession'. *International Studies in Sociology of Education*, *15*(1), 31-48. https://doi.org/10.1080/09620210500200130

Darling-Hammond, L., Chung Wei, R., Andree, A., Richardson, N., & Orphanos, S. (2009). *Professional learning in the learning profession: A status report on teacher development in the United States and abroad.* Dallas, TX: National Staff Development Council and School Redesign Network at Stanford University.

Deehan, J. (2017). *The Science Teaching Efficacy Belief Instruments (A and B): A comprehensive review of methods and findings from 25 years of science education research.* Cham, Switzerland: Springer International Publishing. (ISBN: 978-3-319-42465-1, 86 pages).

Deehan, J. (2021). Online education practices and teaching team compositions in Australian preservice primary science education. *Australian Journal of Teacher Education, 46*(6), 78-97. Retrieved from https://doi.org/10.14221/ajte.2021v46n6.5

Deehan, J. (2022). Primary science education in Australian universities: An overview of context and practice. *Research in Science Education, 52*(6), 1735-1759 https://doi.org/10.1007/s11165-021-10026-6

Deehan, J., Danaia, L., & McKinnon, D. H. (2020). From students to teachers: Investigating the science teaching efficacy beliefs and experiences of graduate primary teachers. *Research in Science Education, 50*(3), 885-916.

Deehan, J., MacDonald, A. & Morris, C. (2024). A scoping review of interventions in primary science education. *Studies in Science Education, 60*(1), 1-43, https://doi.org/10.1080/03057267.2022.2154997

Denessen, E., Vos, N., Hasselman, F., & Louws, M. (2015). The relationship between primary school teacher and student attitudes towards science and technology. *Education Research International, 2015,* 1-7. https://doi.org/10.1155/2015/534690

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38,* 181–199. https://doi.org/10.3102/0013189X08331140

DeWitt, J., & Archer, L. (2015). Who Aspires to a science career? A comparison of survey responses from primary and secondary school students. *International Journal of Science Education, 37*(13), 2170–2192. https://doi.org/10.1080/09500693.2015.1071899

Eggleston, J. (Ed.). (2018). *School-based curriculum development in Britain: A collection of case studies*. Routledge. https://doi.org/10.4324/9780429454622

Enochs, L. G., & Riggs, I. M. (1990). Further development of an elementary science teaching efficacy belief instrument: A preservice elementary scale. *School Science and Mathematics, 90*(8), 694-706. https://doi.org/10.1111/j.1949-8594.1990.tb12048.x

Fentie, R. (2019). Using online Professional Learning Networks (PLNs) for K-6 teachers' professional development in science education?. *Science Education News, 68*(1), 51-54.

Fentie, R. A. (2021). *Exploring Primary Teachers' Professional Learning Network (PLN) Activities for Value as Professional Development in Science Education* (Doctoral dissertation, University of Technology Sydney). Open Publication of UTS Scholars (OPUS) - https://opus.lib.uts.edu.au/bitstream/10453/151035/2/02whole.pdf

Ferguson, H., & Love, S. (2020). *The impact of COVID-19 on Australian higher education and overseas students—what do the numbers say?* Parliament of Australia. https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/FlagPost/2020/August/Universities_and_COVID

Fishman, B., Konstantopoulos, S., Kubitskey, B. W., Vath, R., Park, G., Johnson, H., & Edelson, D. C. (2013). Comparing the impact of online and face-to-face professional development in the context of curriculum implementation. *Journal of Teacher Education, 64*(5), 426-438. https://doi.org/10.1177/0022487113494413

Fitzgerald, A., Pressick-Kilborn, K., & Mills, R. (2021). Primary teacher educators' practices in and perspectives on inquiry-based science education: insights into the Australian landscape. *Education 3-13*, *49*(3), 344-356. https://doi.org/10.1080/03004279.2020.1854962

Fraser, S., Beswick, K., & Crowley, S. (2019). Responding to the demands of the STEM education agenda: The experiences of primary and secondary teachers from rural, regional and remote Australia. *Journal of Research in STEM Education*, *5*(1), 40-59. https://doi.org/10.51355/jstem.2019.62

Georgiou, H. (2023). Are we really falling behind? Comparing key indicators across international and local standardised tests for Australian high school science. *Research in Science Education*, *53*, 1205-1220. https://doi.org/10.1007/s11165-023-10129-2

Goddard, R. D., Hoy, W. K., & Hoy, A. W. (2000). Collective teacher efficacy: Its meaning, measure, and impact on student achievement. *American Educational Research Journal*, *37*(2), 479–507. https://doi.org/10.3102/00028312037002479

Gonski, D. (2011). *Review of Funding for Schooling.* Canberra ACT: Commonwealth of Australia.

Goodrum, D., Hackling, M., & Rennie, L. (2001). *The Status and Quality of Teaching and Learning of Science in Australian Schools*. Canberra: Department of Education, Training and Youth Affairs.

Goodrum, D., & Rennie, L. (2007). *Australian School Science Education - National Action Plan 2008-2012 - Volume 1*. Canberra: Commonwealth of Australia.

Gordon, C., & Debus, R. (2002). Developing deep learning approaches and personal teaching efficacy within a preservice education context. *British Journal of Educational Psychology*, *72*(1), 483–511. https://doi.org/10.1348/00070990260377488

Greenhalgh, S. P., Rosenberg, J. M., Willet, K. B. S., Koehler, M. J., & Akcaoglu, M. (2020). Identifying multiple learning spaces within a single teacher-focused Twitter hashtag. *Computers & Education*, *148* (2020), 1-12. https://doi.org/10.1016/j.compedu.2020.103809

Halsey, J. (2018). *Independent review into regional, rural and remote education.* Canberra, Australia: Commonwealth of Australia. Retrieved from https://docs.education.gov.au/node/50281

Haney, J. J., Wang, J., Keil, C., & Zoffel, J. (2007). Enhancing teachers' beliefs and practices through problem-based learning focused on pertinent issues of environmental health science. *The Journal of Environmental Education*, *38*(4), 25–33. https://doi.org/10.3200/JOEE.38.4.25-33

Heller, J. I., Daehler, K. R., Wong, N., Shinohara, M., & Miratrix, L. W. (2012). Differential effects of three professional development models on teacher knowledge and student achievement in elementary science. *Journal of Research in Science Teaching*, *49*(3), 333-362. https://doi.org/10.1002/tea.21004

Hobbs, L. (2013). Teaching 'out-of-field': Factors shaping identities of secondary science and mathematics. *Teaching Science*, *58*(1), 21-29

Høigaard, R., Giske, R., & Sundsli, K. (2012). Newly qualified teachers' work engagement and teacher efficacy influences on job satisfaction, burnout, and the intention to quit. *European Journal of Teacher Education*, *35*(3), 347–357. https://doi.org/10.1080/02619768.2011.633993

Holbert, K. E., Molyneaux, K., Grable, L. L., & Dixon, P. (2011). Multi-university precollege outreach from a renewable energy focused Engineering Research Center. *In Proceedings of ASEE/IEEE Frontiers in Education Conference*, 1–7 retrieved from http://fie-conference.org/ fie2011/papers/1083.pdf https://doi.org/10.1109/FIE.2011.6142738

