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# Science teachers' professional growth benefits from formal and informal interactions with science centers

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**Abstract**

Research on out-of-school science centers, such as museums, has mostly focused on benefits for students, while benefits for teachers have received less attention. This study examined the professional growth science teachers experienced through their formal and informal interactions with science centers. Fifty-three primary (grades F-6) and secondary (years 7-12) science teachers from Australia participated in a survey. Teachers reported experiencing professional growth benefits when participating in formal professional learning programs, as well as through informal learning opportunities, such as incidentally learning while accompanying students on field trips. Despite the varied ways teachers interacted with science centers, findings show that teachers reported benefits to a range of aspects of their professional growth including science knowledge gains, improved pedagogical practices and increased motivation to teach science. Therefore, teachers' formal and informal interactions with science centers should be considered an important resource for facilitating a range of professional growth benefits for science teachers.

**Keywords:** professional development, in-service science teacher education, informal learning environments, science centers, field trips, professional growth

## INTRODUCTION

Improvements to student outcomes are known to be correlated with teachers' attitudes and knowledge (Keller et al., 2017). Therefore, the provision or improvement of teacher professional development (PD) programs has been a key aspect of education policies around the world (Australian Government, 2022; Committee on Science, Technology, Engineering, and Mathematics, 2024; McElearney et al., 2019; The Royal Society, 2020). Additionally, research has highlighted the role that professional growth may have in improving teacher retention (Allen & Sims, 2017; Buchanan et al., 2013; Shaoan et al., 2025). Given the teacher shortages faced in many countries (Australian Government, 2022; Carver-Thomas & Darling-Hammond, 2019; McPherson & Lampert, 2025; Smith & White, 2024), this further highlights the need to ensure teachers are supported in their professional growth (Rahimi & Arnold, 2025).

However, accessing formal PD programs is often challenging for teachers as they may face time, financial, and location constraints (McElearney et al., 2019). In addition, teachers also have their own individual needs and preferences for PD (Owens et al., 2018), which may not align with the PD experiences available to them (Chval et al., 2008), therefore, it is critical to explore diverse approaches to supporting teacher professional growth. Informal PD experiences are being increasingly recognized as being key contributors to teachers' overall professional growth (Hoekstra et al., 2007; Kyndt et al., 2016) and may provide alternative, personalized and flexible approaches to teacher professional growth. Therefore, this study will focus on how science teachers' professional growth can be supported through formal and informal PD experiences.

Science centers, broadly defined as out-of-school science learning environments, including museums, zoos, and aquariums, can provide teachers with a range

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**Contribution to the literature**

- This study provides evidence that primary and secondary science teachers experience a range of professional growth benefits from both formal and informal interactions with science centers.
- It extends previous research by highlighting the range of incidental professional growth benefits that teachers experience when they accompany their students on field trips to science centers.
- It identifies aspects of science center programs that teachers value.

of formal and informal PD opportunities such as attending formal PD programs, accompanying students on field trips (visits to science centers, commonly called 'excursions' in Australia), accessing educational materials produced by the science centers, and participating in collaborative partnerships, among others (Luehmann & Markowitz, 2007; Phillips et al., 2007). Research on teacher professional growth in these settings has mainly focused on teachers' content and pedagogical knowledge development during formal PD programs (Aaron Price & Chiu, 2018; Holliday et al., 2014a; Melber & Cox-Petersen, 2005; Murcia & Pepper, 2018). The few studies that have reported on changes to science teachers' attitudes have shown conflicting results (Aaron Price & Chiu, 2018; Murcia & Pepper, 2018). Although there is sparse published research on the benefits to teachers of accompanying students on field trips to science centers, there is some evidence that these experiences lead to increased teacher science content and pedagogical knowledge as well as possible affective benefits (Sharma, 2016). As science teacher professional growth should be supported centers a range of aspects including cognitive changes (such as content knowledge), as well as attitudinal and motivational changes (Evans, 2014), this study aims to understand the range of professional growth benefits teachers experience through their formal and informal interactions with science centers. It does so through an exploration of the research question:

*What benefits have science teachers experienced to their professional growth through their formal and informal interactions with science centers?*

The aim of this study is to assist in developing an understanding of the contributions of science centers to in-service science teachers' professional growth and to inform future research about how science centers can continue to contribute to science teachers' professional growth. This is important as it would enable the contribution formal and informal interactions with science centers make to science teachers' professional growth to be recognized, which in turn could enable teachers to have improved awareness and access to these opportunities to support their professional growth needs. It could also have implications for the offerings of science centers. If teachers have increased opportunities to support their professional growth, it is expected that students will ultimately benefit.

## Scope

### *Science centers*

We took a broad view on what constituted a 'science center' to include out-of-school science learning environments that offered science educational programs to teachers and/or their students. This included, but was not limited to, museums, purpose-built science centers, aquariums, and zoos (Friedman, 2010). We defined 'interactions' with science centers to include accompanying school field trips and incursions (in-school programs delivered by staff from science centers), attending PD sessions and accessing online resources (such as lesson plans or videos etc.) among others.

### *Professional growth*

Within the field of teacher professional growth research, there are many terms used to describe the changes and development that teachers undergo in relation to their professional self, including but not limited to, PD, professional learning, professional growth, and teacher learning (O'Brien & Jones, 2014). As the intended outcome of this study was to determine the range of professional growth benefits science centers might provide teachers, a detailed discussion of the nuances of these terms will not be undertaken, and a broad definition of teacher 'professional growth' is used. The terms 'professional growth' and 'professional development' will also be used interchangeably, although it is acknowledged that some researchers define these terms differently (O'Brien & Jones, 2014). In this study, teacher professional growth was defined as encompassing the wide range of changes that teachers experience throughout their career such as changes to knowledge, skills, beliefs, and motivation (Clarke & Hollingsworth, 2002). There is a large amount of literature that explores the processes of how teacher professional growth occurs, with various models proposed (Boylan et al., 2018). As our study focused on what professional growth benefits teachers experienced, rather than detailing the mechanisms of how these benefits occurred, a detailed discussion of the various models of how professional growth may occur is beyond the scope of this article. As this study sought to investigate the range of professional growth benefits teachers may experience, including the attitudinal components that few studies of science centers have

reported on, Evans' (2014) components of learning that contribute to teachers' PD were used as the conceptual framework to consider what professional growth may occur. Evans (2014) defines three main components that contribute to teachers' PD including a behavioral component (what teachers do), an attitudinal component (what teachers feel, including their values and motivation) and an intellectual component (what teachers know). She describes how these three main components are linked, and that a change in one component may influence a change in the other components (for example a change in a teacher's knowledge may influence a subsequent change in a teacher's beliefs or classroom practice) (Evans, 2014). As Evans' (2014) framework has been used in a range of formal (Beresford-Dey & Holme, 2018; Pineda et al., 2022) and informal (Armstrong, 2021) contexts to study teacher and school staff PD, it lends itself to being used in our study across the different types of formal and informal interactions that teachers can have with science centers.

## Literature Review

### *Formal teacher professional development programs at science centers*

Science centers frequently offer formal PD programs for teachers (Phillips et al., 2007; Rennie, 2014; Rennie & McClafferty, 1995). Research on these formal PD programs has typically focused on extensive programs that involve multiple full-day sessions over the course of a year (Aaron Price & Chiu, 2018; Holliday et al., 2014a, 2014b; Murcia & Pepper, 2018) and in some instances also involve intensive summer institutes of 1-2 weeks duration, ongoing support from science center staff and multiple opportunities for students to also interact with or visit the science center (Duran et al., 2009; MacNabb et al., 2006; Pickering et al., 2012). These studies have reported benefits for middle school teachers including increases in middle school science teachers' self-reported measures of science teaching self-efficacy and content knowledge (Aaron Price & Chiu, 2018; Holliday et al., 2014a, 2014b; MacNabb et al., 2006), reduced levels of anxiety (Aaron Price & Chiu, 2018) and increased use of inquiry-based teaching strategies in their classrooms (MacNabb et al., 2006). In a study involving middle school and high school science teachers, Pickering et al. (2012) determined that teachers improved their content knowledge, as well as their ability and confidence in teaching specific science-related skills. For early childhood teachers, Duran et al. (2009) found that teachers' self-efficacy increased and that their beliefs about inquiry-based science teaching changed. Murcia and Pepper (2018) investigated outcomes for primary (elementary) teachers and found they increased inspiration, attitudes, values, knowledge and skills after participating in the PD programs. Whilst these studies highlight the potential of science centers to impact science teachers' PD, and whilst this type of sustained PD is often valued in the educational community, teachers often find participating difficult due to other ongoing demands on their time (Doecke et al., 2008; McKinnon & Lamberts, 2014).

