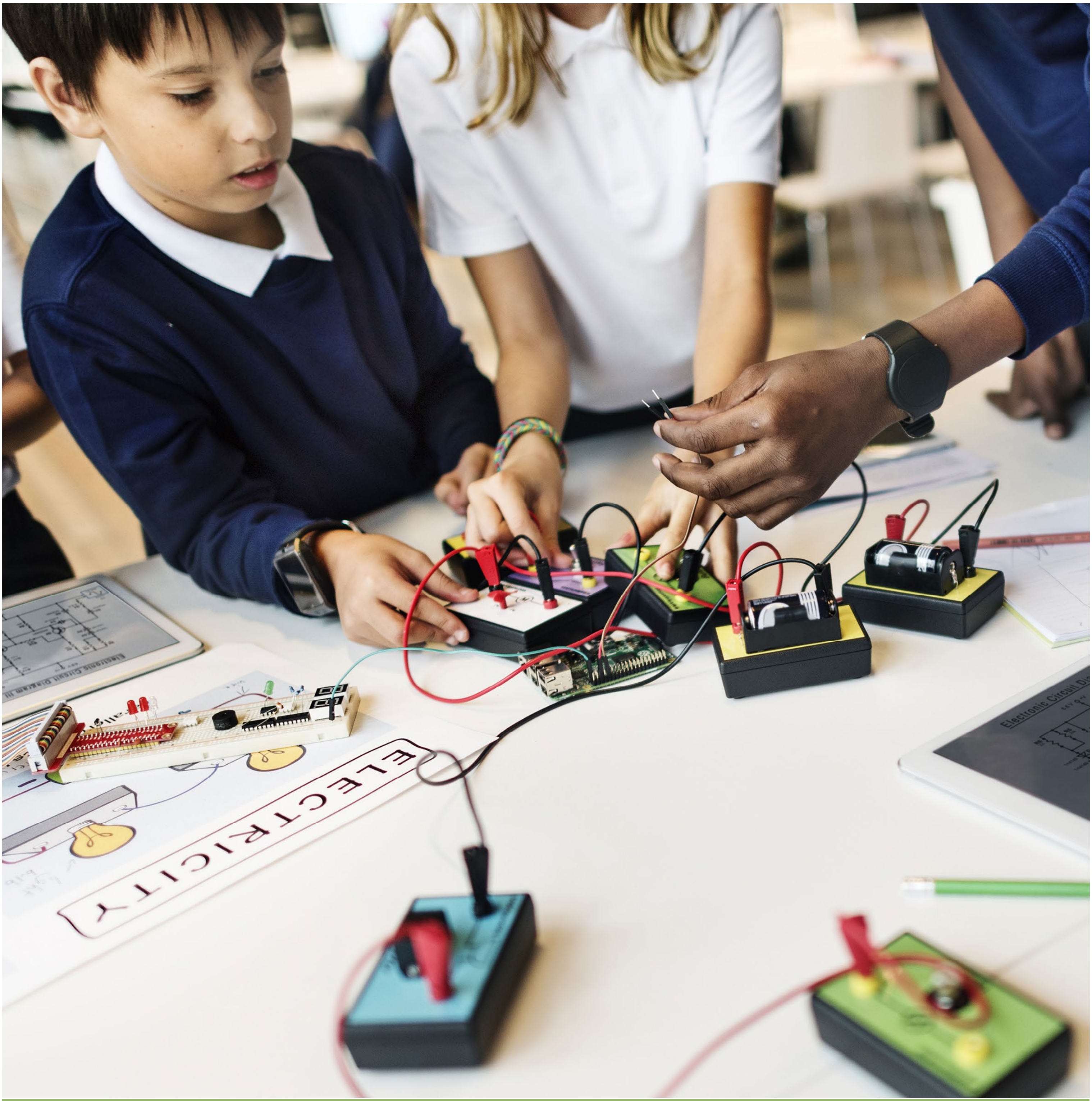

CASE STUDY REPORT

Quality Learning and Teaching in Primary Science and Technology

DECEMBER 2016

UTS
UNIVERSITY OF TECHNOLOGY SYDNEY

This study was commissioned by

ais nsw

RESEARCH TEAM

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SUGGESTED CITATION

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EXECUTIVE SUMMARY

This report presents findings from case studies conducted with six teachers in NSW independent primary schools who were identified by their principals as effective teachers of science and technology. The case studies were designed to illustrate different ways in which primary school teachers plan, implement and evaluate effective science and technology learning and teaching.

The case studies presented here are part of a comprehensive study designed to address the broad research question: *What characterises quality learning and teaching in primary science and technology?* This component of the research was further guided by four overarching questions:

1. What characterises effective primary science and technology teaching and learning?
2. How can teachers be supported and enabled to teach primary science and technology successfully?
3. How do effective primary science and technology teachers overcome barriers that are encountered in practice?
4. How do teachers and schools become effective at science and technology education?

The key findings relating to these guiding questions are summarised below.

WHAT CHARACTERISES EFFECTIVE SCIENCE AND TECHNOLOGY TEACHING?

EFFECTIVE PEDAGOGY

It is generally acknowledged that there are two types of pedagogical knowledge. General pedagogical knowledge includes knowledge of pedagogy applicable to teaching and learning, whereas pedagogical content knowledge (PCK) is specific to the discipline. For example, the pedagogy used in science may be different to that used in English. Findings of this research indicate that extensive PCK was present in each of the case study teachers' practice, but it was the teachers' extensive general pedagogical knowledge that was central to their effective teaching of science and technology.

Teachers involved in the case studies were able to describe the pedagogical frameworks that underpinned their teaching practices, could identify and attend to the learning needs of their students and were aware of students' conceptions. These teachers also displayed a diversity of teaching strategies and employed a variety of classroom activities. Discussion and questioning were widely utilised as teaching and learning techniques. Hands-on activities and investigations were preferred and used to build students' scientific knowledge and capabilities. Opportunities for students and teachers to ask questions and make mistakes in a supportive environment were capitalised on.

The teachers either had sufficient knowledge of the science and technology they were teaching, or acquired this as part of their lesson preparation. They often possessed the requisite knowledge to teach science and technology topics, and were undaunted by the prospect that some content they did not know might surface during lessons.

The teachers understood the content, guiding principles, and practices proposed and implied in the syllabus. They used the New South Wales Science K–10 (incorporating Science and Technology K–6) Syllabus extensively to inform their teaching preparation. Some planned activities by beginning with the syllabus; some came up with teaching ideas and then mapped these back to the syllabus; and others engaged in a programming dance between ideas that came to mind and ideas generated from the syllabus.

POSITIVE LEARNING ENVIRONMENT

Each of the teachers involved in the case studies fostered positive classroom interactions and relationships. They possessed and exhibited positive dispositions towards science and technology, and strove to create a science-rich/science-friendly environment in the classroom. The teachers argued that effective science and technology learning could be accomplished by using everyday materials and that specialised equipment was not required, or even desirable, in the primary context.

EMPHASIS ON STUDENT INQUIRY

Each of the case study teachers used principles of inquiry based learning to provide students with learning opportunities that were challenging and authentic. The teachers took advantage of teachable moments as they arose during science and technology lessons. To varying degrees, they had the flexibility to take advantage of unplanned events, as well as questions or ideas students raised, to promote exploration and investigation during lessons. The teachers spent time finding out what the students already knew and routinely linked inquiry activities to their real life needs and experiences.

HOW CAN TEACHERS BE SUPPORTED?

The case study teachers noted that they had benefited from professional learning opportunities, some within school and others which were offered externally. They commented favourably on the support they received from leaders in the school — typically the principal — and identified this as being important in enabling them to teach science and technology well.

Connections to the community were also a helpful means for supporting student learning. The teachers used various opportunities to connect learning experiences with local communities. For example, they invited parents with relevant expertise to contribute to the learning experiences of students, and created links with secondary school science departments, universities and industry to enhance the pool of scientific expertise within their schools.

HOW DO TEACHERS OVERCOME BARRIERS?

Teachers commented on the barriers that they thought other teachers may encounter when teaching science and technology, for example, ineffective leadership or inadequate resources. These teachers claimed that they did not experience these particular barriers within their own environments. However, they did comment on other barriers, such as school arrangements of timing and scheduling, that affected them.

These teachers' strong commitment to science and technology, combined with their expertise and passion, allowed them to teach science and technology well in primary classes. Although they were aware that barriers exist, these were perceived to be minimal in their own contexts and did not appear to inhibit or prevent them from teaching science and technology effectively.

HOW DO TEACHERS AND SCHOOLS BECOME MORE EFFECTIVE AT TEACHING SCIENCE AND TECHNOLOGY?

The propensity of case study teachers to explore and develop their skills as science and technology teachers was a key feature leading to their proficiency in teaching this subject. These teachers actively engaged with science and technology — they started clubs and organised activities within their schools, and sought professional learning opportunities. They worked in school environments where risk taking was encouraged and the executive staff supported science and technology education. These factors allowed the teachers to flourish and often fill the role of science and technology champion in their school.

IMPLICATIONS OF ALTERNATIVE STAFFING MODELS FOR SCIENCE AND TECHNOLOGY

The case studies suggest that generalist teachers are more than capable of providing quality science and technology education in their own classes. Specialist science and technology teachers can also contribute to effective teaching and learning for students across their primary school. The case studies provide no single path for schools to follow. It should be remembered, however, that all of the teachers in the case studies were considered to be effective by their recommending principals, and this report should be read accordingly.

RECOMMENDATIONS

The following recommendations draw on both the Quality Learning and Teaching in Primary Science Education Literature Review (Aubusson, P., Schuck, S., Ng, W., Burke, P. & Pressick-Kilborn, K., 2015) and the case studies.

It is recommended that teachers:

1. emphasise inquiry based approaches when teaching science and technology
2. employ tools to gather data on the extent of inquiry based teaching and learning in their classes
3. reflect on their overarching pedagogy of science and technology and consider how to imbue it with their own professional and personal values and beliefs
4. embrace opportunities to learn with their students in science and technology
5. display an enthusiasm for science and technology.

It is recommended that schools conduct analyses focused on:

1. gathering information on the extent and richness of inquiry in science and technology teaching and learning. This will provide teachers with evidence as a basis for collaborative reflection on practice and guide development in science and technology. A variety of tools could be used to support this and, if combined with data analytics, would provide baseline and iterative data for teams of teachers to use to target actions that enhance practice
2. teachers' science and technology pedagogical capability. If required, schools could facilitate sustained collaborative professional learning targeting identified needs. The professional learning could be part of the schools' existing professional learning processes, which may include creating opportunities for peer observation of practice
3. the organisational arrangements for science and technology. If required, schools could optimise the scheduling and timing of science and technology lessons
4. leadership support for science and technology. If required, schools could provide additional support for the teaching of primary science and technology such as resources, professional learning, and emphasising science and technology in the school curriculum
5. connections with the community. If required, schools could implement strategies to engage with their communities in communicating about science and technology, as well as drawing on expertise in the community to enhance science and technology
6. the potential advantages of developing a science and technology champion to advocate for primary science and technology education throughout the school.


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INTRODUCTION

This report presents findings from six case studies involving teachers who were identified by their school principal for effectiveness in primary science and technology teaching. The findings presented are part of a comprehensive study designed to address the broad research question: *What characterises quality teaching and learning in primary science and technology?* where quality is indicated by effective teaching that engages students to learn successfully. These case studies were conducted in NSW independent schools where the Science K–10 (incorporating Science and Technology K–6) Syllabus is used.

The Quality Learning and Teaching in Primary Science Education Literature Review (Aubusson et al., 2015) conducted during the first phase of this study identified the following features as characterising quality science and technology teaching and learning:

- an emphasis on student inquiry
- the use of starter activities that arouse and engage students in investigations
- the identification of real needs or problems and investigations of ways of resolving these problems
- the promotion of student questioning
- the exploration of ideas, development of designs, creation of products
- the sharing and subjecting of designs and ideas to scrutiny through evidence based discussions and in trial by experiment
- opportunities to fail and try again
- the support of ways to search for information and find out what is already known
- engagement in authentic activities
- making connections to students' life experiences
- the display and presentation of products of learning and design
- the use of formative assessment to diagnose needs and inform iterative changes to planned learning sequences
- students creating and analysing their own representations and analysing standard technological and scientific representations
- the exploitation of teachable moments for explicit teaching of science and technology principles, skills and processes
- the employment of summative assessment to gather evidence of learning achievements
- the use of a variety of strategies to communicate ideas with a range of audiences
- the use of digital technologies to enhance learning
- opportunities to connect learning experiences with local communities.

For more information, see the Quality Learning and Teaching in Primary Science and Technology Literature Review (Aubusson et al., 2015) commissioned by the Association of Independent Schools of NSW and produced by science and technology teacher education experts from the University of Technology Sydney.

Following the Literature Review and Case Study phases of this research, two additional studies have been conducted to shed further light on barriers and enablers to effective teaching and learning in science and technology. Reports from these (Barriers to the Effective Teaching of Primary Science and Technology: Report on Best-Worst Scaling (BWS), and Supporting the Effective Teaching of Primary Science and Technology: A Discrete Choice Experiment (DCE) Approach), along with final conclusions from the study as a whole, will be available in early 2017.

METHODOLOGY

The case studies that were conducted focused on the question of what constitutes effective science and technology teaching, and investigated it where it is practised — NSW independent primary school classrooms. Being influenced by Grounded Theory (Glaser, 1992; Glaser & Strauss, 1967), the characteristics of good science and technology teaching were not set in advance by the research team. Instead, the case studies were an opportunity to gather data to identify effective science and technology teaching practices, and the principles guiding them. In this way, features of effective science and technology teaching could surface from the data, rather than being presupposed in advance.

RATIONALE

Case study approaches are particularly well-suited to providing rich and deep information about a specific area of interest. They allow investigators to examine a phenomenon like science and technology teaching and learning in the real world setting in which it takes place (Bassey, 1999; Stake, 2003). The rich data case studies often generate provide examples of behaviours and activities that explain actions, practices, and processes where they occur (Cohen, Manion & Morrison, 2013). In a case study of science and technology teaching and learning a wide range of data need to be collected, including the contexts that impinge, promote or inhibit the teaching and learning; descriptions of events that occur in classes; and the reasoning that underpins the ways teachers go about their work. A number of qualitative, interpretive methods were then employed to analyse this data. The results of these analyses help to understand and report the cases in ways that capture the perspectives of teachers (Cohen et al., 2013; Yin, 2003).

The specific case study approach taken in this study can be described as a multiple (Stake, 2003) or collective case study (Yin, 2003). Here, a number of cases were selected and investigated, both individually and as a group, so as to provide insights into the complexities of effective teaching and learning as a practice. This multiple or collective case study approach provides an opportunity to see the phenomenon of effective science and technology teaching in a variety of contexts while also providing a holistic view of the practices of the group of participants. From this holistic view more general conclusions can then be drawn.

The principles of participatory research also inform these case studies. The aim of participatory research is to make the knowledge generated by the research more relevant to practitioners in the field. It does this by focusing on the teachers and positioning them as experts with extensive experiential understanding of their context and practices (Park, 2006). Participant and researcher interact, allowing things to be seen from the perspective of the participant. This interaction also facilitates a reflection on teacher practice, enabling both participant and researcher to see things more clearly and in ways that create new knowledge and understanding of the area being investigated (Atin, 2015; Heron & Reason, 2006).

Participatory inquiry also provides a means for participants to contribute to a variety of aspects of the research process (Heron & Reason, 2006). In this study the broad research agenda was set prior to the start of the research, but other elements of the case studies were discussed and negotiated with participants.

Agency is another typical characteristic of participatory research. In these cases each participant was invited to act as an agent on behalf of primary school teachers in independent school contexts, to provide insights into effective science and technology teaching and learning.

RESEARCH QUESTION

The broad, overarching question guiding the larger research project was: *How can teachers and schools build effective practice, rich learning experiences and improved learning outcomes for students in primary science and technology?* This was investigated by seeking answers to the research question: *What characterises quality learning and teaching in primary science and technology?* The case study research component of this project was guided by this question and was designed to illustrate different ways in which primary school teachers plan, implement and assess students’ learning in effective science and technology programs.

PARTICIPANT RECRUITMENT AND SELECTION

Recruitment of potential participants was undertaken by AISNSW. Principals were invited to identify and nominate teachers they considered to be effective practitioners in the teaching of primary science and technology. Nominations were received and six teachers were invited by the University of Technology Sydney (UTS) research team to engage in participatory case studies in Term 3 of 2015.

Ethics approval for the research was provided by the UTS Human Research Ethics Committee.

The six teachers selected varied in their teaching experience, both in terms of prior experiences and current teaching contexts. Three were primary generalist classroom teachers, and three were specialist primary science and technology teachers. Three were from co-educational schools, two from girls' schools, and one from a boys' school. Five of the schools were located in metropolitan Sydney, while the other was outside of Sydney. The schools varied in terms of science and technology resourcing, ranging from a dedicated primary science laboratory with specialised equipment to regular classrooms with everyday, inexpensive materials gathered by the teacher.