Johari, J., Tan, F. Y., & Zulkarnain, Z. I. T. (2018). Autonomy, workload, work-life balance and job performance among teachers. *International Journal of Educational Management*, *32*(1), 107-120. https://doi.org/10.1108/IJEM-10-2016-0226
Kennedy, J. P., Lyons, T., & Quinn, F. (2014). The continuing decline of science and mathematics enrolments in Australian high schools. *Teaching Science*, *60*(2), 34-46.
Ketelhut, D. J., Mills, K., Hestness, E., Cabrera, L., Plane, J., & McGinnis, J. R. (2020). Teacher change following a professional development experience in integrating computational thinking into elementary science. *Journal of Science Education and Technology*, *29*(1), 174-188. https://doi.org/10.1007/s10956-019-09798-4
Kim, M., Tan, A. L., & Talaue, F. T. (2013). New vision and challenges in inquiry-based curriculum changes in Singapore. *International Journal of Science Education, 35*(2), 189-311. https://doi.org/10.1080/09500693.2011.636844
Klassen, R. M., & Tze, V. M. (2014). Teachers' self-efficacy, personality, and teaching effectiveness: A meta-analysis. *Educational Research Review, 12*, 59-76. https://doi.org/10.1016/j.edurev.2014.06.001
Kleickmann, T., Tröbst, S., Jonen, A., Vehmeyer, J., & Möller, K. (2016). The effects of expert scaffolding in elementary science professional development on teachers' beliefs and motivations, instructional practices, and student achievement. *Journal of Educational Psychology, 108*(1), 21–42. https://doi.org/10.1037/edu0000041
Kokkinos, C. M. (2007). Job stressors, personality and burnout in primary school teachers. *British Journal of Educational Psychology*, *77*(1), 229-243. https://doi.org/10.1348/000709905X90344
Krebs, C. J. (2014). *Ecological methodology (3rd edition.*). New York: Harper & Row.
Levy, A. J., Jia, Y., Marco-Bujosa, L., Gess-Newsome, J., & Pasquale, M. (2016). Science specialists or classroom teachers: Who should teach elementary science?. *Science Educator, 25*(1), 10-21.
Lockman, A. S. (2006). *Changes in teacher efficacy and beliefs during a one-year teacher preparation program* (Doctoral dissertation, The Ohio State University).
Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs. *Research in Science Education*, *31*(2), 289-307. https://doi.org/10.1023/A:1013124409567
Lui, A. M., & Bonner, S. M. (2016). Preservice and inservice teachers' knowledge, beliefs, and instructional planning in primary school mathematics. *Teaching and Teacher Education*, *56*, 1-13. https://doi.org/10.1016/j.tate.2016.01.015
Lumpe, A. T. (2007). Research based professional development: Teachers engaged in professional learning communities. *Journal of Science Teacher Education, 18*(1), 125–128. https://doi.org/10.1007/s10972-006-9018-3
Lumpe, A., Czerniak, C., Haney, J., & Beltyukova, S. (2012). Beliefs about teaching science: The relationship between elementary teachers' participation in professional development and student achievement. *International Journal of Science Education, 34*(2), 153-166. https://doi.org/10.1080/09500693.2010.551222
Lynch, K., Hill, H. C., Gonzalez, K. E., & Pollard, C. (2019). Strengthening the research base that informs STEM instructional improvement efforts: A meta-analysis. *Educational Evaluation and Policy Analysis*, *41*(3), 260-293. https://doi.org/10.3102/0162373719849044
Martin, M. O., Mullis, I. V., Beaton, A. E., Gonzalez, E. J., Smith, T. A., & Kelly, D. L. (1997). *Science achievement in the primary school years: IEA's third International Mathematics and Science Study (TIMSS)*. Boston: TIMSS International Study Centre, Boston College.

McComas, W. F. (Ed.). (2013). *The language of science education: an expanded glossary of key terms and concepts in science teaching and learning*. Springer Science & Business Media.
Mills, R., Bourke, T., & Siostrom, E. (2020). Complexity and contradiction: Disciplinary expert teachers in primary science and mathematics education. *Teaching and Teacher Education*, 89, 103010. https://doi.org/10.1016/j.tate.2019.103010
Murphy, C., & Smith, G. (2012). The impact of a curriculum course on pre-service primary teachers' science content knowledge and attitudes towards teaching science. *Irish Educational Studies, 31*(1), 77-95. https://doi.org/10.1080/03323315.2011.634061
Ng, W., Aubusson, P., Fergusson, J., Pressick-Kilborn, K., & Palmer, T. A. (2018). Science By Doing Stage 4 (2016 to 2018). University of Technology Sydney (UTS). Accessed on the 29th of November 2022 from https://opus.lib.uts.edu.au/bitstream/10453/134516/1/Science%20by%20Doing%20Stage%204%20Evaluation_Final%20report%20March%202018.pdf
NSW Education Standards Authority (NESA). (2017). *Professional Development Requirements*. NSW Education Standards Authority, Sydney. Retrieved from https://educationstandards.nsw.edu.au/wps/portal/nesa/teacher-accreditation/professional-development/pd-requirements
Next Generation Science Standards (NGSS). (2013). www.nextgenscience.org/
Nie, Y., Tan, G. H., Liau, A. K., Lau, S., & Chua, B. L. (2013). The roles of teacher efficacy in instructional innovation: its predictive relations to constructivist and didactic instruction. *Educational Research for Policy and Practice, 12*(1), 67–77. https://doi.org/10.1007/s10671-012-9128-y
Norton, A., Cherastidtham, I., and Mackey, W. (2018). *Mapping Australian higher education 2018*. Grattan Institute.
Nulty, D. D. (2008). The adequacy of response rates to online and paper surveys: what can be done?. *Assessment & Evaluation in Higher Education, 33*(3), 301-314. https://doi.org/10.1080/02602930701293231
Office of the Chief Scientist. (2012). *Mathematics, engineering & science in the national interest*. Canberra: Australian Government.
Organisation for Economic Development and Cooperation (OECD). (2013). What makes urban schools different? *PISA in Focus, 28*.
O'Toole, J., & Beckett, D. (2013). *Educational research: Creative thinking and doing* (2nd ed.). Oxford University Press.
Pajares, F. (1997). Current directions in self-efficacy research. In M. Maehr & P. R. Pintrich (Eds.), *Advances in motivation and achievement* (Vol. 10, pp. 1-49). Greenwich, CT: Information Age.
Pallant, J. (2020). *SPSS Survival Manual: A Step by Step Guide to Data Analysis Using IBM SPSS, (7th ed.).* Allen & Unwin. https://doi.org/10.4324/9781003117452
Queensland College of Teachers (QCT). (2022). *Continuing Professional Development (CPD) Requirements*. Author. Retrieved from https://www.qct.edu.au/professional-development/requirements
Ralls, D., Bianchi, L., & Choudry, S. (2020). 'Across the divide': Developing professional learning ecosystems in STEM education. *Research in Science Education*, *50*(6), 2463-2481. https://doi.org/10.1007/s11165-018-9789-5
Rennie, L. (2005). Science awareness and scientific literacy. *Teaching Science, 51*(1), 10–14.
Riggs, I. M., & Enochs, L. (1990). Toward the development of an elementary teachers' science teaching efficacy belief instrument. *Science Education, 74*, 625-637. https://doi.org/10.1002/sce.3730740605

Roberts, D. & Bybee, R. (2014). Scientific literacy, science literacy and science education. In N. Lederman & S. Abell (Eds.), *The Handbook of Research on Science Education (Volume 2)*, (pp. 545-58), Routledge: New York.

Rowe, E., & Perry, L. B. (2020). Inequalities in the private funding of public schools: parent financial contributions and school socioeconomic status. *Journal of Educational Administration and History, 52*(1), 42-59. https://doi.org/10.1080/00220620.2019.1689234

Said, Z., Summers, R., Abd-El-Khalick, F., & Wang, S. (2016). Attitudes toward science among grades 3 through 12 Arab students in Qatar: findings from a cross-sectional national study. *International Journal of Science Education*, *38*(4), 621–643. https://doi.org/10.1080/09500693.2016.1156184

Saka, Y., Southerland, S. A., & Golden, B. (2009). *Describing the effects of research experiences for teachers attitudes and beliefs: Examining science teachers' self-efficacy beliefs, beliefs of reformed-science teaching, attitudes and pedagogical discontentment.* Paper presented at the annual meeting of the American Educational Research Association, San Diego, CA.

Scher, L., & O'Reilly, F. (2009). Professional development for K–12 math and science teachers: What do we really know?. *Journal of Research on Educational Effectiveness*, *2*(3), 209-249. https://doi.org/10.1080/19345740802641527

Schuelka, M. J. (2013). Excluding students with disabilities from the culture of achievement: The case of the TIMSS, PIRLS, and PISA. *Journal of Education Policy*, *28*(2), 216-230. https://doi.org/10.1080/02680939.2012.708789

Skamp, K., & Preston, C. (Eds). (2021). *Teaching primary science constructively* (7th edition). Cengage.

Stevenson, M., Bower, M., Falloon, G., Forbes, A., & Hatzigianni, M. (2019). By design: Professional learning ecologies to develop primary school teachers' makerspaces pedagogical capabilities. *British Journal of Educational Technology*, *50*(3), 1260-1274. https://doi.org/10.1111/bjet.12743

Teacher Registration Board of the Northern Territory (TRBNT). (2022) Evidence Guide: Full Registration Renewal Requirements. Northern Territory Government. Retrieved from https://www.trb.nt.gov.au/system/files/uploads/files/2019/evidence-guide-for-renewal-of-full-registration-requirements-audit_0_0.pdf

Teacher Registration Board of Western Australia (TRBWA). (2022). *Professional Learning*. Author. Retrieved from https://www.trb.wa.gov.au/Teacher-Registration/Currently-registered-teachers/Renewal-of-registration/Professional-learning

Teachers Registration Board of South Australia (TRBSA). (2022). *Professional Learning*. Author. Retrieved from https://www.trb.sa.edu.au/professional-learning

Teachers Registration Board of Tasmania (TRBT). (2022). *Maintaining Your Registration*. Author. Retrieved from https://www.trb.tas.gov.au/renewal-of-registration/

Thatcher, A., Zhang, M., Todoroski, H., Chau, A., Wang, J., & Liang, G. (2020). Predicting the Impact of COVID-19 on Australian Universities. *Journal of Risk and Financial Management*, *13*(9), 188-208. https://doi.org/10.3390/jrfm13090188

Thomson, S., Wernert, N., Rodrigues, S., & O'Grady, E. (2020). *TIMSS Australia 2019: Highlights*. Australian Council for Educational Research. https://doi.org/10.37517/978-1-74286-616-1

Tschannen-Moran, M., & Hoy, A. W. (2001). Teacher efficacy: Capturing an elusive concept. *Teaching and Teacher Education, 17*, 783-805. https://doi.org/10.1016/S0742-051X(01)00036-1

Tytler, R., & Griffiths, M. (2003). Spending time on primary science in integrated units. *Investigating: Australian Primary Science Journal, 19*(1), 12-16.