There are some studies that have investigated outcomes for science teachers from participating in short-duration formal PD programs through science centers (McKinnon & Lamberts, 2014; Melber & Cox-Petersen, 2005). Melber and Cox-Petersen (2005) studied science PD workshops of 2-3 days duration for elementary and secondary teachers delivered by a science museum. They found that teachers reported increased science content knowledge, increased understanding of scientific fieldwork processes, changed teaching practice and felt better able to connect science content with formal (classroom) instruction. McKinnon and Lamberts (2014) investigated the effects on science teachers' self-efficacy beliefs after participating in four hour-long workshops produced and delivered by a science center in Australia over a period of approximately 1-2 months. They found that participants felt the workshops had increased their confidence and motivation (McKinnon & Lamberts, 2014).

Whilst some of these studies on science teacher PD provided by a science center detailed their research methods and instruments extensively and some even used validated research instruments (for example see Aaron Price & Chiu, 2018; Duran et al., 2009; McKinnon & Lamberts, 2014) other studies only included a few example questions from their data collection instruments and it was unclear at times what definitions or results were used to draw their conclusions. Therefore, future research in this field must ensure that detailed methods are published.

### *Informal teacher learning at science centers*

Sharma's (2016) research investigated how primary (elementary) teachers experienced informal 'incidental learning' (learning that was not targeted at teachers) when accompanying their students on a field trip to a science center in Singapore. Sharma (2016) determined that around 85% of teachers identified they had learned new information, despite the purpose of the field trip being for the students' learning. The new information teachers had learned was then grouped into content knowledge, classroom knowledge (knowledge a teacher has of their own classroom and students), personal/professional knowledge and pedagogical content knowledge. Attitudinal experiences, such as enjoyment and motivation, were alluded to in the interview excerpts, however these were not a focus of the study.

Luehmann and Markowitz (2007) detailed the outcomes of a partnership between a university-based science center and four middle school and four high school science teachers. Staff from the science center worked closely with the individual teachers to tailor a program for their students, which involved multiple planning meetings, multiple classroom visits from the science center staff as well as students also going on a field trip to the science center. Although this partnership is not typical of most student field trips to science centers, the results highlighted that the field trip aspect allowed teachers the opportunity to interact with their students in a different way than they would be able to in a classroom. Subsequently, the teachers felt this enabled them to see their students in a different way, learn more about them and improved their overall relationships with their students. This type of learning could be classified as informal learning, as it was not an intended outcome of the partnership program.

### *Implications for research*

When considering the literature on the benefits science teachers have experienced through their interactions with science centers, it appears that the studies in this area have usually focused on investigating a few specific aspects of science teacher professional growth, such as teachers' science content knowledge. Whether and how these aspects of science teacher professional growth have been defined, also varies in the literature. Additionally, most studies appear to have focused on specific cohorts of teachers, generally elementary and middle school teachers, who were participating in a specific program with a particular science center. Whilst identifying and investigating specific outcomes is important, in order to consider the broader role that science centers may play in influencing teachers' professional growth it is also vital that the range of benefits science teachers may experience is examined, and that teachers across all school levels are considered. Therefore, this study will investigate the range of benefits primary (grades F-6) and secondary (grades 7-12) science teachers experience.

## METHOD

To explore science teachers' professional growth benefits of their formal and informal interactions with science centers, an online survey was undertaken with school level science teachers from Australia. In order to develop this foundational understanding, teachers from across Australia were invited to participate in this study, rather than there being a focus on one particular science center. Ideally, the questionnaire would have also been advertised to teachers through education department communications, and through science centers themselves. However, due to the COVID-19 pandemic restrictions that were placed on educational research in Australia at the time this study was conducted, this was not possible. An online questionnaire was used to capture teachers' experiences as it allowed for an efficient, national dissemination of the research instrument and the ability to capture and analyze large amounts of data (Cohen et al., 2018). Additionally, the online questionnaire was relatively short (less than 15 minutes) and was able to be completed at the time and location of the participants choosing.

### Instrument Development

As the range of benefits teachers have experienced through a variety of interactions with science centers has not previously been explored in the research literature, an established questionnaire did not exist. Therefore, a new questionnaire was developed and is available in **Appendix A**. To inform the construction of the new questionnaire, McChesney and Aldridge's (2018) impact of teacher professional development (ITPD) Questionnaire was used. McChesney and Aldridge (2018) developed their ITPD questionnaire to evaluate teachers' perceptions of the ITPD. They intended the ITPD questionnaire would be a user-friendly instrument that would be able to be applied to a wide range of PD settings, as well as being theoretically grounded, time- and cost-effective and psychometrically sound (i.e., statistically reliable and valid). In validating their questionnaire, McChesney and Aldridge (2018) undertook a trial with 393 teachers to provide evidence to support the instrument's reliability and validity.

McChesney and Aldridge's (2018) final questionnaire consisted of 12 items, measured using a Likert-type 5-point scale: (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, (5) strongly agree. The items were categorized into four sections, consisting of teacher reaction, teacher learning, outcomes (related to the teacher as well as their students) and organizational response (school culture).

Several of the items on the ITPD questionnaire were adapted for this study to ensure the questions made sense in the context of the different types of interactions teachers may have with science centers. Additionally, as the ITPD questionnaire was initially developed to be used for PD programs that were conducted at a whole-school level, items specifically relating to the school's organizational response and school culture were removed. Instead, a question that explored whether teachers believed their colleagues had benefited from the teachers' interaction with a science center was included.

One of the gaps in the current research on science teachers' benefits from their interactions with science centers is an understanding of what teachers have learned. As the questionnaire items of the ITPD questionnaire explored whether teachers perceived they have learned 'new things', several additional questions in the style of the original ITPD questionnaire questions

were developed to further probe what teachers perceived they had learned.

As Evans (2014) describes attitudinal (affective) components of learning contributing to teachers' PD, several question items were added to capture teachers' motivation levels, feelings of capability and beliefs. Additionally, as this study was exploring an area that has not attracted much previous research attention, it was important to ensure that teachers were given the opportunity to elaborate on their responses if they wished to, in order to capture the widest range of experiences. Therefore, two multiple answer questions and two open questions were included at the end of the survey. The final set of questions were compared to Evans' (2014) components of learning that contribute to teachers' PD to ensure that a wide range of potential areas for PD had been included in the questionnaire.

For teachers who indicated they had not interacted with a science center, two multiple answer questions were included to explore if they had faced barriers in interacting with a science center and how they would like to interact with a science center if they were able.

A set of questions was also included at the beginning of the questionnaire to elicit information about teachers' demographics, including information about their current school, their initial teacher education and whether they had undertaken any additional science-related university studies. This was included to assist in determining if there were any demographic factors that influenced teachers' perceived benefits as well as allowing us to consider whether the survey population represented teachers with a range of experiences and backgrounds.

For teachers who indicated they had interacted with a science center, the maximum number of questions they could answer was 38. For teachers who had not interacted with a science center, the maximum number of questions presented was 15. The Qualtrics survey platform (https://www.qualtrics.com/) was used to deliver the questionnaire to participants. It was intended that the full questionnaire (of 38 items) would take 10-15 minutes to complete, with Qualtrics predicting the questionnaire would be 12.7 minutes in duration.

The questionnaire was trialed with six staff and postgraduate students at the researchers' institution. Several minor phrasing and formatting changes were made based on the feedback received to ensure the questions were clear and it was possible to complete the survey electronically on a range of devices. It took trial participants an average of 9 minutes to complete the full questionnaire (38 items). The final questionnaire used in the study is available in **Appendix A**.

## Data Collection

Data collection and analysis methods were approved by the institutional human research ethics committee before the research was conducted. Prior to prospective participants being able to answer the questionnaire, they were asked to read a plain language statement and to indicate whether they were providing informed consent. Only if participants provided informed consent were they able to progress to the questionnaire.

The questionnaire was administered online between October 2020 and January 2021, with the majority of respondents participating in November 2020. The target population for this study sample included school level (primary and secondary) science teachers from across Australia. A total of 71 responses were received. Of this group, 18 responses were removed as the respondents either did not meet the inclusion criteria of having taught science in Australia, did not indicate whether they had interacted with a science center, or did not complete all the Likert-type questions. Therefore, 53 responses were used in the final data analysis. Of the included 53 respondents, 43 participants indicated they had interacted with a science center, and 10 participants had not interacted with a science center.

In order to reach as many science teachers as possible (within the pandemic restrictions on educational research at the time in Australia), the questionnaire was initially advertised through Australian national and state science teacher associations' social media platforms and electronic communications. As organizations and individuals were able to share the digital advertisements within their own networks, it is not possible to state the total number of participants invited to participate. Participating in the questionnaire was voluntary and was not linked to any programs or incentives.