DATA COLLECTION

At the start of the case studies, participating teachers were provided with a set of questions to guide them in collecting the relevant data. The suitability of the four guiding questions was confirmed with the research participants and the AISNSW partners prior to the case studies getting under way. These were:

1. What characterises effective primary science and technology teaching and learning?
2. How can teachers be supported and enabled to teach primary science and technology successfully?
3. How do effective primary science and technology teachers overcome barriers that are encountered in practice?
4. How do teachers and schools become effective at science and technology education?

Each case study teacher worked with a member of the research team to identify methods that would be suitable in providing insights into their own practice. Strategies for gathering evidence and incorporating student voice included the collection of:

- annotated programs and/or units of work
- teacher written reflections on lessons, and email updates sent to the research team member during the term
- photographs/short video clips of students engaging in science and technology learning
- student work samples
- photographs of classroom displays
- photographs/short videos taken by students explaining what they were learning and what was important to them in their learning
- students or teachers interviewing students about their experiences of learning — what did the student like about a lesson/activity/unit? What did they learn?

In addition to gathering evidence themselves, each teacher nominated one regular science and technology lesson to share with an observer from the research team. They also participated in two one-hour interviews — one at the start of Term 3 and another after the lesson observation. The first semi-structured interview focused on the four guiding questions of the case study, and provided an opportunity to negotiate the methods for collecting data, and generate rapport between the teacher and the research team member. The second semi-structured interview was guided by the following questions:

1. What were you trying to achieve in this lesson?
2. Was this science and technology lesson typical of your lessons in this area? Why or why not?
3. Did you feel this lesson was successful — what characteristics helped you decide this?
4. What support is helpful in your teaching of science and technology?

5. What has hindered your teaching of science and technology? If there were problems, how did you overcome them?
6. Is there anything you think I really need to know that has not has not come up?

In Term 4, five of the six case study teachers participated in a day of professional exchange held at UTS to discuss science and technology teaching and learning with one another, members of the UTS research team, and a representative from AISNSW. In addition to making short presentations on their science and technology teaching, they participated in a focus group discussion guided by the research questions above. They also advised on the interpretation of data collected and made recommendations on the format each case study should take. Interviews and focus groups were audio recorded. Participant teachers also contributed to the writing up of their case studies, providing feedback on drafts.

DATA ANALYSIS

Data analysis was a two phase process, combining qualitative description and interpretive analysis (Sandelowski, 2000). The qualitative description phase provided a comprehensive summary of the events and views of participants. Field notes, audio/video recordings and photographs taken during each lesson observations, along with feedback from each teacher, were integral in this process, guiding the reporting of the lesson(s) in each case study. The aim was to describe science and technology teaching and learning holistically. Artefacts (for example, photographs, recordings, programs) provided evidence of the teaching and learning that had been identified by the teachers as good practice. The descriptions that resulted from this process are used to describe each case study and foreground the perspectives of the teacher participants.

The second phase of interpretive analysis focused on interpreting the data, and was guided by the case study research questions. This analysis identified themes across the data. The themes that emerged were:

- teaching and learning context
- nature of unit design and lessons taught
- assessment
- enablers of and barriers to quality science and technology teaching
- advice for colleagues.

The final case study report is organised around these themes, and includes elaborations from individual cases based on the initial qualitative description.

REPORTING

A key objective of the research process was to make each case study report accessible to the target audience, namely educators. To ensure this, case study drafts were written and returned to individual participant teachers for feedback, comments and approval. Five followed the negotiated format, while one preferred to modify it to include a variety of teaching and learning episodes, rather than focus on a single lesson (Case Study 5). Having discussed revisions with the case study teachers to ensure that these accurately reflect their teaching, principals were then asked to confirm that these were consistent with their understanding of the teachers' practice.

In this report each of the six case studies is described, including the context, the lesson or lessons taught, and the enablers of and barriers to effective science and technology teaching. Literature Link boxes are used to indicate where teachers demonstrate characteristics of good practice as identified in the Quality Learning and Teaching in Primary Science and Technology Literature Review (Aubusson et al., 2015). Participating teachers also provide advice for others in the form of Tips for Teachers, which can be found at the end of each case. In some instances, these tips extend beyond what may have been observed in the individual lessons. The report then concludes with a discussion summarising the main features of effective science and technology teaching and learning evident in these case studies.

CASE STUDY 1: YEAR 1 MERMAID SHOW

CONTEXT

THE SCHOOL

The school is an independent girls' school in metropolitan Sydney. It has appoximately 1200 students Preschool to Year 12. The model that this school uses for teaching primary science and technology is one where a specialist science teacher team-teaches with classroom teachers.

THE TEACHER

Amy was a high school science teacher for 18 years. When her own children were young she undertook casual teaching in primary schools, which helped her to identify an interest in teaching younger learners. Amy soon returned to a permanent job as a high school science teacher where she began to specialise in teaching middle school students. After a few years, Amy became aware of a new role at a school at which she had previously taught — as a specialist science teacher in their primary school. Amy was thrilled at the opportunity to combine her love of teaching both science and young children so when offered the job she was eager to accept. Amy has been in this role for several years now and teaches science to Years K–6 as well as promoting school-wide science projects.

"It is a team thing to teach science." Amy

In this specialist science teacher role, Amy co-teaches with the classroom teachers. She develops the ideas for the units in consultation with the classroom teachers and takes the lead in teaching the lessons. The classroom teacher supplements these lessons, often by preparing summaries of the work completed or additional learning to further develop the students' understanding of science and technology. The classroom teacher also follows up the concepts covered with other activities when back in the classroom.

THE TEACHING SPACE

Amy has a designated space to teach science but this is currently shared with after-school care, meaning all resources must be packed away at the end of each day. Amy also conducts some lessons in the year groups' classrooms.

THE LET'S MAKE A MERMAID SHOW UNIT

The idea for the science unit being taught to Year 1 came from a book about mermaids that the class was studying for English. The context for the unit was the production of a mermaid show for the end of the year. Students were investigating where the show should be held and what needed to be considered in putting on such a show.

The students had already investigated high and low sounds in relation to using instruments in the show. They had also considered how well light travels in water using a prawning torch and a light meter. They measured the light and found that the measurement was low in water and higher in air, indicating light did not travel as well in water as it did in air.

This led to them to investigate whether water was the best place for the mermaid show. For this test, students went to a swimming pool and mermaid Mary (a pool assistant) went into the pool to help investigate light, sound and movement in water. The students discovered that the show could not take place in the pool because the audience would not be able to see or hear it well.

THE SYLLABUS

The mermaid unit links to Science K–10 (incorporating Science and Technology K–6) Syllabus Stage 1, Physical World, Material World and Built Environment, and integrates science and technology.

Amy stressed the importance of first thinking of an authentic context that has personal relevance for the students. She thinks that classroom teachers find it advantageous if the context is identified first. Amy advised that she generates ideas for an engaging topic and lesson sequence first, then tests them for applicability to the syllabus. She said this means that the science and technology learning is situated in contexts relevant to students, fits with the other work they are doing and is well integrated with learning in other key learning areas.

Literature Link: It is important to support students to be engaged in authentic activities and make connections to their own life experiences.

THE LESSON

LIGHTING FOR THE MERMAID SHOW

The lesson described here was about half way through the term-long unit. Having decided that they needed to have the show in the theatre area (not in the pool), students were told they needed to design the lighting for the show. They were given torches and instructed to find a surface (cupboard, desk) to complete a set of activities and describe what they saw.

Students were required to shine a torch up close and then far away and write a description of what they saw using whatever words were meaningful to them. They were also given different black covers to place over the end of the torch — one with a small hole and others with different shaped holes. In addition, they were given red, blue and yellow cellophane to experiment with and had to investigate how to use the coloured cellophanes to make the light green.

The idea for the lesson was to relate it back to the theatre and mermaids, and for the students to investigate how they wanted to light their show. Amy believes it is important to use equipment that is relevant to a child's life and so rarely uses science equipment like light boxes. She believes this and other specialised scientific equipment can be introduced when the students are older, particularly when in high school.

LESSON STRUCTURE

The lesson commenced with a recap of the previous lesson in which students had visited the school's swimming pool to decide where to hold their show.

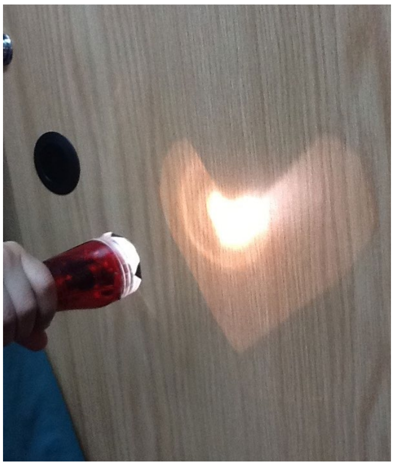
The students were asked to suggest how the stage could be made to look like the sea. Some recommendations were to use a blue mat, blurred light, cut out cardboard and colour. One student suggested using a mirror to reflect the blue carpet.

"We have learned it's better off having the show on land and pretending them (the mermaids) to be in the water. We made high sounds and low sounds — who remembers doing that? We also learned about different sounds for the mermaid show." Amy

THE LESSON IS OUTLINED TO STUDENTS

Amy demonstrated each of the seven experiments that the students were to conduct. She shone a torch on a cupboard and asked the students to describe what they saw. They replied: "It's small, "It's a little circle," and "When it's close, it's more light." Amy moved the torch back and forth and the students noted whether the lighted shape was clear or blurry. Amy explained that they were only going to change one thing at a time and used the term fair test.

Students investigate light



"I've got some torches. There are some interesting things we are going to learn today by doing experiments. I am first going to show you what we're going to do and then we are going to do them." Amy

STUDENTS ARE GIVEN TIME TO EXPLORE

Students collected resources, including a worksheet describing the experiments, and investigated light using the torch. They excitedly conducted the experiments and noted their results on the worksheet with assistance from the classroom teacher and Amy. Ample time was provided to complete the tasks.

Literature Link: Students need time to explore, and opportunities to fail and try again. It takes time for them to obtain more data if the current data are insufficient.

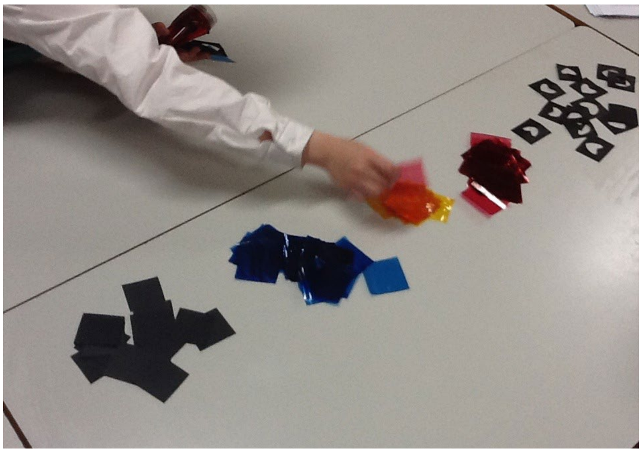
STUDENTS SHARED THEIR RESULTS AND DEVELOPED SHARED MEANING

Students assembled and a group discussion was led by the classroom teacher. The teacher chose students to read out the responses they had recorded on a worksheet and students related the findings back to the context of the show.

The students discussed what they would see if they shone the light on the mermaid's face or on the whole stage. The teacher introduced the term spotlight. Using characters she had drawn on the whiteboard, Amy asked students what light would be appropriate for each. The students agreed that "far away light" would be best. The classroom teacher then used an example from a recent concert to explain that the lighting needed to change during the show to highlight different features.

The students then discussed coloured light and the problem of making green light when only red, yellow and blue cellophane were provided. The students suggested to the teacher that if they overlapped the blue and yellow they could make green.

A range of materials are provided to explore



Based on what they had done with the coloured cellophane, the classroom teacher asked: "If we had the blue and the yellow lights, would [the stage manager] need to buy a green light?" The students were unsure and decided to ask the stage manager at the theatre to show them what lights he had. Thus, the students wanted to seek further information from real world contexts to inform their prediction.

Literature Link: Promotion of student questioning is important in supporting ways to search for information and find out what is already known. The openness or closedness of a teaching and learning experience can be linked to the kinds of questions that drive it.

STUDENTS LEARN FROM REAL LIFE EXPERIENCES

After the lesson, Amy told the students that they would have more lessons on light, including one investigating people who do not have light in their lives, and how they might use braille. Students were next going to investigate what else they could incorporate into the show for people who cannot see. The other topic Amy linked the work to was the need for lighting in dark areas for those who have sight. She linked this to the importance of light for the production (safety lights on steps). She said that she would also introduce the idea that when lighting is poor, people need to use other senses. These activities were designed to connect the students' learning to the real world.

ASSESSING LEARNING

Recordings on worksheets and a lot of discussion helped Amy to assess if the students were learning. The class would also go on to do an oral assessment upon completion of the unit.

Literature Link: Use formative assessment to diagnose needs and inform iterative changes, and summative assessment to gather evidence of learning achievements.

WHY DID AMY CHOOSE THIS LESSON TO HIGHLIGHT FOR THIS CASE STUDY?

Amy chose this lesson because it was midway through a new unit she had developed, and highlighted those features she felt were important in good teaching. The students took what they had already learned and then moved the concept forward with the support of the teacher, exploration of ideas and conducting of experiments to test ideas. The lesson used readily available, everyday equipment and was thoroughly embedded in an authentic relevant context — the mermaid show.

Amy indicated that this was a typical lesson for the Year 1 students that she taught. She stressed that children need to be taught at a level appropriate to their age and ability, and need to find the subject relevant and engaging. Science is everywhere, and when taught in relevant contexts it becomes real and exciting.

"Having all the children engaged is the main thing." Amy

Literature Link: Engage students in authentic activities and make connections to their life experiences.

ENABLERS AND BARRIERS

LEADERSHIP SUPPORT

The Principal and Head of Junior School are very supportive of science at their school and hence created the specialist science and technology teacher role in which they had employed Amy.

The school has provided professional learning opportunities for Amy. They respect her, show that her work is valued and provide the materials and equipment required to teach science and technology.

RESOURCES

Amy believes there is a need for equipment to be simple and where possible consist of everyday materials. Equipment for primary science can be inexpensive and most obtained from supermarkets or by re-using products found around the home and school. Teachers, however, need to know what to do with the resources. There is no purpose in a box of simple equipment in a classroom if there is no planned learning for it. Amy regularly shops for simple school science equipment and has a suitable budget supplied.

Amy looks for things that might be useful and puts them aside. She said she plans to put together an equipment request to parents in the school's newsletters for old CDs, matchboxes, clingwrap tubes and other similar materials. Particular resources she finds very useful in the science classroom are torches, cotton reels, gaffer tape and wine corks. Some specialist pieces of equipment that worked well include simple clip circuit kits.

Amy said the availability of storage space was critical. Although there was ample cupboard space in the room, the fact that the space was shared with after-school care meant that work-in-progress and completed work could not be left out overnight. Amy saw this as a limitation to what she could do.

"It would be good to be able to leave things out but I need to pack it away each day. It is a shared resource room." Amy

PROFESSIONAL LEARNING

Amy finds it relatively easy to come up with original ideas for lessons, but also has been supported by her school to develop these ideas. For example, she attended an external course on science experiments and found it very good. Amy has also attended (and presented at) conferences and watches online science and technology videos for more ideas.

"I constantly gather ideas."

"This school is very supportive." Amy

Amy thinks that primary school teachers find it difficult to source ideas for activities and experiments that suit relevant contexts and the syllabus. She suggests that this is an area that could be targeted for professional learning.

SUSTAINABILITY

Amy and the classroom teachers recognise the importance of keeping science and technology initiatives going in the classroom. Teachers new to the school can be unfamiliar with the way Amy collaborates with colleagues. When classroom teachers first arrive, some view the specialist coming into the classroom to teach science and technology as providing them with release time. Amy emphasises that she needs their involvement for lessons to be productive. She reminds them that science and technology lessons need to be followed up in the classroom at other times during the week, before she next team-teaches the class. Follow up in class is important to support student learning.

SPACE AND TIME

The biggest obstacles for Amy are space and time. She thinks there is a need for a specialised space in her primary school to be dedicated to science. Packing up at the end of each day means extended experiments are difficult to conduct and student work cannot be displayed.

"Having time at the end of the day to put things away so you don't lose anything is a problem." Amy

A barrier can also be the follow up by teachers — it is essential that concepts taught when Amy is in the classroom are followed up in other lessons with the classroom teacher. Amy stresses the importance of the role of the classroom teacher in reinforcing learning once students return to the classroom.

"You need to help teachers realise it is within their capability to create a fair test. Students are not learning facts — that is the message." Amy

WHAT HAS SUPPORTED YOU IN TEACHING SCIENCE AND TECHNOLOGY?

Amy believes her background in high school science helped her to develop an understanding of what learning is age relevant for primary students, because she understands what they will go on to study in secondary school. This allows her to appreciate the bigger picture and the place of primary science and technology learning in the context of learning throughout their whole schooling experience.

Her primary teaching is focused on the students developing knowledge of and skills with science and technology processes — rather than just acquiring subject matter knowledge. She drew attention to Working Scientifically in the syllabus, emphasising that it is primarily about fair testing, observing, predicting, recording and concluding. She also noted that teaching students to design (Working Technologically) is also very important. She usually combines both processes in her topics, as was the case here — conducting fair tests of lighting while designing lighting for the mermaid show.