Tytler, R., Osborne, J., Williams, G., Tytler, K., & Clark, J. C. (2008). *Opening up pathways: Engagement in STEM across the Primary-Secondary school transition*. Canberra: Australian Department of Education, Employment and Workplace Relations.

Unfried, A., Rachmatullah, A., Alexander, A., & Wiebe, E. (2022). An alternative to STEBI-A: validation of the T-STEM science scale. *International Journal of STEM Education, 9*(24), 1-14. https://doi.org/10.1186/s40594-022-00339-x

VanVoorhis, C. W., & Morgan, B. L. (2007). Understanding power and rules of thumb for determining sample sizes. Tutorials in Quantitative Methods for Psychology, 3(2), 43-50. https://doi.org/10.20982/tqmp.03.2.p043

Victoria Institute of Teaching (VIT). (2022). *Professional Learning*. Author. Retrieved from https://www.vit.vic.edu.au/maintain/requirements/learning

Walker, L., Dziadkiewicz, N., & Gigliotti, A. (2020). *How might we enable generalist teachers to become confident science and STEM practitioners?* Paper presented at the Australian Science Education Research Association (ASERA) Conference, Wollongong, Australia. https://youtu.be/1pPYgBvDXnc

Wang, J. (2001). TIMSS primary and middle school data: Some technical concerns. *Educational Researcher*, *30*(6), 17-21. https://doi.org/10.3102/0013189X030006017

Watters, J. J. (2014). Challenges of Elementary Science Teaching. In *The Role of Science Teachers' Beliefs in International Classrooms* (pp. 207-225). SensePublishers, Rotterdam. https://doi.org/10.1007/978-94-6209-557-1_14

Yin, R. K. (2014). *Case study research: Design and methods (5th Ed.)*. London: SAGE Publications.

Yoon, K. S., Duncan, T., Lee, W.-Y., Scarloss, B., & Shapley, K. (2007). *Reviewing the evidence on how teacher professional development affects student achievement* (Issues & Answers Report, REL 2007–No. 033). Washington, DC: U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, Regional Educational Laboratory Southwest. Retrieved from http://ies.ed.gov/ncee/edlabs

Zee, M., & Koomen, H. M. (2016). Teacher self-efficacy and its effects on classroom processes, student academic adjustment, and teacher well-being: A synthesis of 40 years of research. *Review of Educational Research*, *86*(4), 981-1015. https://doi.org/10.3102/0034654315626801

Zhao, Y. (2020). Two decades of havoc: A synthesis of criticism against PISA. *Journal of Educational Change*, 1-22. https://doi.org/10.1007/s10833-019-09367-x

## Appendix 1 – Approaches to Primary Science Teaching Framework

*Approaches to Primary Science Teaching*

| Approach | Description |
|---|---|
| Analogies (Content Representations) | Analogies (Glynn, 2007; Guerra-Ramos, 2011) and Content Represents (CoRes) (Loughran, Mulhall & Berry, 2004) are often verbal ways of developing primary students' understanding of an unfamiliar science concept by its similarities with more familiar concepts. Teachers must take care to draw distinctions between where analogies and CoRes are accurate and inaccurate to avoid either creating or reinforcing alternative scientific conceptions (Skamp & Preston, 2021). |
| Big Ideas/ Inquiry Questions | The 'Big Ideas' in science education (Harlen, 2015) inform global science curricula and can be used to frame learning for students. Such big ideas can also be expressed in the form of inquiry questions to create cohesive student learning across activities, lessons, units and year levels. Some science curricula are now framed around inquiry questions (e.g. NESA, 2017); a useful trend given that preservice primary teachers have difficulty forming researchable questions, resulting in superficial experimental designs (Morrison, 2008). Teachers often struggle to afford student choice in the development or selection of science inquiry questions (Biggers, 2018). |
| Claim-Evidence-Reasoning (CER) Cues | CER cues, either written or verbal, can be used to scaffold primary students understanding of the presentation of claims based on evidence and the associated reasoning needed to connect these two elements (Allen & Park Rogers, 2015). |
| Class Discussions | Class discussions are an essential part of almost all teachers' teaching repertoires and is often explicitly mentioned in primary science education research (Barnett & Morran, 2002; Liou et al., 2017; Metz, 2008). While class discussions can vary in terms of communicators, communication length, spontaneity and degree of teacher control, they would typically require more than one exchange of information amongst 3 or more participants. |
| Community Projects | Community projects are a means of extending science beyond the typical classroom or school environment. Unlike excursions, community projects often include multiple visits or engagements in service of a broad objective (Keil, Haney & Zoffel, 2009; Mueller & Bentley, 2009). Community projects can also incorporate multiple visits to the school by community members (Stevens et al., 2016). |
| Constructivism | Learning that occurs when an individual constructs their knowledge through active cognitive (Kamii & Ewing, 1996) and/or social participation (Vygotsky, 1977) within a phenomenon or situation (Slavin, 1991). Although previously deemed a guiding principle of primary science education (Deehan, 2022), constructivism has been operationalised for teaching through a variety of models and frameworks (Aubusson et al., 2015). |
| 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). Cross curricular integration with science can also occur with art, literacy, music, and drama (Bulunuz, 2013). |
| Debate | Debate can be seen as a means of advancing more typical science classroom dialogue to a more structured processed base on scientific processes and knowledge (Diakidoy & Kendeou, 2001; France, 2021). They are a rigorous and systematic manner of inducting students into science discourse and the analysis of competing claims (Russell & McGuigan, 2018). Structured debates in primary science classes can positively influence learners' motivation and science attitudes (Kim, 2019) |
| Deep Reflection | Deep reflection involves providing support and time for primary learners to consolidate their new, refined science understandings into their existing schemas. This approach is an overarching, intersectional strategy that would typically occur in conjunction with other teaching approaches and would take a variety of forms (brainstorms, reports, group discussions & multimodal representations) (Genc, 2015; Karacalli & Korur, 2014). |
| Diagnostic Assessment for | Learners' alternative conceptions can inform the design and delivery of science learning experiences (McKinnon et al., 2017) and are typically identified through diagnostic assessment at the commencement of a learning and teaching cycle |