## Analysis

### *Quantitative data*

The collected quantitative data was analyzed using descriptive statistics (Onwuegbuzie & Combs, 2015) in IBM SPSS statistics (version 28), and charts were produced in Microsoft Excel. As the research question focused on exploring the range of benefits teachers may experience, and due to the small sample sizes, further statistical investigations were not undertaken.

### *Qualitative data*

There were 18 participants who chose to elaborate on their interactions by providing responses to either one or both of the open questions *"Have you experienced any other benefits from this interaction with a science center that you would like to describe?"* and/or *"Have you experienced any other benefits from a different interaction with a science center that you would like to describe?"*. This resulted in a total of 27 written comments.

The benefits that teachers described through these comments were initially coded by the first author using the question categories from the adapted ITPD

**Table 1.** Tertiary education of questionnaire participants (N = 53)

| Education sector training | Undergraduate science | | Science teaching method | |
|---|---|---|---|---|
| | Number | Percentage (%) | Number | Percentage (%) |
| Primary trained[a] (n = 16) | 2 | 13 | 10 | 63 |
| Secondary trained[b] (n = 28) | 25 | 89 | 26 | 93 |
| Primary and secondary trained (n = 9) | 4 | 44 | 4 | 44 |
| Total (N = 53) | 31 | 58 | 40 | 75 |

Note. [a]Equivalent to years F-6, generally ages 5-12 & [b]Equivalent to years 7-12, generally ages 13-18

**Table 2.** Subjects taught by questionnaire participants (N = 53)

| Subject | Participants | |
|---|---|---|
| | Number | Percentage (%) |
| Primary science | 24 | 45 |
| 7-10 general science | 32 | 60 |
| 7-10 elective/specialty science | 12 | 23 |
| Senior[a] biology | 18 | 34 |
| Senior[a] chemistry | 9 | 17 |
| Senior[a] earth and/or environmental science | 2 | 4 |
| Senior[a] physics | 7 | 13 |
| Senior[a] psychology | 2 | 4 |
| Other [text entry] | | |
| Computer science | 1 | 2 |

Note. [a]Typically years 11 and 12, the final two years of secondary schooling in Australia

questionnaire (McChesney & Aldridge, 2018). These codes included: teacher reaction, teacher learning, practice outcomes, student outcomes, and colleague outcomes. As some of these comments were lengthy, and often described multiple benefits or themes, it was necessary to employ multiple codes for some comments. Inductive coding (Hsieh & Shannon, 2018) was then used to describe two recurring benefit themes that were not a focus of the ITPD questionnaire (McChesney & Aldridge, 2018). The final wording for these two additional themes was: networking, and teachers' relationships with students. Additionally, comments that were unconnected to possible affordances of science centers were categorized under a 'not related' code. The second and third authors then independently applied the codes to the responses collected for one of the two open questions each. All three authors then discussed their categorizations and made minor changes to the coding guide until a consensus was reached. An example of the coding is included in **Appendix B**.

## RESULTS

The results are presented in three parts. The first part describes the demographics of the respondents, including information about their education and current school. The second part details the types of interactions teachers have had with science centers and the benefits they have experienced. The third part provides an account from those respondents who have not interacted with a science center about the barriers they have faced and what they would hope to access from a science center.

### Demographics and Educational Backgrounds of Participating Teachers

Of the 53 teachers who were included in the data analysis, 43 identified as female and 10 identified as male. The teachers had on average 10 years of teaching experience. Despite the survey being distributed through a national science teacher organization, the majority of participants were from the state of Victoria (n = 43) with only 10 participants teaching outside Victoria. It is thought this over-representation of Victorian participants is most likely due to the online survey advertisement being subsequently reshared by a Victoria-based science teacher organization. Teachers predominately taught in metropolitan schools (n = 38) with 15 teachers indicating they taught in regional schools, and no teachers selecting the remote location option.

The majority of teachers were secondary trained (n = 28) with 16 teachers indicating they were primary trained, and nine teachers indicating they were trained in both primary and secondary education. In Australia, although various models of teacher training exist, teachers are often able to select subject-specific teaching method units as part of their initial teacher qualifications such as science teaching methods (Treagust et al., 2015). The tertiary education of the questionnaire participants is outlined in **Table 1**.

Despite some teachers not having studied science in either their initial teacher education or through their other undergraduate university studies, all teachers in this study indicated they had taught a school-level science subject. The science subjects taught by the questionnaire participants are listed in **Table 2**.

**Table 3.** Details of science center interaction (N = 43)

| | Participants | |
|---|---|---|
| | Number | Percentage (%) |
| Number of visits | | |
| 1 | 3 | 7 |
| 2-5 | 16 | 37 |
| More than 5 | 24 | 56 |
| Type of science center | | |
| School-group specific science center (i.e., not generally publicly accessible) | 17 | 40 |
| Science museum[a] | 17 | 40 |
| Aquarium[a] | 1 | 2 |
| Zoo[a] | 5 | 12 |
| Online excursion[b] | 2 | 5 |
| Other [text entry] | | |
| Zoo, science museum, colonial sugar refinery | 1 | 2 |
| Main activity undertaken at science center | | |
| Accompanied a school excursion[b] | 28 | 67 |
| Attended a face-to-face PD | 9 | 21 |
| Accessed online resources | 2 | 5 |
| Other [text entry] | | |
| visited a science center as part of long term planning discussions | 1 | 2 |
| accompanied school incursion | 1 | 2 |
| gathered ideas and resources in person by myself | 1 | 2 |
| No response recorded | 1 | 2 |
| Main reason participant was involved in the interaction | | |
| I wanted to participant in it/I initiated it | 23 | 53 |
| I volunteered to participate | 5 | 12 |
| I was required to participate | 13 | 30 |
| Other [text entry] | | |
| Contributed to student learning | 1 | 2 |
| It was a great way for students to see the links between content and real life use | 1 | 2 |

Note. [a]In Australia, science museums, aquariums and zoos are generally publicly accessible; [b]Field trip; [c]Of the 13 teachers required to participate in their interaction, 12 teachers accompanied an excursion (field trip), highlighting the likelihood of confounding variables

### Teachers' Benefits From Their Interactions With a Science Center

Of the 53 questionnaire participants, 43 participants indicated they had interacted with a science center, with these details displayed in **Table 3**.

The majority of teachers who had interacted with a science center indicated they had had more than five visits to a science center. Considering that the average years of teaching experience was 10 years, this suggests that interactions with science centers are a relatively common occurrence.

Teachers' perceptions of their interactions with science centers were collected through questionnaire sections 6-8 (see **Appendix A** for full survey). Teachers' responses to the 5-point Likert-type questions (Section 6 and Section 7, total of 19 questions) with responses ranging from strongly agree to strongly disagree are presented in **Figure 1**. The questions are presented in order of the most positive response to the least positive response, measured as the combined percentage of teachers who answered "agree" and "strongly agree". For the 18 positively phrased Likert-type questions, the majority of teachers indicated a positive response of "agree" or "strongly agree" for 16 of these questions. Only two items had slightly less than a 50% positive response rate and they were "I felt more capable to teach science after this interaction." and "This interaction has been beneficial to the science teaching strategies (pedagogies) I use in my teaching.", which had positive response rates of 47% and 44%, respectively. Also, for the 18 positively phrased Likert-type questions, every teacher reported at least two answers of either "agree" or "strongly agree", highlighting that all teachers who participated in this study experienced at least some benefit from interacting with a science center. For the negatively phrased Likert-type question "I felt less confident to teach science after this interaction.", no teachers selected "agree" or "strongly agree" indicating that no teachers felt less confident to teach science after their interaction with a science center.