AMY'S TIPS FOR TEACHERS

- *Make science and technology lessons engaging by responding to students' emerging interests in particular topics.* Encourage teachers to make the lessons more interesting for students by developing opportunities for learning more deeply or broadly in areas of interest.
- *Have an explicit purpose in sequencing lessons, resulting in a culminating task*. When there is a clear purpose in a lesson sequence, it makes learning meaningful for students. A context based learning sequence works better than separate, isolated or one-off classes.
- *Keep it real and relevant by maximising use of everyday materials and familiar contexts for learning*. The more scientific equipment young students use, the less it relates to their real life. Experiments do not have to be big and fancy, but children need a reason for finding something out. Teachers need to explicitly identify and acknowledge the relevance of the science and technology learning for their students.
- *Give students time to think and reflect when developing investigations.* Learners need time to explore possibilities as well as support from the teacher when designing investigations.
- *A mix of tasks is important.* Create open-ended tasks and provide breaks from highly demanding self-initiated activities by having short, well-scaffolded investigations with clear instructions interspersed with the open-ended tasks. Scaffolding the design of fair tests is important to build capability of students to design and conduct their own fair tests.
- *Continuously assess what the students are learning and share anticipated outcomes explicitly.* Students must be able to see a clear outcome for each lesson.

CASE STUDY 2: YEAR 3 MAGNETIC MOMENTS

CONTEXT

THE SCHOOL

The school is a co-educational independent faith based school in metropolitan Sydney. This Preschool to Year 6 primary school has approximately 250 students. Science and technology is taught by the classroom teacher.

THE TEACHER

Jeremy studied computer science at university and describes himself as a huge science nerd. He studied teaching because he wanted to empower children to become critical thinkers. When he started at the school three years ago, science and technology teaching was not inquiry based and the teachers used documents from the 1990s. Jeremy saw the introduction of the new syllabus as a great opportunity to become a champion of science and create a new approach because "all the materials had to be done from scratch." Jeremy's Year 3 class had 21 students.

"It was an advantage being a champion of science." Jeremy

THE TEACHING SPACE

Jeremy teaches science and technology in his classroom but has access to a common area for additional space. He said that storage space is a problem but the school is looking at this issue.

THE SCIENCE UNIT

By the end of Year 3 Jeremy wants students to think science is fun and "all around me." He thinks it is important that girls understand that they can be scientists. The overriding belief he tries to instil in his students is "I can do science — I don't know everything and that's OK."

Jeremy believes that the actual content knowledge component of science (the subject matter) has nothing to do with the desired goal of science teaching. He believes that the goal should be helping students to develop analytical processes and positive emotional engagement so they develop positive attitudes towards science.

"I really do think that if we can empower children to have critical thinking skills, to become rationalists, that we can build a better society." Jeremy

THE SYLLABUS AND CONTEXT

Jeremy's favourite way of working out what needs to be done is to open up the Science K–10 (incorporating Science and Technology K–6) Syllabus document and see how things can be pulled from different parts of the syllabus into something interesting. "It's like a puzzle," he said. He brings together elements from across the syllabus to construct units in interesting and appropriate contexts that are relevant for the students.

Jeremy designs contextualised units, but reveals that context to the students progressively over the term rather than at the start of a unit. For example, the unit may commence by investigating electricity and progressively emphasise the study of sustainability within the students' community. He creates the unit and then "pulls in the science" iteratively and as required to contribute to student learning. He believes you need to "create a landscape" of learning for students. Consequently, a unit is not all mapped out in precise detail in advance. The planned unit provides a clear framework but is responsive to student learning as it occurs throughout the unit. This allows for an evolving sequence of learning.

"The program that you teach your children should evolve from the context you are trying to teach. It's not just a learning sequence." Jeremy

Literature Link: Students need to search for information and find out what is already known, engage in authentic activities, and make connections to their life experiences.

THE LESSON

MAGNETIC MOMENTS

The lesson, Magnetic Moments, is part of a unit that leads to students posing a testable question that they investigate through designing and conducting their own experiment.

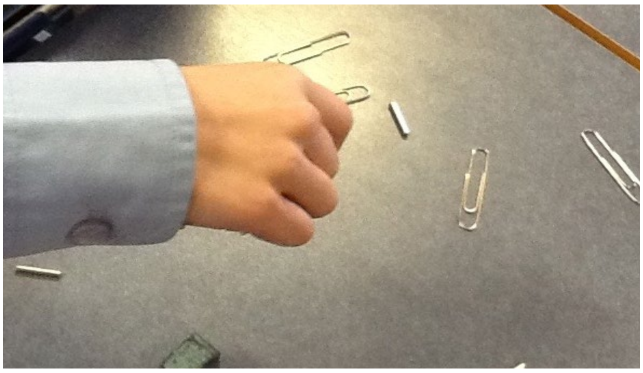
LESSON STRUCTURE

The lesson commenced with a review of what had previously been learned. Jeremy used the interactive whiteboard to display parts of a video he had designed as a stimulus for the lesson. The students had watched it before class and were excited that the video starred Jeremy's dog.

Jeremy progressively displayed information on the interactive whiteboard. First he asked: "What are we going to do today?" and later told the students "we are going to investigate magnets." Jeremy revealed each new element of the lesson and discussed these with the students. He was careful to confirm the nature of the tasks to be completed by them.

One student said he did not like doing a testable question. In response, Jeremy asked another student to explain what a testable question is. She said: "Something that you want to discover that is testable" and, "Testable is something that you can do." The student gave the example that jumping off a cliff is a bad idea and you could not test it. Jeremy noted that if it was a high cliff and the person had a parachute, then it would be testable.

Materials provided for investigation

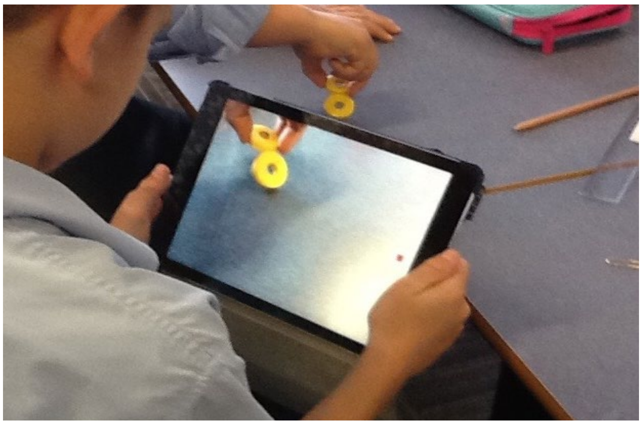


Jeremy revealed on the interactive whiteboard: "Where are we going to go?" and stated "To Magnet Land where you will make a testable question and turn it into our own experiment." He told students that each pair of students would get a container with different materials in it. He displayed a picture of the containers and asked: "What is one of the things you will see in the containers?" The students correctly identified a horseshoe magnet, nails and paperclips. Jeremy told the students they should look at, and play with, everything in the container. They were asked to "discuss with your partner how you would like to demonstrate a push and a pull."

A student pointed out to Jeremy that there was typo in the instructions displayed. Jeremy thanked the boy and addressed the class saying: "When we make mistakes we ...," he paused and the class replied "learn!"

Jeremy revealed four sheets of butchers paper he had placed on the floor outside the classroom. Each of the sheets had a question: for example, "What is one question you've always had about magnets?" The students were expected to reply to on the paper. This technique is based on the Visible Thinking Routine called *chalk talk* that Jeremy has renamed *pencil chat* (Ritchhart, Church, & Morrison, 2011) in which students need to both answer the questions and respond to one other student's answer in writing, rather than verbally.

Students demonstrate push and pull



Jeremy talked to the students about how they might record their work: "You have to document it — there are lots of options." He told students their work needs to be on their iPads as a video and in Book Creator or something similar. The students were instructed to take turns with the roles. For example, he said one person could photograph or film while the other person demonstrates the effect.

Literature Link: Learning technologies are used strategically for increasing the effectiveness of, and student control over, learning in science. Effective primary science teaching practices involve linking science with information and communication technologies.

Jeremy instructed students to look at the school's intranet to find information about what to do in the lesson if they are unsure how to progress.

STUDENTS ARE GIVEN TIME TO EXPLORE

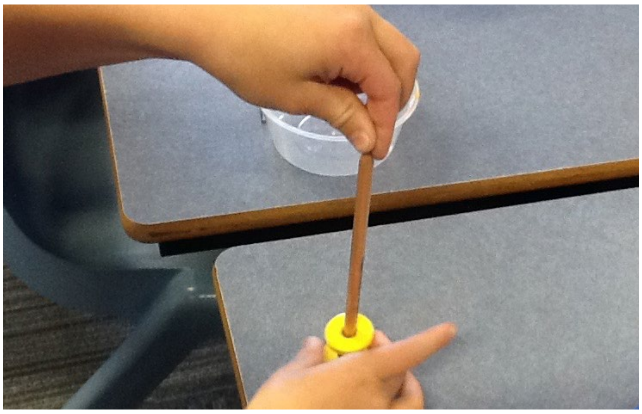
Jeremy handed out the containers with magnetic and non-magnetic items. The students started working promptly and enthusiastically, exploring the items in the box as Jeremy moved around the class assisting students.

Students have time to explore

"Is it possible for a magnet to push as well as pull?" asked Jeremy.

Students used their school-provided iPads to video what happened in their investigations. The videos started with an introduction by the student and then they recorded a push and pull demonstration. For example, a student with two circular magnets showed them on a pencil pushing apart and then turned one magnet over and showed how it was pulled to the other magnet.

Students discover magnets can push



Jeremy instructed the students to document anything interesting that they found.

Literature Link: Students need time to explore and opportunities to fail and try again. Exploration experiences provide students with a common base of activities within which current concepts (i.e. misconceptions), processes, and skills can be identified and conceptual change is facilitated.

Students continued to play with the magnets and were prompted to use the Book Creator app to make a book about their learning. They were comfortable and familiar with the technology and compiled a book within ten minutes.

Students were given ample time to explore with the magnets.

Jeremy asked students to return materials to the container and then move to the *pencil chat* exercise on the butchers paper placed on the floor outside the classroom. Some students had already started answering the questions on these sheets. Jeremy reminded them that on each sheet they must respond to the main question and then to one response from another student.

The bell rang as the students were still completing the *pencil chat* exercise and the class was sent to lunch. Jeremy noted that typically he would allocate time at the end of the class to reflect on what had been done and that an extra half an hour would have been useful for this lesson.

STUDENT QUESTIONS

Jeremy encouraged and responded to student questions during the class. He would sometimes respond with another question or make a comment rather than provide an answer, to encourage the students to think through the answer themselves. Jeremy said that if asked "Why?" he does not like to defer the answer by saying they will do this later. He said that students ask interesting questions and it would be an injustice not to inform them to the level that they understand. He does not just stop with the outcomes planned for the lesson.

Literature Link: Promotion of student questioning is important in supporting ways to search for information and find out what is already known.

ASSESSING LEARNING

Assessment for this unit was described by Jeremy as socratic. He walked around and observed the learning without conducting formal assessment. He assessed the students' learning and gave assistance where needed. The videos produced by the students in this lesson would be viewed later but not formally assessed. There would be summative assessment in science and technology through a science test later in the year.

Literature Link: Use formative assessment to diagnose needs and inform iterative changes, and use summative assessment to gather evidence of learning achievements.

WHY DID JEREMY CHOOSE THIS LESSON TO HIGHLIGHT FOR THIS CASE STUDY?

This lesson was chosen because it was emergent — an open-ended inquiry. He held back from giving answers when the students commenced the practical exercise so that all students could come back with what they learned. He wanted them to "discover a push and pull." Jeremy likes to see students develop a sense of joy and mystery and also to be active, working with other students and getting involved. The Magnetic Moments lesson was a good example of student engagement and learning.

Literature Link: Inquiry based learning requires students to be provided with meaningful learning opportunities that are challenging and authentic. These allow students to develop deep understandings, and ownership of their understandings.

Jeremy noted that some students do not cope with open-ended lessons although, in his class of 21 students, only one or two would fit into this category. For the students who struggle with open-ended investigations, he designs the investigation with them, calling this intervention "the invisible guiding hand to ensure a good outcome." He sees a fully guided lesson where students do not explore as a least favoured option but admits it may be the only option for some and that as a teacher, you need to think about what is best for individual learners.

ENABLERS AND BARRIERS

LEADERSHIP SUPPORT

Jeremy said he receives strong support from the executive leadership team at his school. He was given control and was empowered to make a change in the way science and technology was taught at the school in what he described as "democracy of action." He stated that the Principal trusts the teachers to develop a plan and will support that plan.

The school has a five year action plan for science and technology. Jeremy believes that setting these shared goals is important.

Literature Link: Quality science and technology teaching is more likely to occur when promoted by effective school leadership that places an emphasis on collaborative teams to build capacity throughout a primary school to improve science and technology teaching and learning.

RESOURCES

Jeremy said that resourcing and space are always an issue in teaching science and technology. Jeremy makes about 90% of his teaching resources. He did some research amongst his colleagues at the school and found that teachers looked at a few websites to find good resources. He noted that if teachers cannot find what they want in the first few sites then they will make it themselves. He believes that teachers may now be more inclined to "make their own stuff." He noted that some schools do not tolerate mess and noise and although not a problem at his school, it could limit some teachers.

TECHNOLOGY IN THE CLASSROOM

Jeremy frequently employs digital technology to assist in student learning and said he feels "plugged in." The school has a 1-to-1 iPad program and his Year 3 students had used their school-provided iPads since kindergarten. He stated that there was a lot of "backlash from the parents" when they were first introduced as they did not understand these devices as learning tools. However, the program has been successful and funding has been applied for so that robotics and coding can be introduced.

PROFESSIONAL LEARNING AND NETWORKING

Jeremy finds Facebook and Twitter valuable resources and professional learning tools. He noted #edchat on Twitter as a great source of information. He also participates in a movement called *TeachMeet* where teachers volunteer to host a gathering of other teachers to share resources and talk about what they are doing.

Through his role as a champion of science and technology in the school he has delivered professional learning at his school. His role was to unpack the new syllabus and then present it as professional learning to staff. In doing this he felt that he "shone a light on science" at the school.

Literature Link: Quality science and technology teaching requires knowledge of the curriculum, including purposes and learning outcomes.

TIME

Jeremy said that he thought the most common barrier to teaching science and technology is that teachers do not have enough time to set everything up. He also thought that some teachers may find the subject complicated to teach and that the new curriculum may make it difficult.

Jeremy believes that most opposition to teaching science and technology is around how to write a good unit based on the new syllabus and that this is where there are critical misunderstandings as to what has to happen.

"I think the nice thing is that we do have the syllabus to go off — all the concepts are clearly mapped there." Jeremy

JEREMY'S TIPS FOR TEACHERS

- *Take the opportunity to become a champion of science and technology in your own school.* Coordination of science and technology in a school is important and someone at a school level needs to take on this role.
- *Students need scientific knowledge to understand whether something is testable.* Some teachers may have difficulty thinking like a scientist and so bringing in scientists to talk to students could help.
- *Actively seek out help.* This could be done by asking for support from someone who is known for their strong and innovative teaching of science and technology — ask for opportunities to observe them teach, and for feedback and guidance as you develop your own program. You are unlikely to get this type of help online, so you need to look for a colleague to help you. The person may or may not teach at your school, so look to your professional learning network.
- *Get the students actively involved and moving around during lessons*. Help them develop a sense of joy and curiosity about their world.
- *Teach laterally by ensuring there is a conceptual base to what you are teaching, rather than just focusing on specific facts*. Do not put too much emphasis on recall.

- *Be a confident and passionate teacher of science and technology*. Ensure that you develop your own deep understanding of concepts so that you are able to help learners address their questions productively. Have knowledge of a wide range of relevant, engaging resources that they can access.
- *Provide opportunities to work out why things did not work when a fair test or design and produce task do not go to plan.* This "growth mindset" (Dweck, 2006) is a great teaching opportunity. Tell your students that "Mistakes are how we learn."
- *Provide opportunities for connections to be made in the conceptual knowledge that students gain.* Be willing to try and test new ways of teaching scientific concepts to the students in your class.

CASE STUDY 3: YEAR 5 INVESTIGATIONS

CONTEXT

THE SCHOOL

The school is an independent co-educational primary school in rural New South Wales. It has approximately 150 students. Science and technology is taught by the classroom teacher.

THE TEACHER

Leanne has been a teacher for many years, and at this school for 11 years. She specialised in science when studying her Bachelor of Primary Education and has completed her Professional Accomplishment Accreditation. She set up and runs the science club at the school.

Leanne's Year 5 class has 28 students.

"Right from my university degree and throughout my teaching I have always been passionate about science." Leanne

THE TEACHING SPACE

Leanne teaches science and technology in her classroom and has access to a computer lab. The students are also taken outside to conduct experiments.