| | |
|---|---|
| Alternative Conceptions | (Çelikten, et al., 2012; Tarhan et al., 2013). Alternative conceptions can be sourced directly from learners or through scholarly material. |
| Digital Technology/ Simulations | Any form of digital educational technology delivered to primary students with the aim of enhancing science learning. Technological innovations may include; Robots (Shiomi et al., 2015), Technology Enhanced Curriculum (Varma & Linn, 2012), Augmented Reality (Fleck & Simon, 2013), 3d Games (Lester et al., 2014) and Learning Management Systems (Field, 2009). |
| Direct Instruction/ Transmission | Direct Instruction/ Transmission is the more traditional approach of teacher dissemination of information that places students in a passive recipient role (Jonassen, 1991). It should be noted that direct transmission is often viewed as a necessary part of a balance teaching approach rather than a contradiction of constructivist principles (Godino et al., 2016). |
| Excursions | Excursions are singular education visits to sites relevant to science education that could not be accessed in a regular school environment. It should be noted that these singular visits can vary in length and can include: excursions to local ecosystems (Prokop et al., 2007), museum visits (Martin et al., 2016), university excursions (Ozogul, 2019) and summer camps (White et al., 2018). |
| Group Work/ Cooperative Learning | Cooperative learning occurs when students work together to complete a task that would otherwise be impossible or unreasonable to complete individually (e.g. Deehan et al., 2017). This strategy is often supported with clear expectations in terms of process and output. For example, students or groups of students may be assigned discreet roles within a larger learning task (Tarhan et al., 2013). |
| Guest Speakers | Guest speakers are individuals or groups of individuals who are invited into the science learning of primary students, either digitally or physically, to share relevant perspectives, experiences or expertise. Guest speakers are valued complements to regular science teaching practice by students and teachers alike (Flick, 1990; Knobloch & Allen, 2007). |
| Hands On Tasks | Hands On Tasks occur when learners are physically engaged in the learning process. Such physical tasks may typically be complemented by an array of consolidative activities (Skamp & Preston, 2021), such as classroom dialogue (Varelas, Pappas & Rife, 2006), to ensure science learning objectives are met. Naïve notions of hands on learning can result in activities do not meaningfully advance scientific knowledge or skills (Kleickmann et al., 2016). |
| Individual Reading | Reading practices are a key component to learning in science and most disciplines. Individual reading has been separated from cross curricular integration for its ubiquity and the rich vein of literacy support research in primary science education, such as varied science texts (e.g. Balim et al., 2016; McTigue, 2009), Concept Oriented Reading Instruction (CORI) (e.g. Guthrie et al., 2004; Wigfield et al., 2008), science language transitions (e.g. Brown & Ryoo, 2008; Brown et al., 2010) and problem solving scaffolds (e.g. Bulu, 2008). |
| 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 or complete control of the inquiry process (e.g. Fitzgerald et al., 2019). Inquiry Learning is a means of embodying scientific practice in science learning in alignment with constructivist principles because it requires active, persistent skill use based on personal knowledge (Suduc, Bizoi & Gorghiu, 2015). Questioning, exploration, making and testing for the acquisition of new knowledge are essential (Lemlech, 2009). |
| Joint Construction | Joint Construction is the process by which a teacher (expert) works collaboratively to construct a text or product with one or more students (non-experts) (Hermansson et al., 2019); an approach well established in education broadly (Rose, 2013). It is often a key practice in backward faded scaffolding to gradually increase student independence (Slater et al., 2008). Joint construction has also been linked to positive outcomes in primary science research (Accurso et al., 2016; De Oliveira & Lan, 2014). |
| Lectures | Lectures are longer periods of direct transmission of teacher knowledge to students in a more passive role. Lectures are commonly associated with more objectivist approaches to teaching (Yarusso, 1992). Despite the long-term shifts to more constructivist modes in science education (Davis et al., 1993), more objectivist |

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| | approaches such as lectures have still been commonly reported in primary science education (Goodrum et al., 2001). |
| Modelling | This approach is the physical or digital construction of models to reflect scientific knowledge as a means of linking observations, formal or informal, to scientific theory (Schwarz et al., 2009); and has shown to positively influence primary science and general science learning outcomes (Diakidoy, & Kendeou, 2001; Van Joolingen, 2015; Louca & Zacharia, 2011; Shanahan, 2010). Like many other approaches in this framework, modelling intersects with other approaches, such as inquiry (Nersessian, 1995; Windschitl et al., 2008) |
| Nature of Science Teaching | 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 (Wilcox & Lake, 2018). Essentially, 'Nature of Science' Instruction orients learners to science epistemology (Demirdöğen et al., 2016). Explicit Nature of Science Teaching can enhance the science learning of students engaged in scientific investigations (Lederman & Lederman, 2014), literacy tasks and hands on tasks (Girod & Twyman, 2009). |
| Note Taking | Note taking is where students record science information, either physically or digitally, for later reinforcement, recall and/or reflection. Note taking can involve rote learning, open student response and/or specific strategies (Lee et al., 2008). Despite being a more passive, objectivist teaching approach, note taking can still be an effective science teaching strategy if effectively supported and incorporated within more complex science lessons or units (Lee et al., 2008). Note taking strategies have also shown to work effectively with classroom tablet technologies (Paek & Fulton, 2016). |
| Open/ Guided Discovery | Discovery learning is a constructivist approach, well established in science education literature (Balim, 2009; Koksal & Berberoglu, 2014), whereby students come to know the unknown by actively working to construct knowledge based on new data and information made available to them in their learning environment (De Jong & Van Joolingen, 1998; Matson, 2006). The degree of support offered to students engaged in discovery can vary considerably based on context, ranging from guided discovery with consistent guidance, to open discovery, with minimal to emergent guidance (Abd-El-Khalick et al., 2004). |
| Open/ Higher Order Questioning | Open/ High Order Questions have more than one acceptable answer, with the quality of the answer relating more to a student's process or reasoning rather than a concrete notion of correctness. Such questions are seen as a mechanism for productive discourse in the science classroom (Chin, 2006; 2007), often in service of science literacy (Roberts & Bybee, 2014), and can be improved through teacher professional development (Caulfield-Sloan & Ruzicka, 2005). Bloom's Taxonomy (Forehand, 2010; Krathwohl, 2002), Productive questions (Elstgeest, 2001) and the Solo Taxonomy (Biggs & Collis, 2014) can all serve as frameworks for the development of open/ higher order questions. It should also be noted that open and higher order questioning and thinking is closely associated with inquiry and discovery learning (Matthews, 2002). |
| Other | Other was included in the framework to acknowledge the impossibility of capturing all possible science teaching approaches by allowing teachers to present approaches of which the research team may not be aware. |
| Outdoor Science | Outdoor science occurs when students are able to authentically engage with environments beyond the classroom for the purpose of meaningful science learning (Assaraf & Orion, 2010). Supplementing classroom science with outdoor learning experiences can significantly improve primary students' science knowledge (Prokop et al., 2007) and skills (Ting & Siew, 2014). However, primary teachers have reportedly viewed outdoor science experiences to difficult and inefficient to implement due to time constraints and demanding curricula (Carrier et al., 2013). |
| Peer Tutoring | Peer Tutoring involves at least one student assisting (i.e. the tutor) at least one other student to achieve (i.e. the tutee) a relevant science learning objective in a defined period of time (Stephenson & Warwick, 2001). Such tutoring can occur within and across classes and can be adjusted to suit changing learning needs and objectives. Research has shown that peer tutoring can improve the science content knowledge and attitudes of both tutors and tutee (Topping et al., 2004) |

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| Predict-Observe-Explain (POE) Cues | Predict-Observe-Explain (POE) cues are foundational scaffolds to frame students' sensory data (Observe) in science thinking (Jasdilla et al., 2019). Research has shown that such cues can aid conceptual change in primary science learners (Dial et al., 2009; Westman & Whitworth, 2019). POE cues can also function as catalysts for inquiry learning (Liem, 1990). |
| Project/ Problem-Based Learning | Project/ Problem-based learning uses real-world problems as a starting point for the acquisition and integration of new knowledge into existing schemas (Etherington, 2011; Keil et al., 2009; Sari et al., 2018). This approach to science education helps students to develop transferable skills which can be used in novel situations. Project/ problem based learning can be characterised by the requirement for systems thinking, that often links science to other learning areas, and a lack of immediate clarity regarding the 'correctness' of actions or answers (Stepien & Gallagher, 1993). In essence, such open ended approaches eschew the relative linear, narrative structure of other approaches (Drăghicescua et al., 2014). |
| Science in the Media | Engaging with Science in the Media is a way for primary students to explore socioscientific issues to better understand how science influences societies (Dolan et al., 2009; Presley et al., 2013). Such approaches enable primary learners to engage with important issues, such as: pest eradication, water security and climate change, with supplementary approaches such as debate, group learning, digital technologies (Evagorou et al., 2015; Grumbach, 2019; Kahn & Hartman, 2018). The research on science in the media and associated socioscientific issues has increased considerably over the past decade (Tekin et al., 2016). |
| Second Hand Research | Second hand research involves students analysing data and/or interpreting information that they themselves did not collect directly. Such second-hand research can effectively complement first research experiences to show students how science relates to the world beyond the classroom and improve their scientific knowledge and reasoning (Palincsar & Magnusson, 2001). While subsequent classroom research has shown that second hand research unique benefits for the development of scientific inquiry skills (Hug & McNeill, 2008), it cannot replace firsthand research experiences (Delen & Krajcik, 2015). |
| Station Rotation | Station rotation involves the set up and delivery of separate, but possibly related, learning activities (stations) that students can work through, individually or cooperatively, for periods of time during a science learning experience. These series of activities can be timed or self-paced (Martin et al., 2016). Research has shown that station rotations can covary with highly significant improvement to primary students' science achievement and skill (Ocak, 2010). |
| Student Centred Investigations | Student Centred Investigations are one of the broader conceptualisations of scientific investigation in education research. For an investigation to be considered student centred, full or partial student input into the purpose, parameters, process and/or consolidation of a scientific investigation must be offered. Student centred investigations intersect with other approaches and vary considerably in term of form and function within the science education research literature (Aydede & Matyar, 2009; Quigley et al., 2011; Skamp & Preston, 2021). |
| Teacher Demonstration | Teacher demonstration occurs when a teacher represents the science related actions, skills, knowledge and/or dispositions they wish their students to emulate or embody. Although teacher demonstration is a longstanding approach (Glasson, 1989; Goodrum et al., 2001) often considered to be a more passive teaching approach, it has been linked to improve science learning outcomes (Shepardson et al., 1994) and can be foundational element to more complex science programs (Ozogul et al., 2019). |
| Teacher Lead Investigations | Teacher lead investigations contrast directly with student centred investigations as they offer students with no meaningful input into any phase of a scientific investigation. Often referred to derisively as "on rails" or "cook book" investigations (Özgelen et al., 2008; Şeşen & Mutlu, 2016), teacher lead investigations are often cast as the "traditional approaches" used for control groups in science education research (Balim et al., 2016; Durmus & Bayraktar, 2010; Girod et al., 2010). However, teacher lead investigations can be seen as efficient solutions to resource and time limitations in primary school and beyond (Carrier et al., 2013; Deehan, 2022). |