As the main type of interaction that teachers reported having with a science center was accompanying a field trip, and as the (incidental) benefits for teachers accompanying a field trip have been infrequently reported in the literature, the benefits reported by teachers specifically accompanying a field trip (N = 28) are reported in **Figure 2**. Although outcomes for students are usually the primary focus for conducting student field trips, 75% of teachers 'agreed' or 'strongly

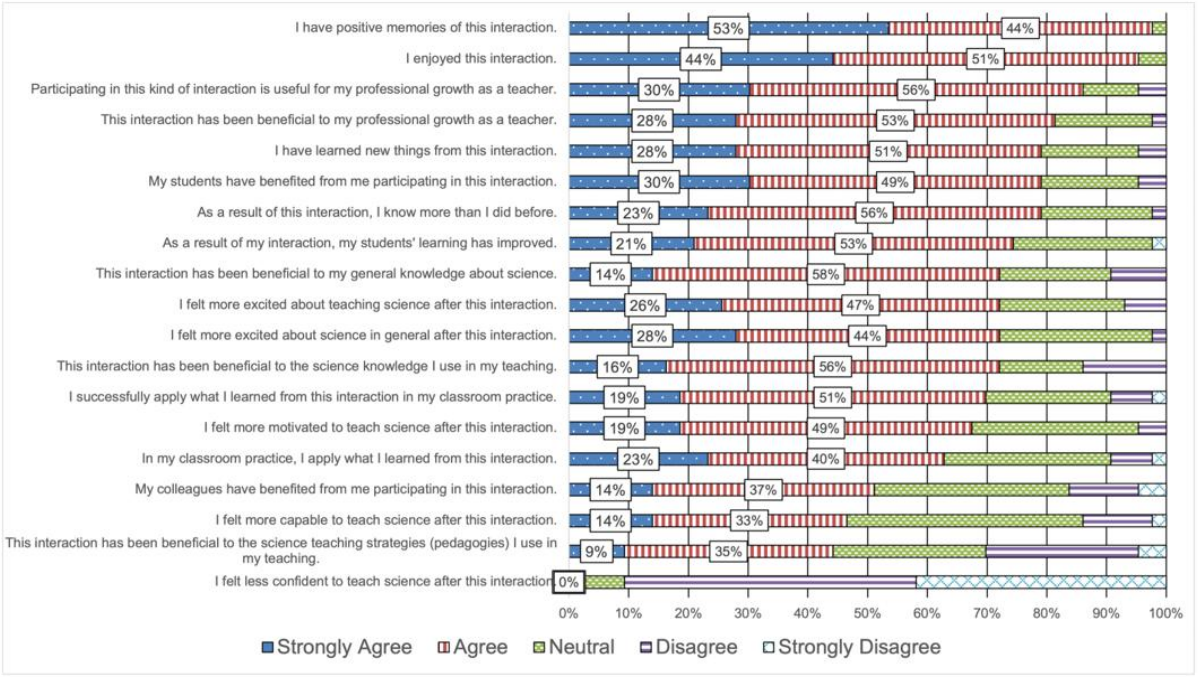


**Figure 1.** Likert-type item response rates by percentage of all teachers who had interacted with a science center (N = 43) (only percentages for 'strongly agree' and 'agree' are shown (the authors' own work)

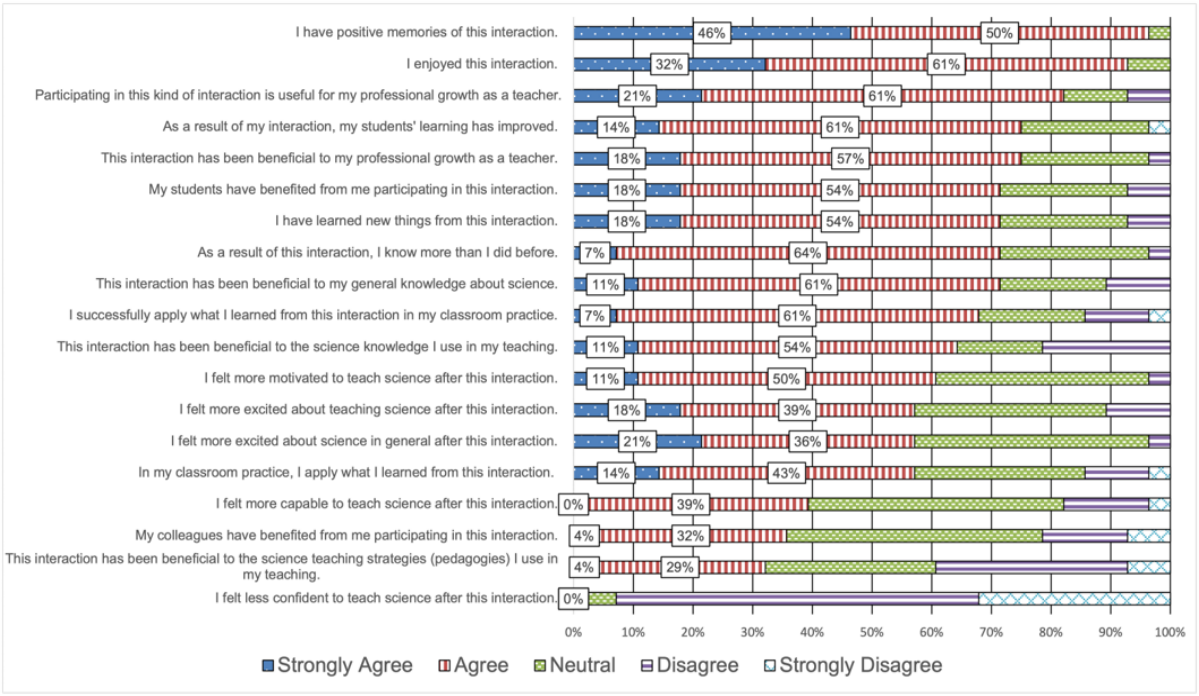


**Figure 2.** Likert-type item response rates by percentage of teachers who accompanied a field trip (N = 28) (only percentages for 'strongly agree' and 'agree' are shown) (the authors' own work)

agreed' with the statement "This interaction has been beneficial to my professional growth as a teacher.". For the remaining 17 positively phrased Likert-type questions, the majority of teachers indicated a positive response of "agree" or "strongly agree" for 14 of these questions.

**Table 4** depicts what teachers enjoyed about their interaction with a science center. The majority of teachers indicated they had enjoyed learning new information or skills, participating in learning activities or experiences themselves and listening to other science professionals. Considering that 29 teachers had accompanied a school field trip or incursion (an in-school program delivered by a science center), the majority of these teachers indicated they had enjoyed learning alongside their students.

**Table 4.** Responses to the question "What did you enjoy about your interaction with the science center? Select all that apply" (N = 43)

| What teachers enjoyed | Participants | |
|---|---|---|
| | Number | Percentage (%) |
| Learning new information or skills | 31 | 72 |
| Participating in learning activities or experiences myself | 26 | 60 |
| Listening to other science professionals | 23 | 53 |
| Learning alongside students | 19 | 44 |
| Exploring exhibits | 18 | 42 |
| Connecting with other science professionals | 17 | 40 |
| Connecting with other science teachers | 10 | 23 |
| Other [text entry] | | |
| Witnessing students [sic] enthusiasm | 1 | 2 |
| Sharing what I had learn [sic] with students as we explored the exhibits | 1 | 2 |
| Enjoyment, and seeing students enjoying and engaging in content | 1 | 2 |
| Seeing students interact with experiments/exhibits | 1 | 2 |
| I enjoyed the fact that my students were having a nice time | 1 | 2 |

**Table 5.** Responses to the question "What science knowledge and/or methods did you learn from this interaction? Select all that apply" (N = 43)

| What teachers learned | Participants | |
|---|---|---|
| | Number | Percentage (%) |
| Refreshed my memory of science content/concepts | 28 | 65 |
| Learned about some new contemporary science research | 15 | 35 |
| Learned about new science research methods/techniques | 14 | 33 |
| Refreshed my memory of science research methods/techniques | 11 | 26 |

Answers to the two open questions also reflected these findings. Teachers described the benefits of networking interactions at science centers including *"Building ongoing professional relationships with a group of people who were equally passionate …"*, *"Connection to science industry and science professionals"* and *"Connection to a community of teachers … and scientists"*. Teachers also highlighted numerous benefits they believed their students had experienced whilst participating in a field trip or incursion. These benefits mainly focused on affective outcomes for their students including *"… students benefited as the experience was 'fun'"*, *"Students were more motivated and engaged when participating in science based topics"* and that the experience *"Increased student motivation"*. Furthermore, two teachers elaborated on why they enjoyed accompanying their students on a field trip:

> Having the opportunity to interact with students in an informal setting (as the teacher but not doing the teaching) – this allowed more time to be spent in conversation with students to determine their understanding of the scientific content and build relationships with them.

> The main benefit of the trip [accompanying a student field trip] for me professionally however was strengthening relationships with students.

As this research aimed to build on past research to determine *what* new information or skills teachers learned, the question "What science knowledge and/or methods did you learn from this interaction?" was asked, and the results shown in **Table 5**.

In the two open questions, several teachers indicated the interactions had been beneficial to the science teaching strategies (pedagogies) they use such as learning: *"Best practice for modelling activities (e.g., of photosynthesis/respiration)"*, *"… a way to integrate sport and science"* and *"Learnt techniques to make science more relatable to students"*. Several teachers also mentioned that the interactions had provided them with a way to connect the science they were teaching with 'everyday' or 'real' life science: *"Learning how science is applicable to every day life."*, *"Provided and inspired more real world contexts to relate science content knowledge to"*, and *"Experiences such as these give me real life opportunities to tell my students about"*.