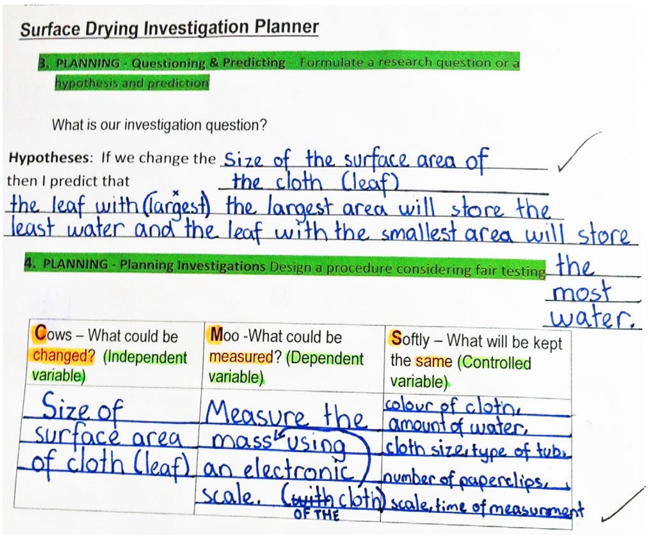
THE SCIENCE AND TECHNOLOGY UNITS

Students record their science and technology learning in a science workbook. They started the year by designing a cover for their workbook and, through a class discussion, developed a mind map about what it means to be a scientist and Work Scientifically. Students were then explicitly taught how to carry out investigations.

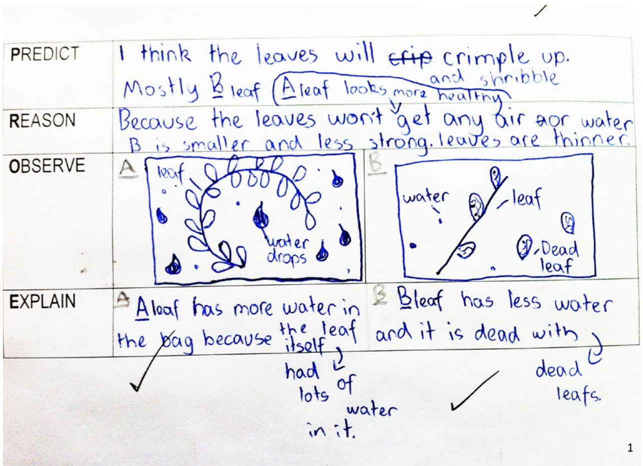
"We spend time discussing real and relevant problems to them." Leanne

First Leanne modelled the process for the students as they conducted a whole class investigation in Term 1. Leanne looked for a relevant topic and chose global warming to discuss with the students. They talked about how animals and plants might survive when the world gets hotter and decided to investigate how things survive in the desert. She then demonstrated to the class how an investigation is conducted by looking at different types of leaves.

Scaffolding inquiry



Students record results



Next, students conducted a guided investigation in groups. They built on their existing learning and used cloth to model evaporation of water from leaves. The students worked in small groups.

During Term 3 the students developed their own testable question and designed an investigation. Leanne said that some students experienced difficulty coming up with questions and she had to help them develop a testable idea. These investigations were conducted in small groups of three to four students.

The students documented their investigations following the criteria for the Young Scientist Awards (Science Teachers' Association of NSW) and the University of Wollongong Science Fair with the view that they would enter their work into these competitions.

"All teachers need to incorporate the process of working scientifically into every aspect of their units." Leanne

During the final term Leanne planned a Design and Make a Picture Book project for the students, integrated with the HSIE unit Why Save the Rainforests? In this unit students would develop a picture book to teach preschool children about the fauna and flora of the rainforest. Students determined the needs and wants of this age group by reading a range of picture books with them. They would then produce a digital picture book with animated features by the end of the year.

Literature Link: Engage students in authentic activities that are connected to their life experiences.

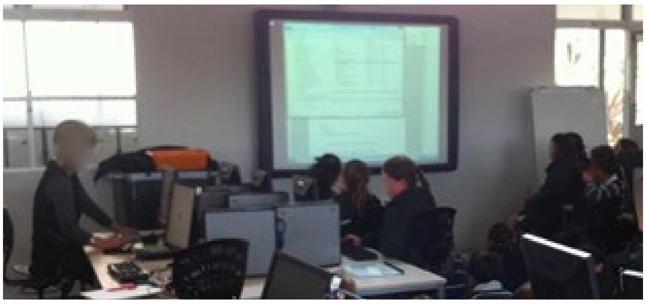
THE LESSON

This lesson took place at the end of Term 3 after the Year 5 students had completed scientific investigations in small groups of three to four students. Leanne was excited because they had just received news that four of her students were prize winners for the Young Scientist Awards. In this lesson the students were in the computer lab preparing entries for the University of Wollongong Science Fair. At the Fair students would display their investigation documents and photos, and explain and describe investigation findings to a panel of judges.

LESSON STRUCTURE

Leanne assembled the students at the front of the room and used the interactive whiteboard to display sections of the scientific report they had been working on. Each section of the report was displayed and Leanne asked the students to explain what was required for each section. The students interacted with the teacher, asking questions and providing responses regarding this. When the students had developed a shared understanding of the requirements of each section, they moved to the computers in their groups to generate their reports.

Group discussion



Leanne moved around the room to each group assisting students as required. She clarified with the students what was required in each section. Leanne believes it is important that students are using scientific language and modelled this when instructing her students. The students discussed their report in their groups and sought clarification where they were unsure. The groups collaboratively agreed on what should be written.

Students are supported to present results

ASSESSING LEARNING

To assess learning, Leanne used an assessment checklist to assist students in monitoring their own completion of the assessment criteria. She incorporated a Visible Thinking Routine called Compass Points that involved students in thinking about what they "**N**eed to do", "Are there any **W**orries they might have", "What are they **E**xcited about" and "Do they have any **S**uggestions?" for moving forward to the next stage in their completion of their projects.

Leanne provided all students with formative written and verbal feedback while in the process of completing their documents. This was typed onto a digital table, with the criteria listed and Leanne's comments and feedback, to help students move forward in their learning and improve the projects and responses.

Literature Link: Use formative assessment to diagnose needs and inform iterative changes, and use summative assessment to gather evidence of learning achievements.

WHY DID LEANNE CHOOSE THIS LESSON TO HIGHLIGHT FOR THIS CASE STUDY?

Leanne chose this lesson because her students were in the process of documenting their science investigations, which they had conducted during Term 2 and early in Term 3. She felt that it would provide a good opportunity to see the students documenting their work. Leanne wanted to highlight the enthusiasm and enjoyment displayed by the students when they talked and wrote about the investigations they had designed and conducted themselves.

ENABLERS AND BARRIERS

Leanne believes that primary teachers need to be motivated and excited by science and technology to overcome barriers. They can do this by communicating with executive staff to discuss difficulties and challenges such as lack of resources, equipment or space for practical implementation of hands-on investigations. She suggests that primary teachers could communicate with a senior school colleague to ask for support in the provision of materials, perhaps through access to their lab assistant if appropriate.

LEADERSHIP SUPPORT

Leanne praised the leadership support she has received at her school. She said the executive staff are very supportive of effective science teaching, both in providing her with professional learning and the purchase of adequate materials, equipment and resources.

"Our school has supported a love of a hands-on approach to science teaching." Leanne

RESOURCES

Leanne said that teachers need adequate access to resources, materials, and equipment to allow students to conduct practical investigations. They need flexibility to implement practical experiments inside the classroom. This means flexibility to adapt and make adjustments to the timetable to allow sufficient time for hands-on investigations.

Leanne notes that primary teachers need to make an additional effort to ensure adequate materials are provided for their students to conduct hands-on investigations.

"If adequate materials are not available, primary teachers need to purchase materials and request out-of-pocket expenses to claim back." Leanne

PROFESSIONAL LEARNING

"I have always put my hand forward for professional development." Leanne

Leanne believes that teachers need adequate professional learning to support their understanding of the process of Working Scientifically as this needs to be embedded into all units every term. This professional learning could take place within the school, depending on the expertise of the existing staff. Leanne has attended professional learning courses at AISNSW related to teaching and implementing the science process, and has transferred this learning into her classroom practice. She particularly noted how she had successfully incorporated the 5Es approach into the teaching of science and technology.

TIME

Leanne said that time could be a huge barrier in the teaching of science and technology. However, she suggested that primary teachers can integrate science teaching into other aspects of the curriculum to ensure that the required learning takes place. She gave the examples of experimental data being integrated into mathematics lessons, and the recording of explanations from science and technology integrated into the Writing and Representing component of English.

LEANNE'S TIPS FOR TEACHERS

- *Provide age-appropriate experiences of Working Scientifically.* This enables students to move forward with relative independence because they have a first-hand understanding of scientific processes.
- *Science and technology units should incorporate original, hands-on scientific investigations*. Actively involve students in Working Scientifically. This includes posing investigation or testable questions about real world problems or scenarios that have real world relevance to the students. Such investigation questions should relate to the students' interests.
- *Students planning investigations need to be supported through explicit teaching.* This helps students decide how they might conduct a fair test experiment, including what equipment they need, and the risk or safety factors to be considered.
- *Students should conduct fair tests in groups.* They should also adopt specific roles within their groups to ensure all students contribute towards the experiment.
- *Students should use a variety of sources to gather background information.* Sourcing outside experts and conducting their own research will help students add to their background knowledge.
- *Students should handle equipment themselves rather than teachers always demonstrating* (depending on safety issues).
- *Students should learn to record their investigations and use technology to record data.* It is important that they can create tables and graphs using tools relevant to their ability.

Leanne recommends that teachers who are reluctant to teach science and technology "... ask for help, have a go, and do some research as it is very inspiring." Leanne

CASE STUDY 4: YEAR 6 FRESH WATER ENVIRONMENTS AND WATER CATCHMENTS

CONTEXT

THE SCHOOL

The school is an independent girls' school in metropolitan Sydney. It has about 900 students in Kindergarten to Year 12. The model that it uses for teaching primary science and technology is one where science is taught by the generalist classroom teacher from Kindergarten to Year 4 but by a specialist science teacher in Years 5 and 6. The science and technology programs in the school are currently being reviewed. Teachers are examining how they teach science and technology and making changes to their current teaching.

THE TEACHER

Deb is the specialist science and technology teacher for Years 5 and 6. She has worked at the school for 18 years, four years as a Year 4 and Year 6 class teacher, two as a Year 7 science teacher, and ten years as the Year 5 and Year 6 science teacher. Deb is passionate about science, a passion instilled in her by her own Year 1 science teacher, and her uncle, a professor of physiology. She aims to convey this passion and instil it in the students she teaches. The central goals in Deb's science and technology teaching practice are to reach all learners, to see lessons from a child's perspective, to provide learning experiences that encourage risk taking in doing and thinking, and to promote a sense of awe and wonder in learning science and technology. Her aim is to develop students who have the skills to be self-directed learners in a rapidly changing world where, in order to thrive and succeed, they must be flexible, creative thinkers and problem solvers.

THE TEACHING SPACE

Deb does not have a designated class space for teaching science and technology — she teaches in the Year 5 and 6 classrooms. The class teachers are present during her lessons but they do not co-teach. Deb needs to be well-prepared for each class, to think ahead and remember to bring everything into the classroom for each lesson.

THE STUDENTS

The Year 6 students in the case study class demonstrate a diverse range of abilities and Deb used a range of teaching strategies to cater for each individual's learning needs. Design and Make activities were particularly important for this group of students because they were "tactile and hands-on students." One of their strengths was group work, which Deb capitalises on in her teaching of this class.

THE UNIT: FRESH WATER ENVIRONMENTS AND WATER CATCHMENTS

The Fresh Water Environments and Water Catchments unit presented in this case study is linked to Stage 3, The Living World strand of the Science K–10 (incorporating Science and Technology K–6) Syllabus. Deb's approach to teaching this unit was inquiry. The big ideas that she wanted the Year 6 students to develop were that what happens upstream affects everything downstream, and that the health of a river depends on human decisions which can permanently change ecosystems. Since there is a requirement to integrate literacy into science and technology teaching at the school, Deb uses literature extensively in her teaching. The starter activity for the unit, used to arouse and engage students, was an analysis of the picture book *Cry Me a River* (McRae, 1991). Students worked in small groups to identify the environmental problems in the story. Deb believes that Year 6 is an important time to learn about the environment because "their eyes are opening up to the world and they know that environmental issues are a concern for all of us and they want to learn about it."

Literature Link: The use of starter activities that arouse and engage students in investigations is a feature of effective science and technology teaching. A good entry activity transitions students positively into the learning environment.

The students had also watched a video on Murray-Darling River Basin ecological issues and their solutions. After taking notes individually from the video (with an emphasis on literacy skills) the students' notes were colour-coded according to the subtopics of water, man,

> *"Being able to organise information is important — the exactness of it is not so important, it's the process of how do we take all this information and make it meaningful." Deb*

land and animals. The students then worked in small groups to organise their information by creating comparison charts according to the problems and solutions. The final product created individually was a flowchart using the student's own visuals and language to illustrate the connectedness of elements of the ecosystem. Most of the students created digital flowcharts on the computer. They explored ideas in the flowcharts about disasters relevant to Australia and hypothesised how to solve them. One example explored how when farmers cut down native Mallee scrubs, the salt level in the soil rose. Because the soil became so salty, they could not grow crops and the land became unfarmable. A student suggested that the farmer could harvest and sell the salt and that would assist in desalinating the land.

In the *Cry Me a River* and Murray-Darling video activities, the students were creating and analysing their own representations, as well as analysing standard scientific representations with Deb.

Literature Link: There is growing evidence that encouraging students to demonstrate their understanding with more than one mode of representation assists with conceptual development.

THE LESSON

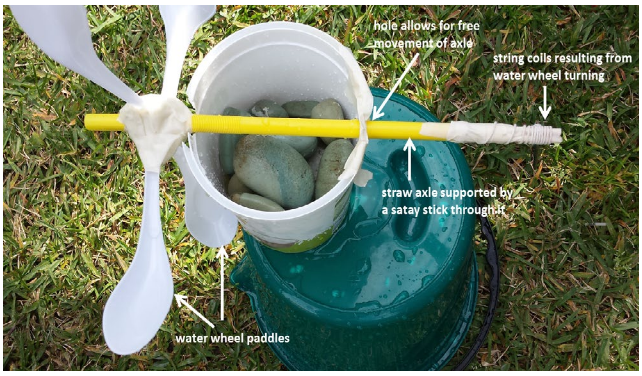
The lesson on water turbines in this case study was connected to two of the students' previous learning experiences. The first of these was the identification of the issue of a large amount of water being diverted from the Snowy River into dams for the hydro-electric scheme. The second was the students' knowledge of different sources of energy and energy efficiency that they had learnt about in Year 5. The Water Turbine activity was intended to assist with the students' understanding of how water is used to generate electricity, and of the efficiency in the transformation of one form of energy to another.

WATER TURBINE DESIGN AND MAKE ACTIVITY

The students had knowledge of the task from their previous science and technology lesson. Deb approached the task in this lesson by getting the students to talk about what they were going to do. To make sure that the students were clear about the purpose and to probe their understanding of the task more deeply, she asked a lot of questions, for example: "What makes turbines go faster or slower?" and "Why have you chosen this design?" Deb seldom told the students directly what to do or what the answer to a question was. She used questions to draw out their thinking and helped them make connections.

The students were visibly excited about the task and there was a lot of animated discussion at the tables. The class was divided into six groups. Each group had the freedom to investigate, for example, the type of material to use for the paddles, the shape of the paddles, and the number of paddles for the water wheel. The design of the axle made use of a long satay stick pushed through a large straw to which the water wheel paddles were attached. At the other end of the axle a string was tied with a small weight attached. As the water wheel turned, the string would coil around the straw and the students recorded the time for the string to coil completely around the axle.

Construction of a water turbine



The students tested their design in a space just outside the classroom, one group at a time with Deb. They were constrained to doing this one group at a time because of the limited availability of watering cans and buckets to do the testing. Inside the classroom, the class teacher was present while the remaining students finished constructing their turbines and went on with further learning on freshwater catchments set by Deb for when they had finished their construction.

Testing a water turbine

A FOCUS ON COLLABORATIVE WORK

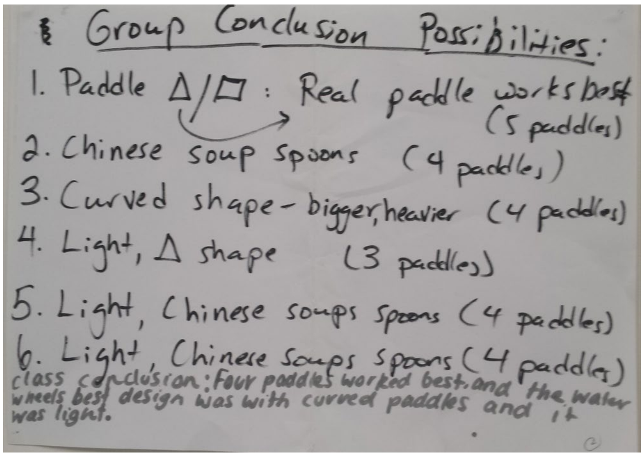
Collaboration is a feature in the students' learning in Deb's class. Deb encouraged the students to explore creatively in their groups and come up with their own solutions to problems. She wanted them to learn independently and constructively with each other and not have every step explained to them by the teacher. The students worked collaboratively in their groups designing, constructing, testing, recording data, sharing ideas and drawing conclusions about their investigations. Testing the water turbine involved one student pouring a steady stream of water on the paddles of the water wheel to make it spin continuously while another student recorded the time for the string to wind round the axle. The students were familiar with fair testing and controlling of variables. Each group constructed at least two designs to test and made conclusions about their designs. They shared their group findings and came to consensus with a class conclusion. Class conclusions are important to Deb. She explained that it is "about data validity" as students need to be aware that scientists do not make conclusions based on one set of data but collaborate with others working on similar investigations to come up with a more valid conclusion. For this task the class conclusion was: "Four paddles worked best, and the waterwheel's best design was with curved paddles and it was light."