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| The 5Es Framework | The 5Es framework underpins the Primary Connections resources (e.g. AAS, 2011; 2012a; 2012b) that are frequently used in Australian primary schools (Albion & Spence, 2013; Aubusson et al., 2019; Hume, 2012) and are well-supported by academic research. This commonly used framework is comprised of five phases: Engage, Explore, Explain, Elaborate and Evaluate (AAS, 2019; Bybee et al., 2006; Bybee, 2015). |
| Watching Videos | Teachers can often provide videos to provide students with information and insights that they would not otherwise be able to access in a classroom environment. There is considerable variation in how videos can be contextualised within science learning sequences; ranging from time fillers to thoughtful catalysts and/or consolidators of active science learning. For example, Chen and Cowie (2014) showed that videos of scientists can engage a wide array of science learners. Recent research has also show that motion graphic animation videos can help to improve primary students' science achievement (Haspari & Hanif., 2019). Further to this point, Koto (2010) found that the inclusion of thoughtfully curated YouTube videos into a discovery learning program can significantly improve Year 5 students' factual, procedural and conceptual knowledge of heat transfer. It is also important to note that videos can be an efficient way of addressing both longstanding (resourcing & time) and emergent (e.g. Covid-19) barriers. |
| Worksheets | A mainstay of science education (Goodrum et al., 2001); physical or digital worksheets provide written and visual cues for students to respond to in a science learning context. Despite being considered a passive learning approach, there is some evidence that worksheets can be effective in consolidating learning (Johnson, et al., 1997). Worksheets have been found to be beneficial in informal science education settings (Mortensen & Smart, 2007; Nyamupangedengu, & Lelliott, 2012) and augmented reality learning environments (Zhang et al., 2020). Worksheets continue to feature prominently in primary science education interventions (Deehan et al., 2024). |

## References


Abd-El-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A., ... & Tuan, H. L. (2004). Inquiry in science education: International perspectives. *Science Education*, *88*(3), 397-419. https://doi.org/10.1002/sce.10118

Accurso, K., Gebhard, M., & Selden, C. (2016). Supporting L2 elementary science writing with SFL in an age of school reform. In *Second language writing in elementary classrooms* (pp. 126-150). Palgrave Macmillan, London. https://doi.org/10.1057/9781137530981_8

Albion, P. R., & Spence, K. G. (2013). Primary Connections in a provincial Queensland school system: Relationships to science teaching self-efficacy and practices. *International Journal of Environmental and Science Education*, *8*(3), 501-520.

Allen, J., & Park Rogers, M. (2015). Formulating scientific explanations using the Claim, Evidence, and Reasoning (CER) framework. *Science and Children*, *53*(3), 32-37.

Assaraf, O. B. Z., & Orion, N. (2010). System thinking skills at the elementary school level. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *47*(5), 540-563. https://doi.org/10.1002/tea.20351

Aubusson, P., Schuck, S., Ng, W., Burke, P., & Pressick-Kilborn, K. (2015). *Quality learning and teaching in primary science and technology literature review Sydney*: Association of Independent Schools, New South Wales.

Aubusson, P., Skamp, K., Burke, P. F., Pressick-Kilborn, K., Ng, W., Palmer, T. A., ... & Ferguson, J. (2019). *Primary connections: Linking science with literacy stage 6 research evaluation final report*. Prepared for Steering Committee of Primary Connections, Australian Academy of Science. Accessed 22 December 2021 https://opus.lib.uts.edu.au/bitstream/10453/134515/1/Primary%20Connections%20Stage%206%20Evaluation_redacted_report_FINAL.pdf.

Australian Academy of Science (AAS). (2011). *Primary Connections: 'Melting Moments': Year 3.* Canberra: AAS

Australian Academy of Science (AAS). (2012a). *Primary Connections: 'Change Detectives': Year 6.* Canberra: AAS

Australian Academy of Science (AAS). (2012b). *Primary Connections: 'Spot the Difference': Year 1.* Canberra: AAS

Australian Academy of Science (AAS). (2019). Primary Connections. Canberra: AAS. http://primaryconnections.org.au/

Aydede, M. N., & Matyar, F. (2009). The effect of active learning approach in science teaching on cognitive level of student achievement. *Journal of Turkish Science Education, 6*(1), 115-127.

Balım, A. G. (2009). The effects of discovery learning on students' success and inquiry learning skills. *Eurasian Journal of Educational Research (EJER)*, (35), 1-20.

Balim, A. G., Inel-Ekici, D., & Özcan, E. (2016). Concept cartoons supported problem based learning method in middle school science classrooms. *Journal of Education and Learning, 5*(2), 272-284. https://doi.org/10.5539/jel.v5n2p272

Balim, A. G., Inel-Ekici, D., & Özcan, E. (2016). Concept cartoons supported problem based learning method in middle school science classrooms. *Journal of Education and Learning, 5*(2), 272-284.

Barnett, M., & Morran, J. (2002). Addressing children's alternative frameworks of the moon's phases and eclipses. *International Journal of Science Education, 24*(8), 859-879. https://doi.org/10.1080/09500690110095276

Biggers, M. (2018). Questioning questions: Elementary teachers' adaptations of investigation questions across the inquiry continuum. *Research in Science Education, 48*(1), 1-28. https://doi.org/10.1007/s11165-016-9556-4

Biggs, J. B., & Collis, K. F. (2014). *Evaluating the quality of learning: The SOLO taxonomy (Structure of the Observed Learning Outcome)*. Academic Press.

Brown, B. A., & Ryoo, K. (2008). Teaching science as a language: A "content-first" approach to science teaching. *Journal of Research in Science Teaching, 45*(5), 529-553. https://doi.org/10.1002/tea.20255

Brown, B. A., Ryoo, K., & Rodriguez, J. (2010). Pathway towards fluency: Using 'disaggregate instruction' to promote science literacy. *International Journal of Science Education, 32*(11), 1465-1493. https://doi.org/10.1080/09500690903117921

Bulu, S. T., & Pedersen, S. (2010). Scaffolding middle school students' content knowledge and ill-structured problem solving in a problem-based hypermedia learning environment. Educational *Technology Research and Development, 58*(5), 507-529. https://doi.org/10.1007/s11423-010-9150-9

Bulunuz, M. (2013). Teaching science through play in kindergarten: Does integrated play and science instruction build understanding?. *European Early Childhood Education Research Journal, 21*(2), 226-249. https://doi.org/10.1080/1350293X.2013.789195