In general, the responses teachers gave to the open questions were lengthy – often involving multiple sentences and detailing multiple benefits. These responses not only added depth to the teachers' descriptions of the benefits they had experienced, they also conveyed a sense of value teachers placed in their experiences with science centers, for example:

> Trips to a science facility such as this really inspired. … They allowed the participants an opportunity to visit truly amazing science facilities ... I talk about these experiences with students and colleagues all the time. I am proud of seeing these things first hand, and I hope that

**Table 6.** Responses to the question "What barrier(s) have you faced in being able to access a science center? Select all that apply" (N = 8)

| Barrier | Participants | |
|---|---|---|
| | Number | Percentage (%) |
| Location | 4 | 50 |
| Cost | 4 | 50 |
| School staffing requirements | 4 | 50 |
| Lack of time | 3 | 37.5 |
| School leadership approval | 1 | 12.5 |
| Other [text entry] | | |
| New teacher, limited opportunity especially during COVID-19 | 1 | 12.5 |
| I did my degree overseas. | 1 | 12.5 |

**Table 7.** Responses to the question "Which ways would you like to interact with or access a science center? Select all that apply" (N = 8)

| Ways teachers would like to interact | Participants | |
|---|---|---|
| | Number | Percentage (%) |
| Access online resources | 6 | 75 |
| Access classroom materials and equipment | 6 | 75 |
| Attend in-person school excursion[a] | 6 | 75 |
| Attend in-person professional development/training | 4 | 50 |
| Attend online professional development/training | 4 | 50 |
| Access general science information | 2 | 25 |
| Access science educators | 2 | 25 |

Note. [a]Field trip

> my excitement in seeing these things carries across to others.

### Teachers Who Had Not Interacted With a Science Center

Ten teachers indicated they had not interacted with a science center. Of these teachers, eight teachers indicated they wanted to interact with a science center, and two teachers indicated they did not want to interact with a science center. All eight teachers who wanted to interact with a science center indicated they faced barriers in accessing these opportunities as outlined in **Table 6**. Teachers in both metropolitan and regional schools indicated location was a barrier to accessing science centers.

For the eight teachers who indicated they would like to interact with a science center in future, **Table 7** indicates the ways they would like to interact.

## DISCUSSION

This study investigated the professional growth benefits science teachers' experienced from interacting with science centers. Science centers in this study were defined to include out-of-school learning environments that offered educational programs to teachers and/or their students, including, but not limited to museums, purpose-built science centers, aquariums, and zoos (Friedman, 2010). This study was unique in that it explored both primary (elementary) and secondary teachers' experiences interacting with a diversity of science centers in a range of formal and informal ways including accompanying field trips and participating in formal PD programs. Additionally, using Evans' (2014) framework for PD and McChesney and Aldridge's (2018) ITPD questionnaire, a research instrument was developed and used that incorporated a range of areas for investigating aspects of professional growth including behavioral, attitudinal and intellectual components.

### Teachers' Perceived Professional Growth

Prior studies into teachers' experiences at science centers have mainly focused on investigating a few specific aspects of teacher professional growth (for example see Aaron Price & Chiu, 2018; Duran et al., 2009; Holliday et al., 2014a, 2014b; MacNabb et al., 2006; McKinnon & Lamberts, 2014; Melber & Cox-Petersen, 2005; Murcia & Pepper, 2018; Pickering et al., 2012). The current study confirms many of these prior findings and brings together the range of benefits teachers may experience through a single interaction with a science center. In addition, teachers were specific about the (intellectual) learning they had including learning new contemporary science research and new knowledge of science research methods and techniques (or refreshing their knowledge of these); changing the science teaching strategies (pedagogies) they used in teaching; as well as refreshing science content and concepts. Through the open questions, teachers also described that they learned how to connect the science they were teaching in their classroom with 'real life' or 'everyday' science, a finding also mentioned by Melber and Cox-Petersen (2005). This suggests that some teachers view some of the science

that they teach as being different or disconnected from science outside their classroom.

The importance of positively influencing affective components of science teachers' professional growth in addition to content and knowledge gains is emphasized by van Aalderen-Smeets and Walma van der Molen (2015) because it fosters teachers' self-efficacy beliefs, which in turn can support sustained changes in classroom practice. Prior research into how participating in PD through science centers affected teachers' attitudes towards science has shown differing results (Aaron Price & Chiu, 2018; Murcia & Pepper, 2018). In our study, primary and secondary science teachers reported a range of behavioral, attitudinal, and intellectual benefits to their professional growth from their prior interactions with science centers, regardless of whether they had a formal or informal interaction with a science center. More than 70% of teachers surveyed found the interactions beneficial to their professional growth, enjoyed their interactions, had learned new things and felt more excited about teaching science. Additionally, over 65% of teachers reported they felt more motivated to teach science and over 45% of teachers felt more capable of teaching science. Although the research methods and instruments of our study and those of Murcia and Pepper (2018) and Aaron Price and Chiu (2018) differed and could explain some of the variation in findings, our results highlight that science centers have the potential to positively influence a range of affective changes for science teachers as well as facilitating intellectual benefits.

Changes to teachers' classroom practices are often one of the goals of teacher PD (Clarke & Hollingsworth, 2002). Through the survey, 70% of teachers indicated they successfully apply what they had learned through their interaction with the science center in their classroom practice (**Figure 1**). This finding highlights the impact of their science center interaction on the behavioral aspects of teachers' professional growth, as well as the translation of learning from their interaction into their classrooms. Additionally, while outcomes for teachers were the primary focus of this study, 74% of teachers reported subsequent benefits for their students' learning due to the teachers' interaction with the science center (see **Figure 1**). As benefits for students are ultimately the goal of many PD activities, this finding demonstrates the potential of teachers' interactions with science centers to impact students.

### Informal Teacher Learning Whilst Accompanying Field Trips

Sharma (2016) determined that primary teachers informally learned a range of new science content knowledge when accompanying students on field trips to science centers. The current study confirms these findings and expands on them by identifying that when accompanying a field trip to a science center, more than half of both primary and secondary teachers learned a range of new science information as well as experienced a variety of affective benefits. These affective benefits included feeling more motivated and excited to teach science and feeling more excited about science in general. In addition, more than half of the teachers in the study also reported that they successfully apply what they learned from the science center interaction in their classroom practice, indicating behavioral professional growth. Sharma's (2016) study identified that teachers learned through communicating with science center staff, learning alongside students and observing their own students. The current study also ascertained that these were aspects teachers enjoyed when accompanying their students on field trips.

In the current study, teachers clearly valued their students' experiences on field trips. For example, despite the two open questions asking about the benefits that the teachers themselves had experienced, 12 of the 18 teachers who provided at least one response to the open questions described benefits they perceived their students had experienced when their students interacted with a science center. These benefits primarily focused on affective outcomes for their students. The focus on student outcomes was also seen in answers to the questionnaire item investigating "What teachers enjoyed about their interaction with a science center" (**Table 4**), where all five of the open-text responses indicated that the teachers enjoyed seeing their students participating and their students' reactions.

In response to the open question, two teachers described how the science center environment allowed them to interact with their students in a way that subsequently meant they were able to strengthen their relationships with their students. This finding echoed previously reported findings highlighting a unique feature of science centers, where teachers are able to observe, interact with and learn alongside their own students whilst the students are participating in science learning experiences led by other science educators and professionals (Luehmann & Markowitz, 2007; Sharma, 2016).

However, Sharma (2016) cautions promoting teachers accompanying student field trips to science centers as PD programs suggesting that expecting teachers to learn on such trips would destroy the "non-threating environment, where the [teacher's] primary focus is on their students" (2016, pp. 219-220) that enables teachers to learn. Whilst the current study is certainly not advocating that teachers should be additionally saddled with their own learning goals when accompanying school field trips to science centers, acknowledging that there may be a diverse range of professional growth opportunities and other benefits available to teachers may allow for the increased understanding and recognition of the important role of science centers, allowing for an improved utilization of

these resources. Future research could consider whether there are benefits or drawbacks for teachers having an awareness of the potential affordances of accompanying students on field trips to science centers.

### Barriers Teachers Faced

The eight teachers who had not interacted with a science center, yet wanted to, identified multiple barriers to their access. Whilst this is a small sample size and few generalizations can be drawn for the larger science teaching population, it is worth noting these reasons to form a broader understanding of the challenges teachers may face in accessing science centers. An unexpected finding was that location was identified as a barrier for teachers at metropolitan schools as well as regional schools, despite many science centers being located in metropolitan areas. All teachers who indicated that cost was a barrier, also indicated that school staffing requirements were a barrier and several teachers indicated time was a barrier.