> *"..the notion of collaboration that underpins all scientific work sharing research and validating each other." Deb*

> *"One of the things about this task that I enjoyed was how we worked together as a team. We rarely argued and we agreed most of the time. I think that one of the reasons that we worked so well together was that we always LISTENED to each other's idea. Which gave the task a positive outcome." Year 6 student*

> *"(what) I enjoyed would probably be when we were timing how fast it would go." Year 6 student*

Water turbine investigation: Group and class conclusions



ASSESSING LEARNING

The students reflected individually on their water turbine experiences by writing down (i) what went well, (ii) what they enjoyed, (iii) what was difficult, and (iv) how it could be improved. Everyone in this mixed-ability class of students was able to articulate these. Responses ranged from those that were less in-depth (for example, what went well — "the spoons spun well"; what was difficult — "the timing of the spinning of the spoons"; how could it be improved — “not to rush, maybe put more sticky tape on”) to those that provided more depth (for example, what was difficult — “ ...our second design. It was very heavy because we had paddles going horizontally as well as going vertically. This meant that it was much slower and it would often collapse because of the weight of plastic, paper, straws, sticks, a lot of tape and water seemed to weigh down nine paddles.”)

Deb feels strongly about using a variety of assessment activities to look for general capabilities and understanding rather than seeking perfection in one or two things. She feels that a lot of the students do well in formal science and technology tests and that test performance does not differentiate sufficiently for her in terms of determining student learning outcomes and report writing. She organises a summative assessment to prepare students for the end-of-Year 6 exams, and ueses a range of formative assessments. For the Fresh Water Environments and Water Catchments unit, these assessments included looking for quality in note-taking and categorising information and verbal discussion (such as linking what they saw to what they learned, and asking questions). She capitalised on the students’ strengths and assessed them through flowcharts, visual summaries, and illustrations. In this lesson, this included assessing the diagrams of the water turbines they had designed.

STUDENTS CONNECTING THE WATER TURBINE LESSON TO OTHER ACTIVITIES AND EVENTS

Deb rented a water catchment model from the Australian Museum’s Museum-in-a-Box outreach program for two weeks. It had upper, middle and lower catchments with a dam and a fish pond. The students could see the dam (a word which many students did not understand when they first came across it while watching the Murray-Darling video) and they could connect it with the water turbines they made. Deb could simulate erosions, chemical spills and floods with the model and thought that being able to physically show what she was talking about to the students was very enriching. The students set erosion scenarios and could see how these would affect the different catchments. They liked the concrete model. For them it was like the real thing, and they could simulate erosion and flooding with food colouring and clay, and add or take away things. The students learned new vocabulary, and the concept of a scientific model and its use to test things. They learned that many of the hypotheses scientists create are based on models.

Water catchment model

The model helped the students see what environmental disasters would look like, how fragile the bush is and that we have choices in how we respond. As a capstone activity, the students will visit a local environment, the Sydney Water Catchment.

At around this time, a group of the students, while on a school ski team excursion to Thredbo, reported that they had seen the beginning of the Snowy River. A student emailed Deb to ask if she would like her to photograph the beginning of the Snowy River and water turbines that she had seen. The class felt connected to this real life experience as Deb used the student’s photos to show the class what one of their peers had seen. These responses from the students validated Deb’s interest in their personal experiences and her view that they were very important in the learning of science and technology.

> **Literature Link:** Students need to be supported to search for information and find out what is already known, and to engage in authentic activities connected to their life experiences.

WHY DID DEB CHOOSE THIS LESSON TO HIGHLIGHT FOR THIS CASE STUDY?

Deb wanted to link design technology to the study of this unit. In her teaching, she stresses that science and technology are both creative endeavours. Teaching the girls to be creative thinkers and to "think outside the box" is important to her. The task in the lesson provided an opportunity for the students to be creative in their design of the turbines, and she encouraged them to explore. For example, after designing a waterwheel with four soup spoons, one of the groups wanted to take that model and construct three sets of them, that is, change the variable to the number of waterwheels (instead of the number of paddles). The group explored this design, but found that the wheel was too heavy and kept falling over even though they had an anchor for it. Deb did not tell them that it was not going to work. Instead she provided the time and encouraged the students to pursue this line of investigation. She felt that if she had said no and told the students that the new design was not going to work, they would not gain any experience of the creativity in science. It was their learning journey to find out that the three sets of wheels were too heavy. She wanted the students to remember the feeling they had when they tested their new design.

"Science and technology is a creative endeavour." Deb

Deb is guided by three elements that make science and technology learning relevant: fun, importance, and personal connection. The turbine making activity had all three elements. The building of the turbines was fun as a collaborative group activity. The students said that it was fun because they had a sense of ownership over the design. They could engage actively in the process where they were making decisions together, challenging each other and coming to an agreement as a group for the design. It was fun because they were displaying and presenting products of learning and design. The task was important because it connected to real life situations and the learning was valuable to each individual. It was personal because they made the decisions about their design and its construction.

*Science and technology lessons are **fun** because:*

lots of activities; making things; experiments; working with friends and new people, we move around, draw, use computers to represent ideas, use and make models, create from our imagination. Year 6 students

*Science and technology lessons are **important** because:*

we figure things out; helps me understand what I see in the world around me and wonder about possible solutions; helps me learn to question and think on my own; teaches us to think about how discoveries are made. Year 6 students

*Science and technology lessons are **personal** because:*

different ways to show learning and understanding; lots of choices; stories to share from own experiences and observations; lots of personal and peer reflection; teaches us to work well with others. Year 6 students

ENABLERS AND BARRIERS

SCHOOL SUPPORT

The Principal is very supportive of the things that Deb does in science and technology. Anything that she requires, the school will purchase. She uses everyday materials and does not think laboratory equipment is essential for primary science and technology. Deb communicates regularly with the secondary school and, if she needs anything, is able to obtain it from there. Not having a science specialist classroom is not a barrier for Deb. According to her, teaching in the students' generalist classroom helps her get to know the students better because she has regular communication with the class teachers.

PARENT SUPPORT

Deb receives positive feedback from parents on parent-teacher nights. She feels great that her teaching strategy of targeting the different learning needs of students is reinforced and acknowledged by parents.

PROFESSIONAL LEARNING

This year Deb completed two professional learning courses focusing on STEAM (science, technology, engineering, arts and mathematics) and creative thinking. STEAM involves integrating STEM learning with the arts. Both professional learning courses validated her approach to teaching, which seeks to connect science and technology learning with creative learning experiences. The courses provided her with ideas and research findings about teaching science creatively.

STAFF REFLECTION SCHEME FOR APPRAISAL

The school has a strong staff appraisal scheme based on reflection. The students fill in surveys about Deb's teaching which provide feedback on her teaching from their perspective. Staff observe each other teach in the classroom and Deb has provided many science and technology teaching ideas to the other teachers through this process. In return she has also learned from other teachers by observing their teaching.

TIME

Deb feels time pressure partly because she teaches creatively and seeks to build on what the students are engaged with, which is often difficult to do because there may not be sufficient time. As a specialist teacher going into the classrooms to teach science and technology, lesson time is tightly bounded and fixed for each lesson. She does not have the independence to manipulate lesson times in the way that generalist teachers with their own classes may be able to.

DEB'S TIPS FOR TEACHERS

- *Create and support a classroom culture where risk taking is encouraged, including teacher risk taking*. Effective science and technology teachers require the ability to let go. Deb models this to her students because that is what scientists do. Letting go means: "This did not work out quite well, let's figure out what we can do about it" rather than "This did not work out right, that's it." Students' books "do not have to be perfect." Unless teachers "loosen up" a bit, they are not letting their students explore what science is about. It means getting messy, and sometimes the work planned does not get finished.
- *Relevant science and technology learning is fun, important, and personal.* It is about developing the individual learner and taking opportunities to extend them in whatever they are doing.
- *Adjust science and technology tasks to the students' learning preferences.* It is important to provide opportunities to do group work and enable students to convey their understanding through different modes of representations.
- *Model real world science in the classroom.* Scientists explore creatively to find solutions. They use both physical and conceptual models, work individually and in teams, and many work with the data from similar studies to draw conclusions.
- *Use a range of formative assessment strategies.* Examples of activities and sources that lend themselves to formative assessment include: student questioning, students' notes from videos, their practical reports and diagrams, constructing flowcharts, categorising information and objects, class discussion, self and group analysis of websites, and the "What went well?", "What did you enjoy?", "What was difficult?" and "How could you have improved this?" reflective strategy.

CASE STUDY 5: SCIENCE AND TECHNOLOGY TEACHING AND LEARNING K-6

CONTEXT

THE SCHOOL

The school is a selective independent boys' school in metropolitan Sydney. It has about 300 students in Preschool to Year 6. The school's parent community is made up of a relatively high percentage of doctors and scientists.

The time for science and technology lessons is incremental across the year levels, starting with 30 minutes per week for kindergarten students and increasing to 90 minutes each week for Years 5 and 6 students. Most students in the school are in the top 15% with respect to academic ability for their age, but within this there is a broad range of ability.

The science and technology program in the school follows the Science K–10 (incorporating Science and Technology K–6) Syllabus.

THE TEACHER

Suzie is a specialist science and technology teacher who teaches across K–6. She is a young teacher who graduated from her university teacher education program four years ago and has worked in the school since then. Suzie is passionate about science, a passion that developed growing up in an environment where science was highly valued and discussed often by her parents, both of whom are in medical professions.

Suzie meets on a regular basis with the high school science department to ensure that there are no overlapping units or activities, and to consider ways to make the progression of students' learning from Year 6 to Year 7 smoother.

THE TEACHING SPACE

The school has a dedicated laboratory designed for primary science and technology where K–6 lessons are taught. On the walls of the laboratory, there is display space for every year level, each of which is filled with photos and work of the students. The laboratory is equipped with relevant, specialised scientific equipment (for example, microscopes, plastic beakers, collection boxes, stop watches) as well as everyday materials from the home and supermarket. There are also animals in the laboratory, and natural history collections. The laboratory has a bookshelf of resources that include syllabus documents from other countries, theoretical teacher resources, and non-fiction books.

APPROACH TO TEACHING SCIENCE AND TECHNOLOGY ACROSS K-6

DEVELOP POSITIVE ATTITUDES IN STUDENTS' FORMATIVE YEARS

Suzie is motivated to share her love of science with students and is committed to inspiring them to like science. She acknowledges that she is teaching students in their formative years and that positive attitudes and values developed in these years will flow through to their secondary school and later life. She uses many strategies for motivating and inspiring students. These include bringing science and technology to life by letting them engage in an authentic way with scientific processes. When students undertake scientific experiences like field work, they use equipment and methods that scientists would actually use. She nurtures the students' natural scientific instincts and encourages curiosity, questioning, and investigation of science and technology in their world.

Literature Link: Allow students to explore ideas, develop designs and create products.

Suzie focuses on science as a human endeavour so that her students understand the importance of science in their lives — past, present and future. She includes learning activities which focus on the lives and work of traditional scientists and invites practicing scientists to work with her students. For example, she discusses Sir Joseph Banks as a traditional scientist with Year 2 students when teaching scientific diagrams in the unit on Wildlife in the Suburbs. She has invited an entomologist from a nearby university to work with her students, undertaken a case study with her class about

"Many great scientists describe their passion for science as having stemmed from their childhood days, for example Charles Darwin, Albert Einstein, Stephen Hawking, Neil Degrasse Tyson and Jane Goodall." Suzie

a taxonomist from Western Australia, and invited students' parents who work in science and technology fields to talk to or work with the students. Suzie is critical of the stereotypical portrayals of scientists and engineers as nerds, geeks and humourless, complete with boring personalities, whose dress sense extends to white coats and safety glasses. She wants to portray scientists and engineers positively, and highlight the values and attributes that they have in common — as problem solvers, passionate about science, inquisitive, knowledgeable, and helping humankind.

INVESTIGATING IN REAL LIFE CONTEXTS

Suzie recognises that students are motivated by wanting to find things out for themselves. Consequently, almost all of the experiences she provides them in science and technology lessons are based around investigations and Working Technologically, where they explore and conduct themselves like scientists or engineers. She notes that investigations are fun for the students and appealing because they find it rational, coming from their own discoveries.

"My favourite science was when I held the snake. When I touched the snake it was scaly and that was pretty good. I didn't know that the snake need the power of the sun, I didn't know that that they needed to heat up their bodies, I didn't know that." Kindergarten student 1

"My favourite experiment was that first experiment with the blue explosion (elephant toothpaste demo)." Kindergarten student 2

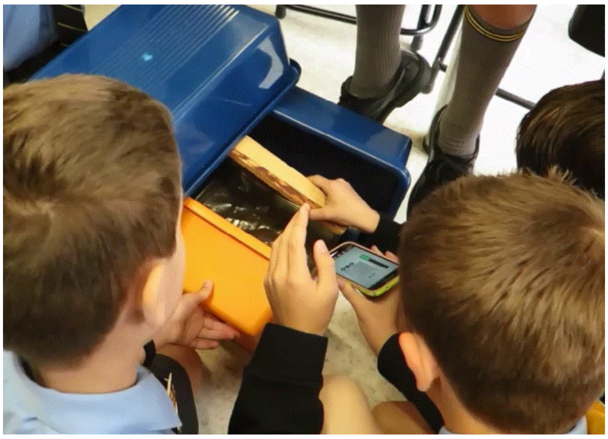
"Science is the most funnest thing I like to do in the whole world because you get to learn new things, you get to know how things work, you get to learn about snakes, animals and the human body." Year 2 student

Investigating science and technology begins in Early Stage 1 in the Places We Play unit. It focuses on exploring immediate surroundings, including the playground, investigating different types of materials, their properties (strong, hard, soft, rough, waterproof, smooth, slippery) and why objects are made from different materials. The students are taught to conduct simple scientific tests involving the idea of fairness. For example, as a class they tested five materials to see which were smooth enough to be used on a slippery dip, and ranked them from the most suitable to least suitable. To conduct the test, they used a plank of wood covered with the test material (for example, plastic tablecloth, yoga mat) in turn, while ensuring a teddy bear that slid down always started from the same place and was not given a push. As a final task, the students designed a slippery dip made from simple materials, one that had a safety feature and a surface that would allow a small teddy bear to slide down. The kindergarten students were required to consider grip (is it smooth enough?) and strengths of materials (are the materials strong enough not to break and can the slippery dip stand up on its own?). Assessment is aimed at getting the students to consider the results of the investigations conducted during the term to make informed selections of materials used for their own slippery dip.

Suzie acknowledges that teaching and learning science and technology in contexts relevant to the students (for example, learning the science around play equipment) greatly enhances and provides depth to their learning of the subject. She acknowledges that it is possible to integrate science with maths (measurement, data recording and representation) or English (appropriate use of factual text), but for other key learning areas it is often easier to link them to science and technology thematically. Suzie also indicates that teaching non-contextually, for example a unit on ecology, can still be engaging and provide rich learning opportunities for students.

Suzie values lessons that elicit spontaneity in learning. An example is a Year 6 spontaneous lesson on sound where students hypothesised and conducted an investigation on the volume of sound. The impetus was an app on Suzie's mobile phone that could measure the volume of sound made in decibels (dB). The students decided to investigate if sound could be captured with a device. They built a testing device (an enclosure made from four plastic trays) to capture the sound when a stick was hit onto a metal tray on the ground. The students tested many different hypotheses about sound and did their best to make their tests fair by controlling the variables. A lot of discussion went on in the group with students offering ideas while Suzie asked questions to help them connect the ideas. Eventually they decided to drop the stick onto the metal tray from a set height in order to keep the sound the same in each test (as opposed to controlling the force of the stick hitting the metal plate). They measured the volume of the sound at different distances from the sound source and found that the sound volume went up (became louder) as they got closer to the source (for example, 72 dB) as opposed to when they were further away (for example, 65 dB). The students offered explanations: "like a ripple in a wave, it gets bigger" and "when you drop a pebble in the water, the wavelength starts to get bigger and bigger and that's what happens when the noise is dying out."

Year 6 testing sound volume



Literature Link: Teachers need to be able to understand the technological concepts and procedures and how these are used by society, as well as have practical technology skills. Relating science and technology to society enables students to see the relevance of what they are learning.