Bybee, R. W. (2015). *The BSCS 5E instructional model: Creating teachable moments*. Arlington, TX: NSTA Press, National Science Teachers Association.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins and effectiveness. *Colorado Springs, Co: BSCS*, *5*, 88-98.
Carrier, S. J., Tugurian, L. P., & Thomson, M. M. (2013). Elementary science indoors and out: Teachers, time, and testing. *Research in Science Education*, *43*(5), 2059-2083. https://doi.org/10.1007/s11165-012-9347-5
Caulfield-Sloan, M. B., & Ruzicka, M. F. (2005). The effect of teachers' staff development in the use of higher-order questioning strategies on third grade students' rubric science assessment performance. *Planning and Changing*, *36*, 157-175.
Celikten, O., Ipekcioglu, S., Ertepinar, H., & Geban, O. (2012). The effect of the conceptual change oriented instruction through cooperative learning on 4th grade students' understanding of earth and sky concepts. *Science Education International*, *23*(1), 84-96.
Chen, J., & Cowie, B. (2014). Scientists talking to students through videos. *International Journal of Science and Mathematics Education*, *12*(2), 445-465. https://doi.org/10.1007/s10763-013-9415-y
Chin, C. (2006). Classroom interaction in science: Teacher questioning and feedback to students’ responses. *International Journal of Science Education*, *28*(11), 1315-1346. https://doi.org/10.1080/09500690600621100
Chin, C. (2007). Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *44*(6), 815-843. https://doi.org/10.1002/tea.20171
Davis, N. T., Jo McCarty, B., Shaw, K. L., & Sidani-Tabbaa, A. (1993). Transitions from objectivism to constructivism in science education. *International Journal of Science Education*, *15*(6), 627-636. https://doi.org/10.1080/0950069930150601
De Jong, T., & Van Joolingen, W. R. (1998). Discovery learning with computer simulations of conceptual domains. *Review of Educational Research*, *68*, 179–201. https://doi.org/10.3102/00346543068002179
De Oliveira, L. C., & Lan, S. W. (2014). Writing science in an upper elementary classroom: A genre-based approach to teaching English language learners. *Journal of Second Language Writing*, *25*, 23-39. https://doi.org/10.1016/j.jslw.2014.05.001
Deehan, J. (2022). Primary science education in Australian universities: An overview of context and practice. *Research in Science Education*, 52(6), 1735-1759 https://doi.org/10.1007/s11165-021-10026-6
Deehan, J., Danaia, L., & McKinnon, D. H. (2017). A longitudinal investigation of the science teaching efficacy beliefs and science experiences of a cohort of preservice elementary teachers. *International Journal of Science Education*, *39*(18), 2548-2573. https://doi.org/10.1080/09500693.2017.1393706
Deehan, J., MacDonald, A. & Morris, C. (2024). A Scoping Review of Interventions in Primary Science Education. *Studies in Science Education*, *60* (1), https://doi.org/10.1080/03057267.2022.2154997
Delen, I., & Krajcik, J. (2015). What do students’ explanations look like when they use second-hand data?. *International Journal of Science Education*, *37*(12), 1953-1973. https://doi.org/10.1080/09500693.2015.1058989
Demirdöğen, B., Hanuscin, D. L., Uzuntiryaki-Kondakci, E., & Köseoğlu, F. (2016). Development and nature of preservice chemistry teachers’ pedagogical content knowledge for nature of science. *Research in Science Education*, *46*(4), 575-612. https://doi.org/10.1007/s11165-015-9472-z

Diakidoy, I. A. N., & Kendeou, P. (2001). Facilitating conceptual change in astronomy: A comparison of the effectiveness of two instructional approaches. *Learning and Instruction*, *11*(1), 1-20. https://doi.org/10.1016/S0959-4752(00)00011-6
Dial, K., D. Riddley, K. Williams, & V. Sampson. (2009). Addressing misconceptions: A demonstration to help students understand the law of conservation of mass. *The Science Teacher*, *76*(7), 54–57
Dolan, T. J., Nichols, B. H., & Zeidler, D. L. (2009). Using socioscientific issues in primary classrooms. *Journal of Elementary Science Education*, *21*(3), 1-12. https://doi.org/10.1007/BF03174719
Drăghicescu, L. M., Petrescu, A. M., Cristea, G. C., Gorghiu, L. M., & Gorghiu, G. (2014). Application of problem-based learning strategy in science lessons–Examples of good practice. *Procedia-Social and Behavioral Sciences*, *149*, 297-301. https://doi.org/10.1016/j.sbspro.2014.08.245
Durmuş, J., & Bayraktar, Ş. (2010). Effects of conceptual change texts and laboratory experiments on fourth grade students' understanding of matter and change concepts. *Journal of Science Education and Technology*, *19*(5), 498-504. https://doi.org/10.1007/s10956-010-9216-9
Elstgeest, J. (2001). The right question at the right time. In W. Harlen (ed.), *Primary Science: Taking the Plunge* (2nd edition). Portsmouth: Heinemann, pp. 36-46.
Etherington, M. B. (2011). Investigative primary science: A problem-based learning approach. *Australian Journal of Teacher Education*, *36*(9), 52-74. https://doi.org/10.14221/ajte.2011v36n9.2
Evagorou, M., Nicolaou, C., & Lymbouridou, C. (2015). School students' emotions about teaching a controversial issue. *School Science Review*, *96*(356), 75-80.
Field, G. (2009). The effects of the use of Renzulli Learning on student achievement in reading comprehension, reading fluency, social studies, and science. *International Journal of Emerging Technologies in Learning (iJET)*, *4*(1), 29-39. https://doi.org/10.3991/ijet.v4i1.629
Fitzgerald, M., Danaia, L., & McKinnon, D. H. (2019). Barriers inhibiting inquiry-based science teaching and potential solutions: perceptions of positively inclined early adopters. *Research in Science Education*, *49*(2), 543-566. https://doi.org/10.1007/s11165-017-9623-5
Fleck, S., & Simon, G. (2013, November). An augmented reality environment for astronomy learning in elementary grades: An exploratory study. In *Proceedings of the 25th Conference on l'Interaction Homme-Machine* (pp. 14-22). https://doi.org/10.1145/2534903.2534907
Flick, L. (1990). Scientist in Residence Program Improving Children's Image of Science. *School Science and Mathematics*, *90*(3), 204-214. https://doi.org/10.1111/j.1949-8594.1990.tb15536.x
Forehand, M. (2010). Bloom's taxonomy. *Emerging Perspectives on Learning, Teaching, and Technology*, *41*(4), 47-56.
France, A. (2021). Teachers using dialogue to support science learning in the primary classroom. *Research in Science Education*, *51*(3), 845-859 https://doi.org/10.1007/s11165-019-09863-3.
Genc, M. (2015). The effect of scientific studies on students' scientific literacy and attitude. *Ondokuz Mayıs Üniversitesi Eğitim Fakültesi Dergisi, 34*(1), 141-152.
Girod, M., & Twyman, T. (2009). Comparing the value added value of blended science and literacy curricula to inquiry-based science curricula in two 2nd-grade classrooms. *Journal of Elementary Science Education*, *21*(3), 13-22 https://doi.org/10.1007/BF03174720

Girod, M., Twyman, T., & Wojcikiewicz, S. (2010). Teaching and learning science for transformative, aesthetic experience. *Journal of Science Teacher Education*, *21*(7), 801-824. https://doi.org/10.1007/s10972-009-9175-2

Glasson, G. E. (1989). The effects of hands-on and teacher demonstration laboratory methods on science achievement in relation to reasoning ability and prior knowledge. *Journal of Research in Science Teaching*, *26*(2), 121-131. https://doi.org/10.1002/tea.3660260204

Glynn, S. (2007). The teaching-with-analogies model. *Science and Children*, *44*(8), 52-55.

Godino, J. D., Batanero, C., Cañadas, G. R., & Contreras, J. M. (2016). Linking inquiry and transmission in teaching and learning mathematics and experimental sciences. *Acta Scientiae*, *18*(4), 29-47.

Goodrum, D., Hackling, M., & Rennie, L. (2001). *The Status and Quality of Teaching and Learning of Science in Australian Schools*. Canberra: Department of Education, Training and Youth Affairs.

Grumbach, E. (2019). From facts to solutions. *Science and Children*, *55*(6), 35-41. https://doi.org/10.2505/4/sc19_056_05_34

Guerra-Ramos, M. T. (2011). Analogies as tools for meaning making in elementary science education: How do they work in classroom settings?. *Eurasia Journal of Mathematics, Science and Technology Education*, *7*(1), 29-39. https://doi.org/10.12973/ejmste/75175

Guthrie, J. T., Wigfield, A., Barbosa, P., Perencevich, K. C., Taboada, A., Davis, M. H., ... & Tonks, S. (2004). Increasing reading comprehension and engagement through concept-oriented reading instruction. *Journal of Educational Psychology*, *96*(3), 403-423. https://doi.org/10.1037/0022-0663.96.3.403

Hapsari, A. S., & Hanif, M. (2019). Motion graphic animation videos to improve the learning outcomes of elementary school students. *European Journal of Educational Research*, *8*(4), 1245-1255. https://doi.org/10.12973/eu-jer.8.4.1245

Harlen, W. (2015). Towards big ideas of science education. *School Science Review*, *97*(359), 97-107.