### Limitations

A limitation in this study is the small sample size of teachers that participated, and that this sample is not representative of the broader Australian teaching population (especially considering the vast majority of respondents were from the state of Victoria). However, whilst the results cannot be generalized to the entire science teaching population in Australia the results do allow for a foundational understanding of the range of professional growth benefits that teachers have experienced through their past interactions with science centers to be developed, which expands on the previously reported literature in this field. This allows the study aim, of identifying the range of professional growth benefits teachers may experience through their interactions with science centers, to be achieved. Subsequently, the results of this study are still able to form an empirical justification for further research in this field to be conducted to understand if there are different groups of teachers that experience different professional growth benefits. The results of the present study, and the discussion would be useful for planning in situ, observational studies as it provides evidence that teachers can experience professional growth benefits through a variety of interactions with science centers, including through incidental learning. It also highlights the potential and varied role of science centers in the ongoing PD of science teachers.

Additionally, teachers self-reported their perceived benefits and the benefits they perceived their students had received, rather than using more objective methods such as pre- and post-testing. Therefore, future research in this field should be conducted in a way that is able to capture the outcomes of teachers and students more objectively, to complement this study. Notwithstanding these limitations, this study was able to achieve its proposed outcome of identifying a range of professional growth benefits teachers experience through their interactions with science centers.

It should also be noted that due to the small sample size, it is likely that not all benefits teachers experience through their interactions with science centers have been uncovered. Therefore, future research should consider larger sample sizes and being mindful that further professional growth benefits may be experienced by teachers.

## CONCLUSIONS

Our findings strengthen and expand on previously published research on the benefits of science teachers interacting with science centers. Our analysis highlighted that teachers across primary and secondary school sectors experience a range of professional growth outcomes and other benefits from formal and informal interactions with science centers, including incidental benefits when accompanying students on field trips. This is certainly not grounds for requiring teachers to interact with science centers, nor is it suggesting that teachers will always have benefits through interacting with science centers. This study is however recommending that science centers should be considered as sites for potentially meeting a range of teachers' affective and cognitive professional growth needs.

Teachers highly valued their experiences with these science centers and the unique features science centers offered, such as the ability to learn from other science professionals and learn alongside their own students. It is hoped staff in science centers are able to feel inspired and motivated by these findings as it is evidence that their programs and offerings have a broad-reaching impact. Science centers may also be able to use the outcomes of this study to consider which aspects of their own programs might benefit teachers and to highlight these features to teachers. From a research perspective, further investigations into how science centers contribute to benefits for teachers and the factors that affect these are needed to better understand the role of science centers in the complex and multi-faceted process of ongoing professional growth for in-service science teachers.

Ultimately, improving students' learning in science is the main goal of many PD programs. In this study, 74% of teachers reported subsequent benefits for their students' learning due to the teachers' interaction with the science center. Therefore, teachers' interactions with science centers should not only be valued for the impact they can have on teachers, but also for their potential benefits for students.

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## REFERENCES


Aaron Price, C., & Chiu, A. (2018). An experimental study of a museum-based, science PD programme's impact on teachers and their students. *International Journal of Science Education, 40*(9), 941-960. https://doi.org/10.1080/09500693.2018.1457816

Allen, R., & Sims, S. (2017). Improving science teacher retention: Do national STEM learning network professional development courses keep science teachers in the classroom? *Education Datalab*. https://cms.wellcome.org/sites/default/files/science-teacher-retention.pdf

Armstrong, P. (2021). 'You never stop learning on the job': Informal professional development among school business leaders in England. *Management in Education, 35*(2), 94-100. https://doi.org/10.1177/0892020620969897

Australian Government. (2022). The national teacher workforce action plan. *Department of Education*. https://www.education.gov.au/download/17364/national-teacher-workforce-action-plan-publication/35084/document/pdf

Beresford-Dey, M., & Holme, R. (2018). Optional assessment submission within Master's-level learning: Teachers' perceptions. *Professional Development in Education, 44*(3), 428-443. https://doi.org/10.1080/19415257.2017.1338186

Boylan, M., Coldwell, M., Maxwell, B., & Jordan, J. (2018). Rethinking models of professional learning as tools: A conceptual analysis to inform research and practice. *Professional Development in Education, 44*(1), 120-139. https://doi.org/10.1080/19415257.2017.1306789

Buchanan, J., Prescott, A., Schuck, S., Aubusson, P., Burke, P., & Louviere, J. (2013). Teacher retention and attrition: Views of early career teachers. *Australian Journal of Teacher Education, 38*(3). https://doi.org/10.14221/ajte.2013v38n3.9

Carver-Thomas, D., & Darling-Hammond, L. (2019). The trouble with teacher turnover: How teacher attrition affects students and schools. *Education Policy Analysis Archives, 27*, Article 36. https://doi.org/10.14507/epaa.27.3699

Chval, K., Abell, S., Pareja, E., Musikul, K., & Ritzka, G. (2008). Science and mathematics teachers' experiences, needs, and expectations regarding professional development. *Eurasia Journal of Mathematics, Science & Technology Education, 4*(1), 31-43. https://doi.org/10.12973/ejmste/75304

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education, 18*(8), 947-967. https://doi.org/10.1016/s0742-051x(02)00053-7

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.). Routledge. https://doi.org/10.4324/9781315456539

Committee on Science, Technology, Engineering, and Mathematics. (2024). Federal strategic plan for advancing stem education and cultivating stem talent. *U.S. National Science & Technology Council*. https://bidenwhitehouse.archives.gov/wp-content/uploads/2024/11/2024fedSTEMplan.pdf

Doecke, B., Parr, G., North, S., Gale, T., Long, M., Mitchell, J., Rennie, J., & Williams, J. (2008). *National mapping of teacher professional learning in Australia project. Final report*. Monash University. https://doi.org/10.13140/2.1.4204.1123

Duran, E., Ballone-Duran, L., Haney, J., & Beltyukova, S. (2009). The impact of a professional development program integrating informal science education on early childhood teachers' self-efficacy and beliefs about inquiry-based science teaching. *Journal of Elementary Science Education, 21*(4), 53-70. https://doi.org/10.1007/BF03182357

Evans, L. (2014). Leadership for professional development and learning: Enhancing our understanding of how teachers develop. *Cambridge Journal of Education, 44*(2), 179-198. https://doi.org/10.1080/0305764x.2013.860083

Friedman, A. J. (2010). The evolution of the science museum. *Physics Today, 63*(10), 45-51. https://doi.org/10.1063/1.3502548

Hoekstra, A., Beijaard, D., Brekelmans, M., & Korthagen, F. (2007). Experienced teachers' informal learning from classroom teaching. *Teachers and Teaching, 13*(2), 189-206. https://doi.org/10.1080/13540600601152546

Holliday, G. M., Lederman, J. S., & Lederman, N. G. (2014a). "Wow! Look at that!": Discourse as a means to improve teachers' science content learning in informal science institutions. *Journal of Science Teacher Education, 25*(8), 935-952. https://doi.org/10.1007/s10972-014-9409-9

Holliday, G. M., Lederman, N. G., & Lederman, J. S. (2014b). Comfort and content: Considerations for informal science professional development. *International Journal of Science Education, Part B, 4*(4), 356-375. https://doi.org/10.1080/21548455.2013.855834

Hsieh, H.-F., & Shannon, S. (2018). Content analysis. In B. B. Frey (Ed.), *The SAGE encyclopedia of educational research, measurement, and evaluation* (pp. 393-394).

Keller, M. M., Neumann, K., & Fischer, H. E. (2017). The impact of physics teachers' pedagogical content knowledge and motivation on students' achievement and interest. *Journal of Research in Science Teaching, 54*(5), 586-614. https://doi.org/10.1002/tea.21378

Kyndt, E., Gijbels, D., Grosemans, I., & Donche, V. (2016). Teachers' everyday professional development: Mapping informal learning activities, antecedents, and learning outcomes. *Review of Educational Research, 86*(4), 1111-1150. https://doi.org/10.3102/0034654315627864

Luehmann, A. L., & Markowitz, D. (2007). Science teachers' perceived benefits of an out-of-school enrichment programme: Identity needs and university affordances. *International Journal of Science Education, 29*(9), 1133-1161. https://doi.org/10.1080/09500690600944429

MacNabb, C., Schmitt, L., Michlin, M., Harris, I., Thomas, L., Chittendon, D., Ebner, T. J., & Dubinsky, J. M. (2006). Neuroscience in middle schools: A professional development and resource program that models inquiry-based strategies and engages teachers in classroom implementation. *CBE—Life Sciences Education, 5*(2), 144-157. https://doi.org/10.1187/cbe.05-08-0109

McChesney, K., & Aldridge, J. M. (2018). A new tool for practitioner-led evaluation of teacher professional development. *Teacher Development, 22*(3), 314-338. https://doi.org/10.1080/13664530.2017.1418418

McElearney, A., Murphy, C., & Radcliffe, D. (2019). Identifying teacher needs and preferences in accessing professional learning and support. *Professional Development in Education, 45*(3), 433-455. https://doi.org/10.1080/19415257.2018.1557241

McKinnon, M., & Lamberts, R. (2014). Influencing science teaching self-efficacy beliefs of primary school teachers: A longitudinal case study. *International Journal of Science Education, Part B, 4*(2), 172-194. https://doi.org/10.1080/21548455.2013.793432

McPherson, A., & Lampert, J. (2025). An analysis of Australian teacher workforce policy: Challenges and opportunities for teacher recruitment and retention. *Policy Futures in Education, 23*(2), 446-463. https://doi.org/10.1177/14782103241283106

Melber, L. M., & Cox-Petersen, A. M. (2005). Teacher professional development and informal learning environments: Investigating partnerships and possibilities. *Journal of Science Teacher Education, 16*, 103-120. https://doi.org/10.1007/s10972-005-2652-3

Murcia, K., & Pepper, C. (2018). Evaluating the social impact of a science center's STEM professional learning strategies for teachers. *Issues in Educational Research, 28*(2), 438-451.