Suzie thinks that it is important to relate lessons to science and technology in society and incorporate current scientific and technological advances and events into these. It shows the students that what they are learning is relevant in today's society and plays a hugely significant role in their lives. It helps them to form strong positive values and attitudes about future involvement in science and technology while still in their formative years. For example, the space probe New Horizons flew past Pluto in July 2015, after a nearly decade-long journey. The Year 5 students had started a countdown in May and visited the website to look at photos of Pluto, the data, and newspaper releases. This made the space unit that they were learning more relevant and up to date. It also showed that science knowledge is evolving because Pluto, which was initially thought to be small and blue, turned out to be brown. In the classroom, when the European robotic laboratory Philae probe landed on a comet and had a problem releasing one of its legs, the students designed and constructed space probes with shock absorbers. Suzie seeks to make learning authentic by helping students to relate science and technology to events that are happening around them.

Literature Link: Engage students in authentic activities that are connected to their life experiences.

A VARIETY OF STRATEGIES TO INTEREST STUDENTS IN PRIMARY SCIENCE AND TECHNOLOGY

Investigating is a major strategy in Suzie's teaching of science and technology. Investigations include queries generated by the students themselves. For example, in relation to fair testing, students are asked to devise questions involving paper planes which they can solve using fair testing. Another example is in a unit on sport science where the students develop questions for investigation such as: does wearing sand shoes make you jump further and do glasses make your reflexes slower? Apart from investigations, Suzie uses a variety of other strategies to engage the primary students to learn science and technology.

Literature Link: Promotion of student questioning is important in supporting ways to search for information and find out what is already known. Inquiry based learning focuses on questioning, critical thinking and problem solving where evidence from investigative questioning is gathered and possible explanations considered.

SOCIAL-CONSTRUCTIVIST AND MODELLED GUIDED AND INDEPENDENT TEACHING METHODS

Pedagogically, Suzie bases her teaching on the Social-Constructivist and the Modelled Guided and Independent (MGI) teaching methods. Using the MGI model, she models how to do a fair test and write it up, and then the students undertake a fair test in teams before they do it independently. In this way, the task is handed over to the students, giving them progressively more independence to enable them to develop skills in the various processes of conducting a fair test.

Literature Link: Constructivist learning theory posits that learners come into the classroom with worldviews (also called prior knowledge) that they have already constructed in order to make sense of the world around them. Social-constructivist teaching elicits misconceptions explicitly, rendering them open to scrutiny through investigation and discussion.

Suzie structures each of her units around the MGI model and as the students get older there is gradually less scaffolding. Suzie said that "by the time they get to Year 6, they are phenomenal, and you can give them an aim and they can design the entire experiment based on that aim." The students work in teams of three when working on experiments. Peer support is important as the students provide assistance to each other without the need to seek Suzie's help all the time.

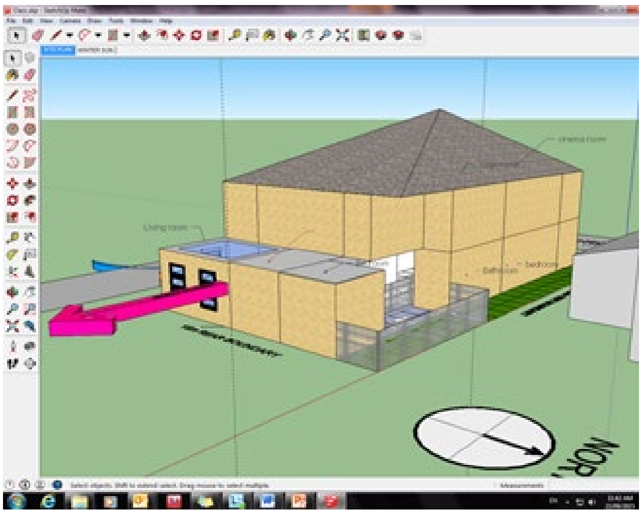
Literature Link: A variety of approaches to science and technology education, derived from social-constructivism, make misconceptions explicit and open to scrutiny through investigation and discussion. Use a variety of strategies to communicate science ideas.

USE OF DIGITAL TECHNOLOGY

An example of the effective use of digital technology was when Year 5 students designed a sustainable house using the 3D design software, Google SketchUp. The following is an excerpt from a student explaining the task:

"This term we have been doing science and we've been exploring passive heating and cooling with Google SketchUp. We are building SketchUp houses. With this you make sure you have at least three hours of sunlight during the winter and the same in the summer. We have to decide who we have in the house and what they need. We have a clear plan of what rooms we actually need and how we cater for each person. This will help us plan our house so we have a clear plan so we don't get stuck in the middle...the first person is a 48 year old adult who is a cartoonist and works from home, he needs a sound proof study, with plenty of books and stationery. He would also need a computer plugged into his electricity system so he can email his boss about his drawings....we need to make them fit the specifications we have been given from the other houses on the street and the council so we have been learning about insulation and cross-ventilation and passive heating so we can make the house to fit those specifications... I really like using SketchUp because it lets you design what you want and you can choose what you want to do so you can choose whatever colour you want your house and how big you want all the rooms so it's really good and easy that way." Year 5 student

Designing a sustainable house using SketchUp



INCURSIONS AND EXCURSIONS

Suzie organises incursions such as inviting an educational organisation to set up a planetarium in the school hall, and conducts activities based on outcomes in the Science K–10 (incorporating Science and Technology K-6) Syllabus. For excursions, she has taken the Year 2 students on a fossil hunting expedition in the Hunter Valley Quarry, and organised a Science Day Out — a whole school excursion to celebrate science and technology. Programs were customised to meet the needs of different classes, and were held at Taronga Zoo, Darling Harbour, Imax, Powerhouse Museum, Maritime Museum, Wildlife Sydney Zoo and Sea-Life Sydney.

GUEST SPEAKERS AND SCIENTIST-IN-RESIDENCE

To enable students to see how real scientists work, Suzie organises scientists as guest speakers and scientists in residence to work with the students. One of the guest speakers was Lucy Hawking, who with her father Stephen Hawking, has co-authored a series of books popularising science for primary aged children. Suzie has also organised a scientist in residence program where the scientist visited the school one day a week for six weeks. On each of these days, the scientist worked with the three Year 6 classes on sustainability and design where the students designed solar cars following a sustainable and performance-driven brief.

CELEBRATING SCIENCE AND TECHNOLOGY

Science and technology is regularly celebrated in school assemblies. For example, Suzie will give a talk on something that occurs globally, such as Earth Hour. Sometimes a class does a scientific presentation at assembly, for example, when the students used a musical piece to teach the rest of the school how to remember the names of the planets in our solar system. On Open Days, science and technology is celebrated in the laboratory and in the playground for everyone to see.

A SUSTAINABLE COMMUNITY GARDEN

Suzie was allocated part of the school grounds where some year levels and the science club students developed a garden with a worm farm, water tank, greenhouse, garden beds and a pond. About ten tonnes of earth were moved to fill the beds and paths were made around the garden beds. The students planted a native garden, tended the garden, germinated seeds, and harvested fruits and vegetables grown in the garden. The pond, designed mostly by the students, utilises solar panels to run a biological filter, and a cistern prevents water from evaporating. The pond is used in science and technology lessons that study food chains and webs, ecosystems, and water quality testing.

Literature Link: Working Technologically is about designing, building and evaluating, and matching materials to purpose. It involves identifying real needs or problems and seeking or building solutions.

SCIENCE CLUB

Suzie runs the science club twice a week to cater for students who are particularly passionate about science. The science club allows these students to do science outside the curriculum, to share and encourage their specific passions, and to assist with projects that support science. It provides extension activities for some students.

TEACHING THAT BALANCES SCIENTIFIC CONCEPTS WITH SCIENTIFIC PROCESSES

"A balance between learning scientific concepts with scientific processes is necessary because experiments can underpin the learning of concepts and the conceptual framework underpins the kinds of experiments to be done and they do come hand in hand, you need to have both." Suzie

Suzie believes that it is important that students learn all the strands in the Science K-10 (incorporating Science and Technology K-6) Syllabus and develop an understanding of scientific concepts in the disciplines of chemistry, physics, biology, earth science, space science, and environmental science. She thinks that the syllabus-related outcomes in the science and technology strands provide the foundational knowledge for the students. Suzie advocates that teachers can facilitate the learning of scientific principles by students conducting investigations that draw these out. In doing that, students also learn the processes involved in the scientific method. It is important that students learn science concepts while developing science process skills. Suzie believes that good science and technology teachers preserve the integrity of the subject and that their practices should reflect the understanding that science and technology is valuable and engaging on its own. She is concerned that "tacking on" science and technology in other subjects could sometimes "dilute" the learning of science processes and concepts. In contrast, she thinks that history, English, and mathematics can be incorporated to enrich science and technology lessons without compromising the integrity of science and technology.

ASSESSING LEARNING

Suzie assesses for understanding of concepts and scientific processes, as well as values and attitudes, in practical work. Values and attitudes are assessed formatively, for example, she assesses whether the students are "persevering with tasks to completion and are ... asking questions and being curious about the phenomena." For K–2 students, assessment is based on anecdotal evidence such as work samples and their responses in discussions. For Years 3-6 students, more formal assessment tasks are completed at the school. She uses a variety of formative and summative assessment strategies that include rubrics, verbal explanations, and quizzes on concepts.

ENABLERS AND BARRIERS

SCHOOL SUPPORT AND STRONG MENTORSHIP

The school does what it can to minimise obstacles. There is a generous budget for Suzie to purchase science equipment and materials for teaching.

Suzie acknowledges that she has "learned from the best" — her mentor, who was the past K–6 science and technology teacher. There is constant discourse between her and her mentor about science and technology teaching, including discussing research in science education journal articles, for example, trends towards contextual learning in science. These mentored activities address questions that Suzie has about her own practice, as well as new ideas that are appropriate within the school context. Suzie is encouraged to continue with her own learning, to "move forward" and to defend the importance of her subject area.

PROFESSIONAL LEARNING: LEARNING ON THE JOB AND BEING REFLECTIVE

Suzie is constantly improving herself through professional learning. She has attended conferences and presentations, for example, Stephen Hawking's talk at the Opera House, as well as ones by Paul Davies, Lawrence Krauss and Neil Degrasse Tyson. She also attended a 10-week short course in science at a university to keep up to date with current science research. She recently participated in the Bush Blitz Teachlive scientific expedition as one of five teachers selected nationally in 2016. The aim of this expedition was to experience first-hand how scientists survey wildlife and make discoveries, and to bring this knowledge back to the classroom. The 2016 expedition took place at Bruny Island, Tasmania which Suzie described as "amazing, and I really got to understand what scientists go through when they are classifying things." These professional learning activities refresh Suzie's interest in science.

> *"I attend talks such as the ones by Stephen Hawking and Neil Degrasse Tyson because it keeps my passion for science alive, makes me more creative and I can then share appropriate bits with my students who, strangely enough, I keep bumping into at these events." Suzie*

Learning on the job is part of how Suzie got to where she is now. She reflects constantly to improve herself. She self-evaluates after every lesson, asking questions such as "were the students engaged, were they restless, is there a need to plan something more structured or simpler?" Suzy is able to see when she has made a mistake and learns from it so that she will not make the same mistake again. She has experimented with pedagogy over her four years of teaching and is still developing units, always finding different ways to teach more effectively.

Suzie realises that, in her setting, she is fortunate not to have experienced many of the barriers faced by teachers. However, finding the opportunity in a busy school schedule to take her students on science excursions is difficult. Another issue is looking after the laboratory. She makes use of some of her personal time shopping for things, doing the inventory, and cleaning the laboratory during the school holidays.

SUZIE'S TIPS FOR TEACHERS

- *Know the science and technology content that you are teaching.* Learn the concepts you are trying to teach, know a bit more than the students and be a step ahead of them. Knowing the concepts helps you break them down to simpler steps to help students learn in a fun and simple way. Make use of YouTube, and quality science TV shows/books (for example, *Magic School Bus, Veritasium* by Derek Muller on YouTube, *Bill Nye the Science Guy* shows, and the *Cosmos* series).
- *Promote independent learning for students*. Setting the class a fair test to conduct in small groups can seem daunting if you like the room to be quiet. But the discourse between the students provides a rich educational experience for them as they are problem solving together, working out differences of opinion, being aware of their errors and making attempts to correct them. Giving them time without constant input is necessary for them to learn how to think.
- *Plan science and technology lessons with a focus on how you will sequence the teaching of scientific concepts and principles.* Break scientific principles down and build on them during the learning rather than teaching complex principles in one go. Planning is an important element to successful lessons, so that you are clear about the conceptual understandings that you want students to develop.
- *Engage with colleagues for support*. Be supported and enabled to teach primary science and technology successfully by engaging with other science and technology teachers, sharing, swapping, and creating new ideas to assist with teaching.
- *Learn together with students*. Sometimes you may have to learn with students. It is important not to obstruct those who have lots of questions. It could become a balancing act when you are trying to enrich (which is the ethos of Suzie's school) rather than accelerate. Enrichment means focusing on depth and breadth — for example, integrate concepts learnt with ethical considerations or with science and technology issues in society or history of science. This could include highlighting key discoveries that have impacted society, or emphasising the role of women in science and technology.

CASE STUDY 6: KINDERGARTEN STAYING ALIVE MINI-UNIT

CONTEXT

THE SCHOOL

The school is an independent co-educational school in metropolitan Sydney. It has approximately 1200 students enrolled from Preschool to Year 12. The model for teaching primary science and technology is one where generalist classroom teachers teach their own class, but the science and technology program for the grade is written by one class teacher in each year. There are three classes in each year from K–6.

THE TEACHER

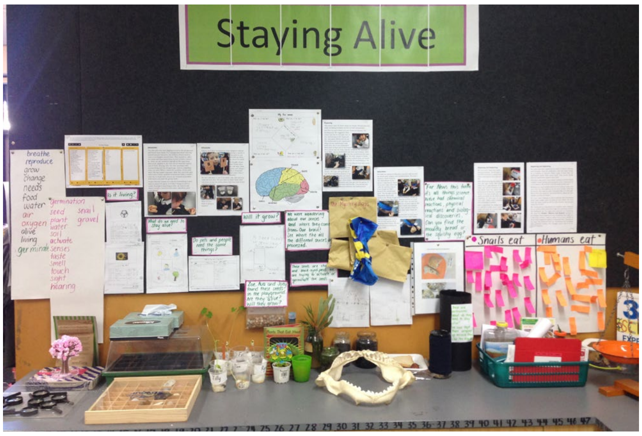
After working post-secondary school in the film industry, Jane completed her teaching degree as a mature age student, with a focus on early childhood education. Her passion is teaching mathematics and she writes the maths program for her year. Jane, however, usually approaches teaching in her own classroom with a focus on a project so that students' learning is integrated across key learning areas in the curriculum. As such, she adapts and annotates the year programs, and then documents the mini-units that she develops in responsive to her students' interests. Mini-units can be as long as a few lessons or a few weeks. Jane is guided by the students' engagement as to duration. Her own teaching philosophy has been influenced by the Reggio Emilia approach. Jane has taught at the school for ten years across the primary school, and has recently collaborated with the STEAM coordinator at the school on various projects. This is her third consecutive year teaching kindergarten.

Jane has 21 students and a teaching assistant who works in her class for approximately half of each school day.

THE TEACHING SPACE

Jane teaches science and technology lessons in her kindergarten classroom. Specialist teachers in other subject areas also teach in this room so she needs to share the space. The classroom has a wet area and sink. Jane's classroom has a display board that specifically focuses on the students' learning processes and products related to the science and technology unit, which she adds to throughout the term. She also has low benches near the wet area that can be used for display of 3D products and other items brought into school by the students. If she could change one thing about the space, it would be to have easily moveable furniture which would allow her to quickly configure the classroom to suit different types of activities.

Noticeboard and display cumulatively documents students' learning



Literature Link: Creating a science-rich/science-friendly environment is important. The products of learning and design should be displayed.

THE STAYING ALIVE UNIT: A SEEDS-INSPIRED MINI-UNIT, PLANTS AND THEIR NEEDS

The students across the three kindergarten classes at Jane's school were learning about characteristics of living and non-living things in Term 3. A core inquiry based program guided the teaching and learning in each of the classes, with flexibility for each teacher to tailor and document individual implementation. This core program was framed by the 5Es approach, which Jane draws on to structure her mini-units. She finds this a useful way to sequence the teaching and learning activities. Within lessons she also often uses the strategy of Predict-Observe-Explain.

"When I asked the class the question, 'Is this seed alive?', we had mixed responses. Both Tess and Amy said it was a tricky question, because as a seed, it wasn't alive but it could come alive at any moment if provided with water and other life giving needs." Jane

In the initial lesson of the broader unit, three students in Jane's class excitedly came in after lunch clutching an old sandwich bag containing seeds that they had found in the playground. Jane used the seeds as an impetus to pose questions in an impromptu class discussion about how you can tell whether something is living or not living. Through her questioning of the students, Jane realised that while they already had some knowledge about plants, few had worked with plants in what she called a scientific way — by developing their knowledge using the skills of science rather than gardening. From here, Jane designed a sequence of lessons, which featured hands-on investigations focused on finding out about plant needs, the features of plants and their jobs. The sequence included a small group research project that resulted in the students collaboratively creating a poster about a particular feature of a plant (for example, roots, leaves, stems).