Hermansson, C., Jonsson, B., Levlin, M., Lindhé, A., Lundgren, B., & Norlund Shaswar, A. (2019). The (non) effect of Joint Construction in a genre-based approach to teaching writing. *The Journal of Educational Research*, *112*(4), 483-494. https://doi.org/10.1080/00220671.2018.1563038

Hug, B., & McNeill, K. L. (2008). Use of First-hand and Second-hand Data in Science: Does data type influence classroom conversations?. *International Journal of Science Education*, *30*(13), 1725-1751. https://doi.org/10.1080/09500690701506945

Hume, A. C. (2012). Primary connections: Simulating the classroom in initial teacher education. *Research in Science Education*, *42*(3), 551-565. https://doi.org/10.1007/s11165-011-9210-0

Jasdilla, L., Fitria, Y., & Sopandi, W. (2019). Predict Observe Explain (POE) strategy toward mental model of primary students. *Journal of Physics: Conference Series*, *1157*(2), 1-6. https://doi.org/10.1088/1742-6596/1157/2/022043

Johnson, D. M., Wardlow, G. W., & Franklin, T. D. (1997). Hands-on activities versus worksheets in reinforcing physical science principles: Effects on student achievement and attitude. *Journal of Agricultural Education*, *38*(3), 9-17. https://doi.org/10.5032/jae.1997.03009

Jonassen, D. H. (1991). Objectivism vs. constructivism: Do we need a new philosophical paradigm? *Educational Technology Research and Development*, *39*(3), 5-14. https://doi.org/10.1007/BF02296434

Kahn, S., & Hartman, S. (2018). Debate, dialogue, and democracy through science! *Science and Children*, *56*(2), 36-44. https://doi.org/10.2505/4/sc18_056_02_36
Kamii, C., & Ewing, J. K. (1996). Basing teaching on Piaget's constructivism. *Childhood Education*, *72*(5), 260-264. https://doi.org/10.1080/00094056.1996.10521862
Karaçalli, S., & Korur, F. (2014). The effects of project-based learning on students' academic achievement, attitude, and retention of knowledge: The subject of "electricity in our lives". *School Science and Mathematics, 114*(5), 224-235. https://doi.org/10.1111/ssm.12071
Keil, C., Haney, J., & Zoffel, J. (2009). Improvements in student achievement and science process skills using environmental health science problem-based learning curricula. *The Electronic Journal for Research in Science and Mathematics Education, 13*(1), 1-18.
Kim, D., & Bolger, M. (2017). Analysis of Korean elementary pre-service teachers' changing attitudes about integrated STEAM pedagogy through developing lesson plans. *International Journal of Science and Mathematics Education*, *15*(4), 587-605. https://doi.org/10.1007/s10763-015-9709-3
Kim, S. S. (2019). The Effect of maker class emphasizing small group discussion and debate on elementary school students' science learning motivation and scientific attitude. *Journal of the Korean Society of Earth Science Education*, *12*(1), 54-63. https://doi.org/10.15523/JKSESE.2016.9.1.54
Kleickmann, T., Tröbst, S., Jonen, A., Vehmeyer, J., & Möller, K. (2016). The effects of expert scaffolding in elementary science professional development on teachers' beliefs and motivations, instructional practices, and student achievement. *Journal of Educational Psychology*, *108*(1), 21–42. https://doi.org/10.1037/edu0000041
Knobloch, N. A., Ball, A. L., & Allen, C. (2007). The benefits of teaching and learning about agriculture in elementary and junior high schools. *Journal of Agricultural Education*, *48*(3), 25-36. https://doi.org/10.5032/jae.2007.03025
Koksal, E. A., & Berberoglu, G. (2014). The effect of guided-inquiry instruction on 6th grade Turkish students' achievement, science process skills, and attitudes toward science. *International Journal of Science Education*, *36*(1), 66-78. https://doi.org/10.1080/09500693.2012.721942
Koto, I. (2020). Teaching and learning science using youtube videos and discovery learning in primary school. *Mimbar Sekolah Dasar, 7*, 106–118. https://doi.org/10.17509/mimbar-sd.v7i1.22504
Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. *Theory into Practice*, *41*(4), 212-218. https://doi.org/10.1207/s15430421tip4104_2
Lederman, N. & Lederman, J. (2014). Research on teaching and learning of the nature of science. In N. Lederman & S. Abell (Eds.), *The Handbook of Research on Science Education (Volume 2),* (pp. 600-620), Routledge: New York. https://doi.org/10.4324/9780203097267
Lee, P. L., Lan, W., Hamman, D., & Hendricks, B. (2008). The effects of teaching notetaking strategies on elementary students' science learning. *Instructional Science*, *36*(3), 191-201. https://doi.org/10.1007/s11251-007-9027-4
Lemlech, J. K. (2009). *Curriculum and Instructional Methods for Elementary and Middle School* (7th Edition). Upper Saddle River, New Jersey: Pearson.
Lester, J. C., Spires, H. A., Nietfeld, J. L., Minogue, J., Mott, B. W., & Lobene, E. V. (2014). Designing game-based learning environments for elementary science education: A narrative-centered learning perspective. *Information Sciences*, *264*, 4-18. https://doi.org/10.1016/j.ins.2013.09.005

Liem, T. (1990). *Invitations to Science Enquiry* (2nd edition). Thornhill, Ontario: S17 Science. http://www.stmary.ws/HighSchool/Physics/home/links/techStuff/TikLiemScientificInquiry.pdf

Liou, H. H., Yang, S. J., Chen, S. Y., & Tarng, W. (2017). The influences of the 2D image-based augmented reality and virtual reality on student learning. *Journal of Educational Technology and Society*, *20*(3), 110-121.

Louca, L. T., & Zacharia, Z. C. (2012). Modeling-based learning in science education: cognitive, metacognitive, social, material and epistemological contributions. *Educational Review*, *64*(4), 471-492. https://doi.org/10.1080/00131911.2011.628748

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching*, *41*(4), 370-391. https://doi.org/10.1002/tea.20007

Martin, M. O., Mullis, I. V. S., Foy, P., & Hooper, M. (2016*). TIMSS 2015 international results in science.* Retrieved from Boston College, TIMSS & PIRLS International Student Center website: http://timssandpirls.bc.edu/timss2015/international-results/

Matson, J. O. (2006). Misconceptions about the nature of science, inquiry-based instruction, and constructivism: Creating confusion in the science classroom. *Electronic Journal of Literacy through Science*, 5(6), 1-10.

Matthews, M. R. (2002). Constructivism and science education: A further appraisal. *Journal of Science and Technology*, *11*(2), 121-134. https://doi.org/10.1023/A:1014661312550

McKinnon, D.H., Danaia, L. & Deehan, J. (June, 2017). The design of preservice primary teacher education science subjects: The emergence of an interactive educational design model. *Journal of Astronomy & Earth Sciences Education (JAESE), 4*(1), 1-24. https://doi.org/10.19030/jaese.v4i1.9972

McTigue, E. M. (2009). Does multimedia learning theory extend to middle-school students?. *Contemporary Educational Psychology*, *34*(2), 143-153. https://doi.org/10.1016/j.cedpsych.2008.12.003

Metz, K. E. (2008). Narrowing the gulf between the practices of science and the elementary school science classroom. *The Elementary School Journal*, *109*(2), 138-161. https://doi.org/10.1086/590523

Morrison, J. A. (2008). Individual inquiry investigations in an elementary science methods course. *Journal of Science Teacher Education*, *19*(2), 117-134. https://doi.org/10.1007/s10972-007-9086-z

Mortensen, M. F., & Smart, K. (2007). Free-choice worksheets increase students' exposure to curriculum during museum visits. *Journal of Research in Science Teaching*, *44*(9), 1389-1414. https://doi.org/10.1002/tea.20206

Mueller, M. P., & Bentley, M. L. (2009). Environmental and science education in developing nations: A Ghanaian approach to renewing and revitalizing the local community and ecosystems. *The Journal of Environmental Education*, *40*(4), 53-64. https://doi.org/10.3200/JOEE.40.4.53-64

Nersessian, N. J. (1995). Should physicists preach what they practice?. *Science and Education*, *4*(3), 203-226. https://doi.org/10.1007/BF00486621

NSW Education Standards Authority (NESA). (2017). *NSW Syllabus for the Australian Curriculum, Science and Technology K-6*. NSW Education Standards Authority, Sydney. Retrieved from: http://educationstandards.nsw.edu.au/wps/portal/nesa/k-10/learning-areas/science/science-and-technology-k-6-new-syllabus