O'Brien, J., & Jones, K. (2014). Professional learning or professional development? Or continuing professional learning and development? Changing terminology, policy and practice. *Professional Development in Education, 40*(5), 683-687. https://doi.org/10.1080/19415257.2014.960688

Onwuegbuzie, A. J., & Combs, J. P. (2015). Emergent data analysis techniques in mixed methods research: A synthesis. In A. Tashakkori, & C. Teddlie (Eds), *SAGE handbook of mixed methods in social & behavioral research* (pp. 397-430). SAGE.

Owens, D. C., Sadler, T. D., Murakami, C. D., & Tsai, C.-L. (2018). Teachers' views on and preferences for meeting their professional development needs in STEM. *School Science and Mathematics, 118*, 370-384. https://doi.org/10.1111/ssm.12306

Phillips, M., Finkelstein, D., & Wever-Frerichs, S. (2007). School site to museum floor: How informal science institutions work with schools. *International Journal of Science Education, 29*(12), 1489-1507. https://doi.org/10.1080/09500690701494084

Pickering, J., Ague, J. J., Rath, K. A., Heiser, D. M., & Sirch, J. N. (2012). Museum-based teacher professional development: Peabody fellows in earth science. *Journal of Geoscience Education, 60*(4), 337-349. https://doi.org/10.5408/11-241.1

Pineda, H., Lorca, A., Cortes, S., Gador, S., Mangompit, R. M., Pacaldo, F. J., & Lorca, E. (2022). Development and evaluation of a professional development program on designing participatory action research projects for basic education teachers. *Advanced Education, 21*, 161-184. https://doi.org/10.20535/2410-8286.266663

Rahimi, M., & Arnold, B. (2025). Understanding Australia's teacher shortage: The importance of psychosocial working conditions to turnover intentions. *The Australian Educational Researcher, 52*(1), 383-409. https://doi.org/10.1007/s13384-024-00720-5

Rennie, L. J. (2014). Learning science outside of school. In N. G. Lederman, & S. K. Abell (Eds.), *Handbook of research on science education* (vol. 2, pp. 120-144). Routledge.

Rennie, L. J., & McClafferty, T. (1995). Using visits to interactive science and technology centers, museums, aquaria, and zoos to promote learning in science. *Journal of Science Teacher Education, 6*(4), 175-185. https://doi.org/10.1007/BF02614639

Shaoan, M. M. R., Namanyane, T., Feng, M., & Arif, M. (2025). A systematic literature review on the importance of teacher recruitment and retention in global educational reform. *Frontiers in Education, 9*. https://doi.org/10.3389/feduc.2024.1447752

Sharma, S. (2016). *Incidental learners: Exploring primary school science teachers' learning during the science enrichment programmes at the Science Center Singapore* [PhD thesis, The Australian National University].

Smith, E., & White, P. (2024). Science for all? School science education policy and STEM skills shortages. *British Journal of Educational Studies, 72*(4), 397-424. https://doi.org/10.1080/00071005.2024.2322964

The Royal Society. (2020). Policy briefing on teachers of the sciences: Recruitment, retention and development. *The Royal Society*. https://royalsociety.org/-/media/policy/topics/education-skills/policy-briefing-on-teachers-of-the-sciences.pdf

Treagust, D. F., Won, M., Petersen, J., & Wynne, G. (2015). Science teacher education in Australia: Initiatives and challenges to improve the quality of teaching. *Journal of Science Teacher Education, 26*, 81-98. https://doi.org/10.1007/s10972-014-9410-3

van Aalderen-Smeets, S. I., & Walma van der Molen, J. H. (2015). Improving primary teachers' attitudes toward science by attitude-focused professional development. *Journal of Research in Science Teaching, 52*(5), 710-734. https://doi.org/10.1002/tea.21218

# APPENDIX A

**Appendix A** presents the questionnaire that was used in the study. At the end of the questionnaire, **Figure A1** depicts the logic details that were used in the online survey flow.

### Survey: How Do Science Centers Contribute to Teachers' Professional Growth?

#### *Legend*

[ ] survey logic and details – also see the diagram at the end of the survey for a flowchart of the survey logic

*compulsory questions

### Section 1: Plain Language Statement and Consent (1 Question)

#### *(Institute-approved) plain language statement*

1.1 Consent: Do you voluntarily consent to participate in this questionnaire, with the understanding that the purpose of this research is to investigate the role of science centers in influencing teachers' professional growth and that participation in this project is for research purposes only?*

*In this research teachers' professional growth refers to the wide range of changes that teachers experience throughout their career such as changes to knowledge, skills, beliefs and motivation.*

- I consent
- I do not consent [skip to end of survey]

### Section 2: Demographics and Employment Questions (7 Questions)

2.1 Are you teaching, or have you ever taught, science in a school in Australia*

- Yes
- No [skip to end of survey]

2.2 How many years have you been teaching? [text entry]

2.3 Select which sector of teaching you are trained in

- Primary
- Secondary
- Primary AND secondary
- Other (please specify) [text entry]

2.4 Which state/territory do you currently (or did you last) teach in?

- ACT
- NSW
- NT
- QLD
- SA
- TAS
- WA
- VIC

2.5 Which type of location is your current (or last) school in?

- Metropolitan
- Regional
- Remote
- Other [text entry]

2.6 What is your gender?

- Woman
- Man

- Non-binary
- Prefer not to disclose
- Prefer to self describe [text entry]

2.7 Which science subjects have you taught? *Select all that apply*

- Primary science
- Years 7-10 general science
- Years 7-10 elective/specialty science
- Senior biology (years 11-12)
- Senior chemistry (years 11-12)
- Senior earth and/or environmental science (years 11-12)
- Senior physics (years 11-12)
- Senior psychology (years 11-12)
- Other (please specify) [text entry]

### Section 3: Tertiary Education Questions (4 Questions)

3.1 Did you study a science teaching method (or any science disciplines) as part of your teaching qualification?

- Yes
- No

3.2 Have you undertaken any undergraduate science subjects? (i.e., outside of your teaching qualification)

- Yes
- No

[if 3.1 = yes]

3.3 Which science teaching method(s) did you study for your teaching qualification? *Select all that apply*

- 7-10 science
- General primary
- General primary with a primary science specialty
- Senior biology (year 11-12)
- Senior chemistry (year 11-12)
- Senior earth and/or environmental science (year 11-12)
- Senior physics (year 11-12)
- Senior psychology (year 11-12)
- Other (please specify) [text entry]

[if 3.2 = yes]

3.4 Which undergraduate science subject disciplines(s) did you study at university? *Select all that apply*

- Biology
- Chemistry
- Earth and/or environmental science
- Physics
- Psychology
- Other (please specify) [text entry]

### Section 4: General Science Center Questions (5 Questions)

For this research, science centers include out-of-school science settings such as science museums, school-specific science education centers, zoos, aquariums etc.

4.1 Have you interacted with a science center as part of your **in-service teaching?***

*These interactions might include accompanying school excursions, attending Professional Development (PD), and accessing online resources (such as lesson plans or videos) etc.*

- Yes [skip to 4.5]
- No

4.2 Have you wanted to interact with a science center?

- Yes
- No [skip to end of survey]

4.3 What barrier(s) have you faced in being able to access a science center? *Select all that apply*

- Location
- Cost
- School staffing requirements
- School leadership approval
- Lack of time
- Other (please describe) [text entry]

4.4 Which ways would you like to interact with or access a science center? *Select all that apply*

- Access online resources (such as lesson plans or videos)
- Access classroom materials and equipment
- Attend in-person professional development/training
- Attend online professional development/training
- Attend in-person school excursion
- Access general science information
- Access science educators
- Other (please describe) [text entry]

[skip to end of survey]

4.5 How many in-person visits have you had to a science center over your teaching career?

- 1
- 2-5
- More than 5

### Section 5: Specific Science Center Interaction Questions (3 Questions)

For the following questions, choose **one specific interaction** you have had with a science center and answer all the questions with respect to that interaction.