Literature Link: Teachers need to identify and exploit teachable moments that allow explicit teaching of science principles. Teachers should connect classroom based science learning to students' experiences and exploit these teachable moments.

THE SYLLABUS

The unit linked to the Science K–10 (incorporating Science and Technology K–6) Syllabus, Early Stage 1, Natural Environment, Working Scientifically and Values and Attitudes outcomes. In the mini-unit, science and technology was integrated with other learning areas in the primary curriculum, including visual arts, mathematics, and English.

Jane emphasised the importance of being very familiar with the syllabus outcomes from across the primary curriculum, in order to be able to design and document students' learning relating to these.

THE LESSON

The lesson described here was about one week into the mini-unit. With the goal of promoting students' knowledge about characteristics and needs of plants through Working Scientifically, Jane designed a lesson specifically focusing on developing what she calls the skills of science. The targeted skills for development in this lesson were observing, classifying, comparing and contrasting, and asking questions. Prior to the children coming into the classroom for the after-lunch lesson, Jane had set up four activity stations, one relating to each skill. She had cleared the desks of all other equipment, provided an attractive display of the necessary materials and delineated space at each station.

LESSON STRUCTURE

The students came into the classroom excitedly following their lunch break, and Jane engaged them in a short, guided meditation exercise to settle and focus them in preparation for learning. The lesson commenced once the class was calmly seated adjacent to the interactive whiteboard and Jane was seated facing the class. There were three other adults in the classroom who had been recruited to assist the students during the lesson, including a pre-service teacher completing her professional experience placement, the teaching assistant, and the researcher.

QUESTIONS ARE POSED TO THE STUDENTS, TO CONNECT THIS LESSON WITH THEIR PREVIOUS LEARNING

Jane posed a question to the class to start the lesson: "What have we been thinking about and looking at in science lately?" Immediately, a number of students' hands were raised. Jane built on their answers and posed further questions related to their responses. This served both to focus the learning and provide an opportunity to use specific scientific terms. It also provided Jane with insight into the students' understandings. For example, when one of the students spoke about the seeds that they were

"By asking the right questions, we can help stimulate investigations where students are identifying objects, making comparisons, making predictions, testing ideas, and sharing discoveries, all while observing their environment." Jane

growing, Jane asked the class members: "Put your hand up if your seed hasn't germinated yet." She then posed the question: "Why do you think it hasn't?"

Next, Jane introduced the four focus skills for the lesson. She asked the students about the senses that they would be using when observing, emphasising that scientists need to use all of their senses. Jane told the students that they were going to be scientists now — they giggled as she asked them to put on their imaginary lab coats and protective glasses, which they all pretended to do.

Jane then put up a chart on the interactive whiteboard. She had allocated the students to four small groups, taking into account their varying literacy skills. She ensured that there was a competent reader and writer in each group. This meant that when the group arrived at the station, at least one student was able to read the instructions aloud to the group. The adult's role at the station was to facilitate the students' learning by posing questions and helping them to maintain focus on the task at hand, if needed.

"Each time I teach this Staying Alive unit, I find a different way to do it that best meets the interest of the students in the class at that time." Jane

STUDENTS ROTATE THROUGH THE STATION ACTIVITIES

The students had to look for their own name on the chart, and then they were gradually dismissed, group by group, to move to the station allocated.

Observing: At this station, the students had to closely observe apples using magnifying glasses, describe one in a small group conversation, and carefully sketch it using coloured pencils.

Sketching a familiar fruit using drawing materials

Classifying: Students were given a large container of bi-valve shells Jane had collected at the beach. They were each given smaller plastic take-away food containers and asked to individually sort a handful of the shells. Once the students had sorted them, they were asked to explain the characteristics used to classify the shells. Students explained their reasoning to a peer or the adult assistant. They were then directed to sort the shells in a different way. At this station, students were given paper and lead pencils, with freedom to record as they wished.

Shells classified and re-classified

Comparing and contrasting: Jane was based at this station and helped the students to use microscopes connected to iPads to compare and contrast a variety of leaves she had gathered. She interacted constantly with the student pairs, asking them questions about the features of the various leaves.

Students using mini-microscopes connected to a tablet app to observe leaves

Posing questions: Students worked with the teaching assistant to start a KWL[1] chart about snails and worms. They used iPads to take photographs and make audio recordings of their "W" questions, which were subsequently incorporated into short video clips using the Educreations app.

Literature Link: Digital technology is an integral part of students' lives. Using digital technology to communicate meaning is a valuable mode of expression that contributes to learning.

After 15 minutes, music played signalling the students to end their activity, set up the station in preparation for the next group, and to rotate. In the lesson, there was enough time for three rotations. Jane indicated that the materials would remain set up for a final rotation the following day.

STUDENTS ENGAGE IN A REFLECTIVE CLASS DISCUSSION FOCUSED ON THEIR LEARNING

The lesson concluded with Jane bringing all of the students back to the floor as a group. Jane asked: "Put your hand up and tell me, what did you like doing?" As students in the class were chosen to share their responses, Jane again asked follow up questions that probed the students' understanding of the scientific skills. For example, when one student said she liked the leaf station most, Jane asked her to "tell me something that you noticed" so that the discussion focus shifted to veins in leaves. Jane emphasised that comparing and contrasting means noticing how things are alike and different. The lesson concluded with the videos from the Educreations groups being shared on the interactive whiteboard, and students being asked to "take your lab coats off, and your protective glasses."

Literature Link: Students need time to explore, and have sufficient opportunities to challenge and restructure the concepts and abilities they develop.

1 A 'KWL' chart documents what the students know about the topic at the outset of the unit (K), what they want to know or would like to learn more about or are wondering about (W) - usually recorded as questions, and then, at the end of the unit, what they have learnt about the topic (L).

ASSESSING LEARNING

Jane's questioning during class discussion, as well as questioning from the other adults during the station activities, helped her assess the learning. She observed indicators of students' engagement in the station tasks. Three of the four station activities also resulted in written, drawn or digital products which could inform assessment of learning and planning for subsequent tasks. Photographs taken by Jane throughout the lesson documented the students' engagement in the activities for classroom display. The photographs also provided points of reference during other lessons in the learning sequence.

Literature Link: Use formative assessment to diagnose needs and inform iterative changes, and use summative assessment to gather evidence of learning achievements.

WHY DID JANE CHOOSE THIS LESSON TO HIGHLIGHT FOR THIS CASE STUDY?

Jane emphasised that this lesson reflected her belief in the importance of hands-on tasks which use readily available or inexpensive resources. She also chose this lesson because it engaged her students in learning from tasks with multiple pathways for completion that had open-ended, multiple solutions. Jane believes that kindergarten children can be autonomous learners when given support to develop independence, and provided with scaffolding from the teacher or other adults assisting in the classroom, or from peers in their group. Jane chose a lesson requiring students to be involved in both collaborative and independent learning.

"It's the doing that's important in science and technology."
Jane

ENABLERS AND BARRIERS

ENGAGING PARENTS, STUDENT TEACHERS AND YEAR 6 BUDDIES

Jane invites other adults and older students to assist her in the classroom, to promote the students' science and technology learning. She provides explicit, clear written instructions to helpers so that their involvement is scaffolded and purposeful. Sometimes assistance from others also helps students to document their learning when their developing literacy skills could otherwise present an obstacle. For example, when her kindergarten students have scheduled time with their Year 6 buddies, Jane engages the buddies as scribes to support science journal writing.

"I emailed the parents calling for 'all things science' for the children's news in Term 3. The children have conducted experiments, brought in things of wonder and curiosity, and developed their own fact files, for example, Fleur's home-made information report on slugs and snails." Jane

EFFICIENT, ACCESSIBLE STORAGE OF RESOURCES

Jane has a personal storeroom that is accessed from her classroom where she is able to store resources. She decided a few years ago to use the classroom's tote tray storage unit for class resources such as maths equipment, science and technology equipment and other stationery. Clear labelling of the trays, including pictures, makes the resources accessible to students at all times and allows materials to be easily found when needed.

Accessible storage of classroom materials promotes student autonomy

Jane commented that her personal resource storage system contrasts with that found elsewhere in the school. She believes that a more efficient system is needed across the primary school for science and technology resources, as it was often difficult to locate non-consumables needed for lessons. Jane thought that a science and technology committee of interested teachers could be formed so that resource organisation and purchases could be more coordinated, reducing the need for teachers to spend their own money.

SCHOOL CULTURE THAT PROMOTES FLEXIBILITY IN PROGRAM DESIGN AND DELIVERY

"I always do my own thing. I don't know in advance what the children's interests will be." Jane

Jane has the freedom and trust of the school executive, which is reflected in her flexible approach to programming. Once she understands students' interests in relation to the broad topic kindergarten are studying, Jane develops a plan with clear outcomes for students' learning. At the same time she remains comfortable with changing direction as the learning happens. She carefully, cumulatively documents the sequence of learning as it unfolds, through photographs, work samples, quotes from students, and her own reflective annotations on the plan. Jane looks for natural integration across the curriculum wherever possible. She maps students' learning in relation to the relevant syllabus outcomes as she documents the teaching and learning program.

PRESSURES OF TIME

According to Jane, time is always a significant consideration when planning for student engagement in sustained inquiry, as well as in design and create tasks. She teaches in a school where a number of specialist teachers teach her class on any one day. Jane overcomes the obstacle of a fragmented timetable by integrating learning areas in her teaching program, and she prioritises hands-on learning experiences across the curriculum. She acknowledges that in some weeks another subject might "take a back seat" to allow for a sustained focus on science and technology. Over the year, however, she ensures that her class program is balanced. Jane wishes that there were more opportunities for her to observe her colleagues teaching science and technology, and to learn from them about ways in which she could develop her own practice.

JANE'S TIPS FOR TEACHERS

- *Capitalise on the scientific curiosity that young learners bring to the classroom.* This is a key to ensuring that the students are engaged and motivated in their learning.
- *Draw on expertise from the school and local community.* Identify parents with knowledge of science or who work in areas related to science, and engage them in planning and delivering the class science and technology program.

> *"As a primary teacher, it's impossible to be an expert in everything." Jane*

- *High, explicit expectations of students*. Explicitly teach kindergarten students to independently investigate and inquire in collaborative groups. Young students can be supported to take responsibility for their learning in science and technology lessons. Start with whole class, project based inquiry and gradually shift to small group inquiry based tasks as students develop greater autonomy.
- *Purposefully design questions to ask the students as a scaffold for class and small group discussion, to promote conceptual development and wonder*. The questions that you ask as a teacher will frame the possibilities for students' learning about scientific concepts and processes. Provide parent helpers and teaching assistants in the classroom with a question schedule for group activities they are facilitating.
- *Be open to continually learning, and sharing your own excitement about, and enjoyment of, learning*. As well as seeking out relevant professional learning courses, watch science-related television programs and digital videos, read, follow science educators and engage in exchanges through social media, and have conversations with colleagues with expertise in areas in which you want to develop. Show your students that you too are always learning. Share with them something of your own life and interests related to science and technology when it is relevant to their learning in the classroom.

> *"I've become interested in science and technology — it can happen! But you have to have a mindset of professional growth and tenacity; you have to be willing to teach yourself." Jane*

- *Value links between learning at home and school*. Create spaces for classroom displays of objects brought into school by children from home that relate to the science and technology unit. Integrate these objects into lessons and class discussions. Regularly invite parents into the classroom to share in the students' learning.
- *Make materials and equipment used in lessons readily available to students*. At times outside of science and technology lessons, such as during free play or wet lunches, create possibilities for students to further investigate and explore in their own time, outside of more structured or directed tasks.
- *Aesthetics are important*. Display materials, students' work or products, and quality, novel resources for lesson activities in attractive ways so that there is excitement about, and pride in, learning. Select and present materials and resources for learning so that they are inviting. They do not have to be expensive or brand new, just thoughtfully chosen and presented to students.
- *Use digital technologies to create new tasks previously inconceivable in a kindergarten classroom*. Use tablet apps such as Educreations to create digital video explanations, for example, so that students with limited writing skills can explain their understanding verbally and with greater complexity. When introducing new apps to young students, timetable the lesson when you know you will have assistance from buddies or adult helpers.

DISCUSSION OF CASES

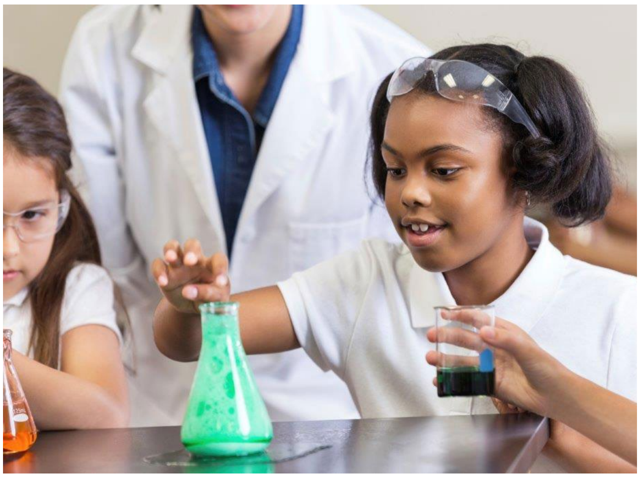
This section discusses findings from across the six case studies and considers implications arising from different models of approaches to the teaching and learning of science and technology in NSW independent primary schools.

The lessons reported were chosen by each teacher to showcase their teaching of science and technology. Most features of quality teaching and learning identified in the Quality Learning and Teaching in Primary Science and Technology Literature Review (Aubusson et al., 2015) were evident in the practices of the case study teachers.

Table 1. Case study and science and technology organisational models

Case Study	Title	Organisational model
1	Year 1 Mermaid Show	Amy is a *specialist* science and technology teacher who co-teaches with the Preschool to Year 6 classroom teachers.
2	Year 3 Magnetic Moments	Jeremy teaches science and technology as a *generalist classroom teacher*.
3	Year 5 Investigations	Leanne teaches science and technology as a *generalist classroom teacher.*
4	Year 6 Fresh Water Environments and Water Catchments	Deb is a *specialist* science and technology teacher for Years 5 and 6. The generalist classroom teacher is present during lessons but does not co-teach.
5	Science and Technology Teaching and Learning K–6	Suzie is a *specialist* science and technology teacher who teaches K–6 science and technology without the classroom teacher present.
6	Kindergarten Staying Alive Mini-unit — It Grew from Seeds Found in the Playground	Jane teaches science and technology as a *generalist classroom teacher.*

Three teachers were specialist science and technology teachers (CS 1, 4 and 5) and three were generalist primary classroom teachers (CS 2, 3 and 6). The use of a specialist teacher in science and technology is not currently typical in NSW primary schools. The way in which three specialist teachers worked was different in each case: one included collaborative planning and teaching with each generalist classroom teacher, Preschool to Year 6 (CS 1); the second comprised a specialist teacher teaching the lessons, with follow up lessons taught by the usual class teacher who was present for the specialist's lesson but did not co-teach with the specialist (CS 4); and for the third, the class teacher withdrew when the specialist took the class (CS 5). The three generalist teachers taught science and technology, as well as other subjects in the K-6 curriculum. Some generalist classroom teachers integrated science and technology with other key learning areas.



WHAT CHARACTERISES EFFECTIVE SCIENCE AND TECHNOLOGY TEACHING AND LEARNING?

In addressing what characterises effective primary science and technology teaching and learning, three main themes were identified: effective pedagogy, a positive classroom environment, and an emphasis on student inquiry. Each theme is discussed below.

EFFECTIVE PEDAGOGY

All case study teachers exhibited extensive pedagogical content knowledge (PCK) and, in particular, demonstrated strong general pedagogical knowledge. They displayed a diversity of teaching strategies, and employed a variety of appropriate classroom activities in science and technology. The pedagogies of the teachers appeared to be consistent with their general teaching orientation, and the inquiry approaches used were particularly suited to this subject. When teachers were asked about the models of teaching or teaching approaches they employed, they all referred to inquiry. The teaching that was observed and described was often consistent with the approaches discussed in the Quality Learning and Teaching in Primary Science and Technology Literature Review (Aubusson et al., 2015). These include inquiry based learning, specifically the Generative Learning Model, Learners' Questions Model and the 5Es Instructional Model. The case study teachers appear to have drawn on these and similar approaches in order to develop their own unique and context specific adaptation of inquiry.

Of particular interest is the way in which these teachers draw upon their rich general pedagogical knowledge to inform how they teach science and technology. PCK proposes that there is specific pedagogical knowledge associated with each discipline, and that the implementation of this knowledge is important in ensuring effective learning in each subject. Yet, in these case studies, the teachers' extensive general pedagogical knowledge was central to their teaching of science and technology. As a result, they have developed eclectic pedagogies which draw together elements of a variety of effective approaches.

The inquiry approaches that case study teachers described, and the lessons observed, were consistent with many characteristics of effective science and technology teaching, and this is evident in many of the examples highlighted in each case study. Science and technology-rich activities, events and experiences were used to stimulate discussion that would bring students' ideas, understandings and conceptions to the surface. The teachers promoted analytical discussions focusing on their students' varied conceptions and ideas, introducing scientific knowledge when, and at a depth to which they considered appropriate, for their classes. They used fair tests and experiments to empirically scrutinise the merit of ideas that were open to direct observation and could be practically investigated. The teachers were each a source of robust scientific information for students, to varying degrees. All of the teachers encouraged their students to seek out information from varied sources such as other students, experts, parents, books, and the Internet.