Nyamupangedengu, E., & Lelliott, A. (2012). An exploration of learners' use of worksheets during a science museum visit. *African Journal of Research in Mathematics, Science and Technology Education*, *16*(1), 82-99. https://doi.org/10.1080/10288457.2012.10740731
Ocak, G. (2010). The effect of learning stations on the level of academic success and retention of elementary school students. *The New Educational Review, 21*(2), 146-157.
Özgelen, S., Hacıeminoğlu, E., & Yılmaz Tüzün, Ö. (2008). *Investigation of Pre-service Teachers' Reasoning Abilities and Learning Approaches in Inquiry Based Learning Environment*. https://narst.org/sites/default/files/2019-07/2008_Abstracts.pdf
Ozogul, G., Miller, C. F., & Reisslein, M. (2019). School fieldtrip to engineering workshop: pre-, post-, and delayed-post effects on student perceptions by age, gender, and ethnicity. *European Journal of Engineering Education*, *44*(5), 745-768. https://doi.org/10.1080/03043797.2018.1518408
Paek, S., & Fulton, L. A. (2016). Elementary students using a tablet-based note-taking application in the science classroom. *Journal of Digital Learning in Teacher Education*, *32*(4), 140-149. https://doi.org/10.1080/21532974.2016.1206491
Palincsar, A. S., & Magnusson, S. J. (2001). The interplay of first-hand and second-hand investigations to model and support the development of scientific knowledge and reasoning. In S. M. Carver & D. Klahr (Eds.), *Cognition and instruction: Twenty-five years of progress* (pp. 151–193). Lawrence Erlbaum Associates Publishers.
Presley, M. L., Sickel, A. J., Muslu, N., Merle-Johnson, D., Witzig, S. B., Izci, K., & Sadler, T. D. (2013). A framework for socio-scientific issues based education. *Science Educator*, *22*(1), 26-32.
Prokop, P., Tuncer, G., & Kvasničák, R. (2007). Short-term effects of field programme on students' knowledge and attitude toward biology: a Slovak experience. *Journal of Science Education and Technology, 16*(3), 247-255. https://doi.org/10.1007/s10956-007-9044-8
Quigley, C., Pongsanon, K., & Akerson, V. L. (2010). If we teach them, they can learn: Young students' views of nature of science aspects to early elementary students during an informal science education program. *Journal of Science Teacher Education, 21*(7), 887-907. https://doi.org/10.1007/s10972-009-9164-5
Roberts, D. A., & Bybee, R. W. (2014). Scientific literacy, science literacy, and science education. In *Handbook of Research on Science Education, Volume II* (pp. 559-572). Routledge. https://doi.org/10.4324/9780203097267-38
Rose, D., & Martin, J. R. (2013). *Intervening in contexts of schooling*. In J. Flowerdew (Ed.), Discourse in context: Contemporary applied linguistics (vol. 3, pp. 447–475). London: Continuum.
Russell, T., & McGuigan, L. (2018). Progression. In Serret, N. & Earle, S. (Eds.). *ASE Guide to Primary Science Education* (pp.92-103). Hatfield, UK: Association for Science Education.
Sari, D. K., Banowati, E., & Purwanti, E. (2018). The effect of problem-based learning model increase the creative thinking skill and students activities on elementary school. *Journal of Primary Education, 7*(1), 57-63.
Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., ... & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, *46*(6), 632-654. https://doi.org/10.1002/tea.20311

Şeşen, B. A., & Mutlu, A.(2016). Predict-observe-explain tasks in chemistry laboratory: Pre-service elementary teachers' understanding and attitudes. *Sakarya University Journal of Education*, *6*(2), 184-208. https://doi.org/10.19126/suje.46187
Shanahan, M. (2010). Reading as scientists. *Science and Children*, *48*(1), 54-58. https://doi.org/10.1353/bkb.0.0304
Shepardson, D. P., Moje, E. B., & Kennard-McClelland, A. M. (1994). The impact of a science demonstration on children's understandings of air pressure. *Journal of Research in Science Teaching*, *31*(3), 243-258. https://doi.org/10.1002/tea.3660310305
Shiomi, M., Kanda, T., Howley, I., Hayashi, K., & Hagita, N. (2015). Can a social robot stimulate science curiosity in classrooms?. *International Journal of Social Robotics*, *7*(5), 641-652. https://doi.org/10.1007/s12369-015-0303-1
Skamp, K., & Preston, C. (Eds). (2021). *Teaching primary science constructively* (7th edition). Cengage.
Slater, S. J., Slater, T. F., & Shaner, A. (2008). Impact of backwards faded scaffolding in an astronomy course for pre-service elementary teachers based on inquiry. *Journal of Geoscience Education*, *56*(5), 408–416. https://doi.org/10.5408/jge_nov2008_slater_408
Slavin, R. E. (1996). Research on cooperative learning and achievement: What we know, what we need to know. *Contemporary Educational Psychology*, *21*, 43–69. https://doi.org/10.1006/ceps.1996.0004
Stephenson, P., & Warwick, P. (2001). Peer tutoring in the primary science classroom: upper primary students teaching infants. *Investigating*, *17*(2), 11-13.
Stepien, W., & Gallagher, S. (1993). Problem-based learning: As authentic as it gets. *Educational Leadership*, *50 (7)*, 25-29.
Stevens, S., Andrade, R., & Page, M. (2016). Motivating young Native American students to pursue STEM learning through a culturally relevant science program. *Journal of Science Education and Technology*, *25*(6), 947-960. https://doi.org/10.1007/s10956-016-9629-1
Suduc, A. M., Bizoi, M., & Gorghiu, G. (2015). Inquiry based science learning in primary education. *Procedia-Social and Behavioral Sciences*, *205*, 474-479. https://doi.org/10.1016/j.sbspro.2015.09.044
Tarhan, L., Ayyıldız, Y., Ogunc, A., & Sesen, B. A. (2013). A jigsaw cooperative learning application in elementary science and technology lessons: physical and chemical changes. *Research in Science and Technological Education*, *31*(2), 184-203. https://doi.org/10.1080/02635143.2013.811404
Tekin, N., Aslan, O., & Yilmaz, S. (2016). Research Trends on Socioscientific Issues: A Content Analysis of Publications in Selected Science Education Journals. *Journal of Education and Training Studies*, *4*(9), 16-24. https://doi.org/10.11114/jets.v4i9.1572
Ting, K. L., & Siew, N. M. (2014). Effects of outdoor school ground lessons on students' science process skills and scientific curiosity. *Journal of Education and Learning*, *3*(4), 96-107. https://doi.org/10.5539/jel.v3n4p96
Topping, K. J., Peter, C., Stephen, P., & Whale, M. (2004). Cross-age peer tutoring of science in the primary school: Influence on scientific language and thinking. *Educational Psychology*, *24*(1), 57-75. https://doi.org/10.1080/0144341032000146449
Van Joolingen, W. R., Aukes, A. V., Gijlers, H., & Bollen, L. (2015). Understanding elementary astronomy by making drawing-based models. *Journal of Science Education and Technology*, *24*(2-3), 256-264. https://doi.org/10.1007/s10956-014-9540-6

Varelas, M., Pappas, C., & Rife, A. (2006). Exploring the role of intertextuality in concept construction: urban second graders make sense of evaporation, boiling and condensation. *Journal of Research in Science Teaching, 43*(7), 637-666 https://doi.org/10.1002/tea.20100

Varma, K., & Linn, M. C. (2012). Using interactive technology to support students' understanding of the greenhouse effect and global warming. *Journal of Science Education and Technology, 21*(4), 453-464. https://doi.org/10.1007/s10956-011-9337-9

Vygotsky, L. S. (1977). The development of higher psychological functions. *Soviet Psychology, 15*(3), 60-73. https://doi.org/10.2753/RPO1061-0405150360

Westman, B., & Whitworth, B. (2019). Supporting second-grade students' thinking using the PEOE strategy. *Science and Children, 56*(7), 44-49. https://doi.org/10.2505/4/sc19_056_07_44

White, R. L., Eberstein, K., & Scott, D. M. (2018). Birds in the playground: Evaluating the effectiveness of an urban environmental education project in enhancing school children's awareness, knowledge and attitudes towards local wildlife. *PloS one, 13*(3), https://doi.org/10.1371/journal.pone.0193993

Wigfield, A., Guthrie, J. T., Perencevich, K. C., Taboada, A., Klauda, S. L., McRae, A., & Barbosa, P. (2008). Role of reading engagement in mediating effects of reading comprehension instruction on reading outcomes. *Psychology in the Schools, 45*(5), 432-445. https://doi.org/10.1002/pits.20307

Wilcox, J. & Lake, A. (2018). Teaching the nature of science to elementary children. *Science and Children, 55*(5), 78-85. https://doi.org/10.2505/4/sc18_055_05_78

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education, 92*(5), 941-967. https://doi.org/10.1002/sce.20259

Yarusso, L. (1992). Constructivism vs. Objectivism. *Performance and Instruction, 31*(4), 7-9. https://doi.org/10.1002/pfi.4170310404

Zhang, J., Huang, Y. T., Liu, T. C., Sung, Y. T., & Chang, K. E. (2020). Augmented reality worksheets in field trip learning. *Interactive Learning Environments*, https://doi.org/10.1080/10494820.2020.1758728