*If you have had more than one interaction with a science center, choose which interaction you found **most beneficial** to yourself and answer the questions thinking about that particular experience.*

5.1 Which type of science center did your interaction take place at?

- School-group specific science center (i.e., not generally publicly accessible
- Science museum
- Aquarium
- Zoo
- Other (please specify) [text entry]

5.2 What was the main activity you participated in during this interaction?

- Accompanied a school excursion
- Attended a face-to-face PD
- Attended an online PD
- Accessed online resources (e.g. lesson resources, science newsletter, videos)
- Other (please specify) [text entry]

5.3 Which of the following best describes your main reason for participating in this interaction?

- I wanted to participate in it/I initiated it
- I volunteered to participate
- I was required to participate
- Other (please specify) [text entry]

### Section 6: Adapted ITPDQ Questions (11 Questions)

For the **specific interaction** you had with a science center, select how much you agree or disagree with the following statements:

[Likert-type responses: strongly disagree, disagree, neutral, agree, strongly agree]

6.1 I have positive memories of this interaction.

6.2 I enjoyed this interaction.

6.3 This interaction has been beneficial to my professional growth as a teacher.

6.4 Participating in this kind of interaction is useful for my professional growth as a teacher.

6.5 As a result of this interaction, I know more than I did before.

6.6 I have learned new things from this interaction.

6.7 In my classroom practice, I apply what I learned from this interaction.

6.8 I successfully apply what I learned from this interaction in my classroom practice.

6.9 As a result of my interaction, my students' learning has improved.

6.10 My students have benefited from me participating in this interaction.

6.11 My colleagues have benefited from me participating in this interaction.

### Section 7: Additional Likert-Type Questions (8 Questions)

For the **specific interaction** you had with a science center, select how much you agree or disagree with the following statements:

[Likert-type responses: strongly disagree, disagree, neutral, agree, strongly agree]

7.1 This interaction has been beneficial to the **science knowledge** I use in my teaching.

7.2 This interaction has been beneficial to the **science teaching strategies (pedagogies)** I use in my teaching.

7.3 This interaction has been beneficial to my **general knowledge** about science.

7.4 I felt more excited about **science in general** after this interaction.

7.5 I felt more excited about **teaching science** after this interaction.

7.6 I felt more **capable to teach** science after this interaction.

7.7 I felt more **motivated to teach** science after this interaction.

7.8 I felt **less confident to teach** science after this interaction.

### Section 8: Further Details Questions (4 Questions)

8.1 What did you enjoy about your interaction with the science center? *Select all that apply*

- Connecting with other science teachers
- Connecting with other science professionals
- Learning new information or skills
- Learning alongside students
- Listening to other science professionals
- Exploring exhibits
- Participating in learning activities or experiments myself
- Other (please specify) [text entry]

8.2 What science knowledge and/or methods did you learn from this interaction? *Select all that apply*

- Learned about some new contemporary science research

- Refreshed my memory of science content/concepts
- Learned about new science research methods/techniques
- Refreshed my memory of science research methods/techniques
- Other (please specify) [text entry]

8.3 Have you experienced any other benefits from **this interaction** with a science center that you would like to describe?

*You can include benefits related to yourself, your students, your colleagues or your broader school community.*

[text entry]

8.4 Have you experienced any other benefits from **a different interaction** with a science center that you would like to describe?

*You can include benefits related to yourself, your students, your colleagues or your broader school community.*

[text entry]

**Closure and invitation for interview participation**

[end of survey]

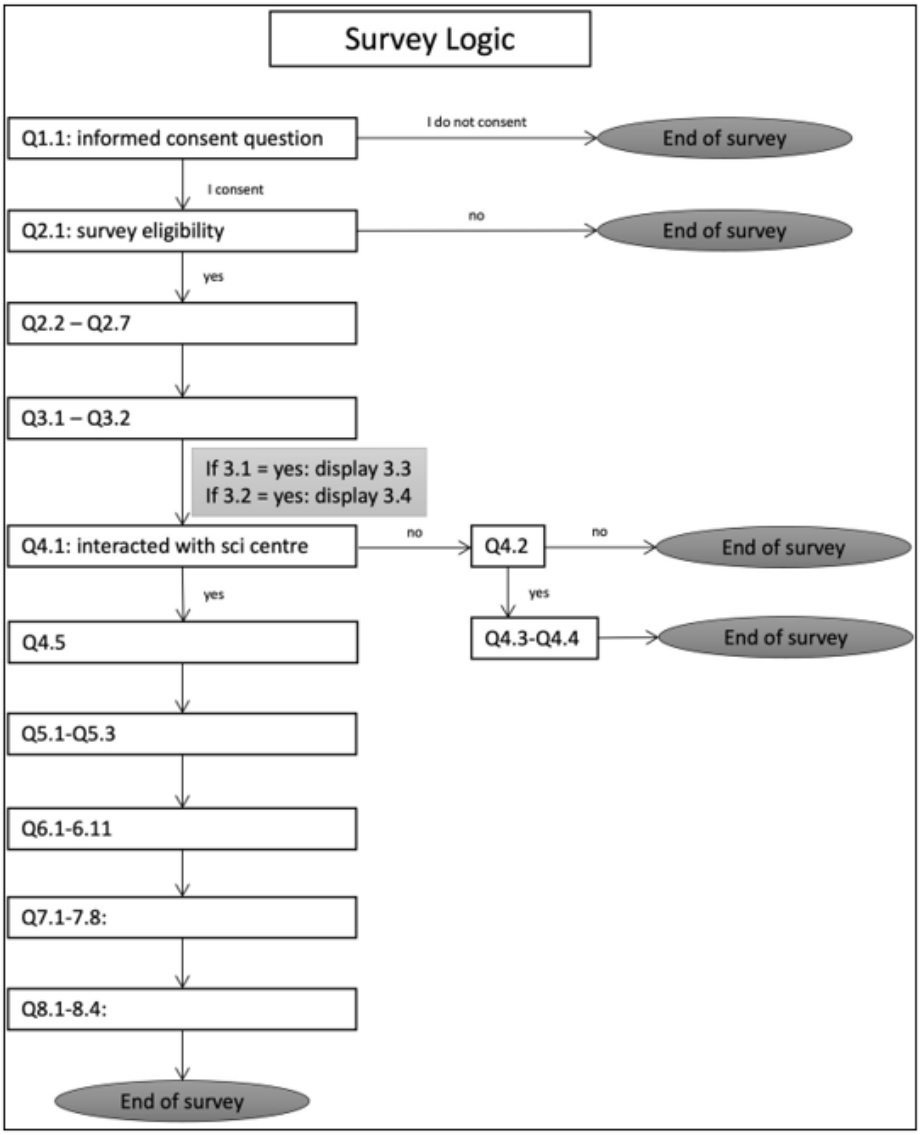


**Figure A1.** Survey logic diagram (the authors' own work)

## APPENDIX B

**Table B1.** Example coding for responses to the open questions

| Code | Description of code | Example of responses for this code |
|---|---|---|
| Teacher reaction | Participants mention their feelings, for example, their attitudes, values and level of excitement. | The benefits of this excursion for me were that I enjoyed resparking my own love of learning new things and science. And sharing this with students. |
| Teacher learning | Participants describe various types of knowledge teachers need to be able to teach. This includes knowledge about science as well as knowledge about teaching strategies. | Learnt techniques to make science more relatable to students |
| Practice outcomes | Participants refer to changes in how they go about teaching (including how they prepare to teach and their classroom practice) | Involvement in special events such as Science Week. Re-designing linked curriculum such as Social Studies and English to be more inquiry-based and science focused. |
| Student outcomes | Participants refer to benefits (any) for students | It is great to have students out of the classroom to witness real life experience of concepts learnt in the classroom. |
| Colleague outcomes | Participants refer to benefits (any) for colleagues | My colleagues … benefited as the experience was 'fun'. |
| Networking | Participants mention networking, collaborating or connecting with other people or organizations | Connection to science industry and science professionals |
| Teachers' relationships with students | Participants describe changes to their relationship(s) with their students | Having the opportunity to interact with students in an informal setting (as the teacher but not doing the teaching)- this allowed more time to be spent in conversation with students to determine their understanding of the scientific content and build relationships with them |
| Not related | Participants mention something that is unrelated to benefits of interacting with science centers. | I never knew it existed before I went there |