The teachers stressed that their teaching and learning focused on the development of students' skills, processes and dispositions. There was also ample evidence that they worked towards the development of student understandings of science and technology content knowledge.

The teachers' planning and preparation was informed by their knowledge of the learning needs of students in their class, an understanding of science content and processes, and an awareness of students' likely conceptions. They were familiar with, understood, and used the syllabus extensively to inform their lesson preparation. Some planned their science and technology activities beginning with the syllabus (CS 3, 4, 5 and 6), some came up with teaching ideas and then mapped these back to the syllabus (CS 2), and others engaged in a programming dance between ideas that came to mind and ideas generated from the syllabus (CS 1).

The purpose of each learning activity was clearly outlined to students. Discussion and questioning were widely utilised as teaching and learning techniques, and students were allowed to fail and try again. Hands-on activities and investigations were preferred and used to build students' knowledge and skills. There were ample opportunities for students and teachers to ask questions and make mistakes in a supportive environment. The teachers routinely provided feedback, often as informal formative assessment, to students on their learning as they carried out investigations. They were not concerned with knowing in advance all of the science content that might come up in a sequence of lessons. The teachers were satisfied with knowing enough to start an inquiry and were confident that they could learn what was needed as the learning progressed. They were all comfortable learning alongside their students.

The teachers monitored and reflected upon the ways in which their students responded to science and technology lessons through mostly informal means. They gathered information on their students' dispositions towards science and technology, and identified and commented on students' engagement in the activities and their interest in what they were learning. Formal mechanisms were sometimes used to obtain feedback from students on science and technology, such as surveys to gather data on students' perceptions of teaching (CS 4).

POSITIVE CLASSROOM ENVIRONMENT

All of the teachers fostered positive classroom interactions and relationships. The teachers each said they were passionate about science and this was reflected in their teaching. Interestingly, none explicitly expressed a passion for technology, although a positive disposition was evident. They displayed enthusiasm and confidence in their science and technology teaching and strove to create a science-rich/science-friendly environment in the classroom. The products of science and technology learning were prominently displayed in learning spaces, and the teachers all aimed to foster student interest, creativity, and curiosity in science.

It is likely that the allocation of substantial time for science and technology, and the display of science and technology-related materials, contributed to an overarching positive environment. In all classes, it was evident that science and technology was highlighted and valued as important, but this was not done by merely saying so. Rather, the valuing was evident in the teachers' overt and genuinely positive dispositions. This included their affirmative talk about science and technology, as well as expressions and manner during activities. When teachers talked about science and technology-related ideas or products, the examples seemed to imply a sense of worth or importance. The sense of enjoyment and fun associated with the activities and the connections made to daily life also strengthened positive perceptions for students.

It seems that almost all of the elements identified as contributing to positive classroom environments are derived first and foremost from the disposition of the teacher. However, each of the teachers showed that they also drew on students' existing and emerging interests and excitement for learning to develop and sustain a positive classroom environment. Each emphasised the notion that science and technology provides valuable ways of knowing and problem solving, as well as being intellectually interesting, rewarding and an enjoyable field to pursue.

EMPHASIS ON STUDENT INQUIRY

In each of the case studies, teachers used inquiry based learning to provide students with learning opportunities that were challenging and authentic. They used starter activities to arouse interest and engage students in investigations which led to teachable moments. These were used to facilitate the learning of science and technology principles, skills and processes within the learning sequence. Teachers exhibited flexibility in taking advantage of these moments as they arose from investigations the students carried out.

Each teacher spent time finding out what their learners already knew, and inquiry activities were often developed from the questions posed by teachers. Students were encouraged to ask questions and seek answers to these throughout the learning. The teachers supported students in their search for information and assessed learning during the class to inform their learning progression. Inquiry activities were routinely linked to students' real life needs and experiences.

The Quality Learning and Teaching in Primary Science and Technology Literature Review (Aubusson et al., 2015) identified a continuum of inquiry, from closed to open-ended. The sample lessons in the case studies appeared to range across this continuum. It is noteworthy that when the inquiry had a science emphasis, investigations tended to gather evidence that led to acceptable conclusions, claims or propositions that reflect the subject matter. By contrast, when the inquiry had a technology emphasis, often solving a problem, the activity allowed students to create a variety of solutions. These solutions varied in the extent to which they resolved the problem, which was evaluated as part of the activity (CS 4).

Collaboration in inquiry and problem solving activities was common, with teachers positioning themselves within teams working on investigations or developing solutions. A variety of strategies were used in different classes to encourage students to report and share work in progress and to present final products or outcomes to their peers. In this and other ways, teachers ensured that the work of teams and individuals contributed to the learning in science and technology. There were occasions where individuals and teams conducted investigations relatively independently from their classmates and the teacher (CS 3). These investigations were usually made public to, and shared with, the class. Consistent with the Quality Learning and Teaching in Primary Science and Technology Literature Review (Aubusson et al., 2015), collaboration with the wider community was evident with teachers sometimes inviting parents with relevant expertise to contribute to the learning experiences of students (CS 6). Some created links with secondary school science departments, universities and industry to enhance the pool of scientific expertise within their schools (CS 4 and 5).

SUPPORTING SCIENCE AND TECHNOLOGY

The case study teachers indicated that they felt well supported, which enabled them to provide a productive learning environment for their students. They noted that their classrooms and the equipment to which they had access were adequate to teach science and technology. Although there were differing views on what resources were required and how difficult these were to acquire and store, the teachers were able to adapt and teach science and technology effectively. It was agreed that specialised equipment was not necessary to teach science and technology well — in fact teachers believed that effective science and technology learning could be accomplished by using everyday materials. Some teachers argued that using items familiar to students was better than using specialised laboratory equipment because this provides authentic experiences connected to the real world. However, two teachers (CS 1, and 5) had access to, and used, highly specialised science equipment such as microscopes.

A number of teachers commented on the desirability of not having to pack away resources and student work after a lesson. Some, particularly generalist classroom teachers, noted that timetabling of science and technology sometimes constrained the type and duration of activities they used.

In the lessons observed, all teachers but one (CS 1) used Information and Communications Technology (ICT) to facilitate teaching and learning. Apart from using ICT for production, communication and display (for example, word processing and presentation tools), the students also used devices to digitally capture events (for example, images) and access the Internet to gather information and seek explanations. In this way, the provision of ICT resources was critical in supporting ways in which the teachers approached science and technology during the observed lesson.

All of the teachers noted that they had benefited from science and technology professional learning opportunities, either offered within the school or externally. Support for these professional learning activities from the schools was valued. The teachers also used their own time and resources to engage with science and technology outside the school. This ranged from watching television programs and digital video clips of relevance to primary science and technology topics (CS 6), to attending presentations by science experts on varied topics well beyond those typically addressed in the primary context (CS 5). While teachers had support for formal professional learning within their schools, they also independently invested time and sought out support they found personally and professionally rewarding.

All of the case study teachers perceived that the executive leadership teams within their respective schools were supportive of science and technology. They praised their school leaders and pointed to the support they received as being key to enabling them to teach science and technology well. The teachers were recognised within their schools for their work. Both generalist and specialist case study teachers were involved in whole school science and technology initiatives. Some, for example Leanne (CS 3), had started and led a school science club, and Jane (CS 6) had initiated science week activities.

The teachers indicated that having a supportive school or local community was of great benefit. To augment their capacity to provide rich learning experiences for their students, teachers identified and drew on parents as helpers (CS 6) or experts (CS 5). Supportive secondary school science departments, with which the schools had connections, and local universities were also used by teachers to enrich their science and technology lessons.

HOW DO TEACHERS OVERCOME BARRIERS?

Teachers commented on the barriers that they thought others may encounter when teaching science and technology, such as ineffective leadership or inadequate resources, and claimed that they did not experience these particular barriers within their own environments. However, they did comment on other barriers, such as school arrangements of timing and scheduling. For example, Jane (CS 6) frequently borrowed time from other subjects in one week to devote more time to science and technology, then returned the time to those subjects in other weeks in her class timetable. She also integrated science and technology with other subjects in the curriculum.

The case study teachers had overcome other barriers, such as those related to resources or space, by drawing on strong PCK and a confidence in their ability to teach science and technology. For example, their knowledge of what they were required to teach, together with their confidence in the field, allowed them to take the initiative in organising and obtaining materials and equipment. In each school, the teachers managed their own material resources but were supported to purchase what they required. Some of the teachers also expended personal funds on resources for their classes (CS 6).

Barriers related to low teacher PCK, such as a lack of professional expertise or negative attitudes towards science and technology, were largely non-existent among the case study teachers. This is not unexpected given the process of nomination and selection for inclusion in the current research. These teachers possessed extensive PCK and demonstrated a willingness to pursue continuing professional learning in the area of science and technology.

Other barriers identified within each of the schools varied considerably. Three of the case study schools had resolved many of the challenges usually associated with effective teaching of science and technology by appointing a specialist teacher. Others had at least one generalist teacher — the case study teacher — who had built up resources for their own classes as and when required. These teachers willingly expressed ideas as to how systems or processes in their school could be improved so as not to present barriers for others. These included having a central science and technology storeroom with a borrowing system to keep track of resources, a system for replacing consumables, and a science and technology committee at the school level.

The case study teachers' strong commitment to science and technology, combined with their expertise and passion, allowed them to teach effectively in their primary classes. Although they were aware that barriers exist, these were perceived to be minimal within their own contexts and did not appear to inhibit or prevent them from teaching science and technology effectively.

HOW DO TEACHERS AND SCHOOLS BECOME EFFECTIVE AT SCIENCE AND TECHNOLOGY?

The propensity of case study teachers to explore and develop their skills as science and technology teachers was a key feature leading to their proficiency in teaching this subject. These teachers actively engaged with science and technology — they started clubs and organised activities within their schools, and actively sought professional learning opportunities. They worked within school environments where risk taking was encouraged and the executive leadership team supported science and technology education. These factors allowed them to flourish and often fill the role of science and technology champion at their school.

All of the teachers exhibited independence in their teaching of science and technology. Three were appointed as leaders of science and technology in their schools and taught the subject across the school or designated stage. Some of the case study teachers welcomed and cultivated support from colleagues, worked closely with other teachers (CS 1), and had a mentor in the school (CS 5). Others (CS 2 and CS 6) were relatively isolated as science and technology-philes, with one teacher mentioning being a "Lone Ranger" amongst the teachers in her stage.

The case study teachers had the confidence and knowledge to act without extensive collaboration with their teaching colleagues. A notable exception was the teacher in CS 1 who worked closely with colleagues. She had previously initiated and created the current state of collaboration with colleagues, some of whom had been reluctant teachers of science and technology. The support of colleagues ranged from co-teaching, which had been cultivated by the case study teacher, to appreciation of the subject generally. Consequently the case study teachers drew on supportive executive leadership team members, their own professional resources, and networks beyond the school to sustain themselves in their commitment to science and technology.

The case studies demonstrate that effective science and technology teaching can readily occur in a variety of spaces, ranging from everyday classrooms to specialised primary school laboratories. The teachers involved exercised considerable autonomy in organising, managing and conducting science and technology lessons in their classes.

There is evidence from the cases (CS 1) that a highly capable science and technology champion may readily generate interest in science and technology among others and promote the effective teaching of this key learning area. However, the case studies suggest that a single effective teacher of science and technology may feel isolated. In short, different avenues for progress can be suggested. The first suggestion discussed below is derived directly from the case studies. The second is more speculative and applies to teachers who do not exhibit the science and technology PCK and positive disposition of these case study teachers. These are not intended to be mutually exclusive nor prescriptive.

Where a school has identified that it has relatively low science and technology capability it may be possible to improve this. The case studies suggest that having at least one science and technology champion can be critical for encouraging effective science and technology teaching and learning throughout a school. A science and technology champion can provide the model, encouragement and advice to develop the capabilities of other teachers. As noted above, a direct and simple way of achieving this may be to appoint a staff member who demonstrates these capacities. It may be equally productive to invest in developing the expertise of an enthusiastic existing staff member. This strategy would also need to be combined with executive leadership support and provision of resources.

However, merely appointing a champion in and of itself may not be sufficient because strategies to overcome problems associated with the isolation and siloing of expertise may also be required. We speculate that a distributed and collaborative form of leadership within a school may be possible if productively promoted and well supported by the school executive. It may be possible, as suggested in the Quality Learning and Teaching in Primary Science and Technology Literature Review (Aubusson et al., 2015), to develop collective science and technology PCK, such that the expertise does not reside within a single individual. Achieving this would require an investment in on-going professional learning and require a team approach, at least at the stage or year level. Ideally this might be supported through the careful development of a professional learning community or communities of teachers in or across schools.

It may be that a variety of professional learning opportunities and investment in resources may themselves bring about developments in science and technology teaching and learning. The case studies do not provide evidence regarding this possibility as the number of case studies was limited, and none allowed the study of all teachers in a school. The case study teachers all began teaching with a long-term interest in science and technology. This may be an artefact of sampling in identifying effective teachers of science and technology, but it is also possible that having at least one such enthusiast in each school may be essential. Schools that have numerous teachers with positive dispositions and at least modest science and technology PCK, a supportive executive, the availability of relevant professional learning opportunities, and the provision of well-organised resources may have the necessary foundational requirements to support effective primary science and technology teaching and learning.

Given that many teachers do not overcome the barriers to effective primary science and technology teaching, initiatives to improve this within and across schools would require that these barriers be identified and reduced. The next phase of this research project investigates these barriers. Results from this can be found in the Barriers to the Effective Teaching of Primary Science and Technology: Report on Best-Worst Scaling (BWS), and Supporting the Effective Teaching of Primary Science and Technology: A Discrete Choice Experiment (DCE) Approach), which will be released in early 2017.

IMPLICATIONS OF ALTERNATIVE STAFFING MODELS FOR SCIENCE AND TECHNOLOGY

The case studies suggest that the generalist teachers in this study were more than capable of providing effective science and technology education in their own classes. Specialist science and technology teachers in a primary school can also contribute to effective science and technology teaching and learning for students across the school. The case studies provide no single path for schools to follow. However, it is worth stressing that all of the teachers in the case studies were considered to be effective by their recommending principals.

One of the challenges identified in the case studies not evident in the literature relates to feelings of isolation which some science and technology teacher enthusiasts experienced. This may have implications for the development of science and technology capability. In the case study schools, there were two themes of isolation which are discussed below.

In schools that employed a specialist science and technology teacher, the expertise tended to reside with these experts. There was no need for capability to be developed and distributed across the school because these specialist teachers taught all of the science and technology. There are inherent risks in this model, as the departure of one teacher would have an immediate and profound impact on the quality of science and technology teaching and learning in the school. Re-instating effective science and technology teaching would then require the availability of a similarly effective expert and the ability of the school to rapidly employ this replacement.

In schools where the effective teacher was a generalist, it is unclear whether these teachers contributed to the science and technology expertise of others in the school. It is possible that schools may be under-utilising opportunities to share and build on the expertise of highly capable generalist teachers. Given the current workload of the case study teachers, and the time they devote to preparing for and teaching their own classes, it is unclear whether this would be feasible or sustainable.

The role of PCK, and its development as a means to enhancing science and technology, is not in dispute. The case studies show that extensive PCK is central to the work of effective teachers. General pedagogical knowledge and its application to science and technology was also evident. As a result, this study suggests that there are implications for primary school science and technology PCK.

A starting point in the development of teachers' PCK in science and technology is often science and technology specific teaching models or approaches, such as those identified in the Quality Learning and

Teaching in Primary Science and Technology Literature Review (Aubusson et al., 2015). However, the case studies suggest an alternative starting point, whereby the development of PCK might begin with professional learning that privileges the generalist pedagogical knowledge primary school teachers possess, particularly that related to inquiry learning. From this starting point, and working from this strength, the next step would be to elaborate on its adaptation to the teaching and learning of science and technology. Then, specific science and technology pedagogies might be introduced in the teachers' learning journey as they become more confident and able to draw on more specialised teaching approaches. The professional learning sequence suggested here builds on existing strengths and their application to science and technology.

The different models involving specialist teachers in the delivery of primary science and technology are of interest in this research study, especially given current interest regarding specialist teachers within the profession (Office of the Chief Scientist, 2015). There have recently been calls for all teachers to have a specialisation (Teacher Education Ministerial Advisory Group, 2015) and, as this report goes to press, NSW Board of Studies Teaching and Education Standards (BOSTES) is considering applications from a number of universities to recognise a science and/or technology specialisation in their primary teacher education degrees. Therefore, models described in the case studies have significant implications for the teaching of science and technology.

The employment of a science and technology specialist to teach and lead education in this subject area may either require additional staffing investment or changes to staffing arrangements within a school. The feasibility of this for individual schools is beyond the scope of this research. We only note that such action had been taken in three of the case study schools.

In the case study schools employing specialist science and technology teachers, two had specialist teachers with full responsibility for teaching science and technology to all primary students, either across the school K–6 (CS 5) or to classes within a stage (CS 4). Other teachers were not involved in the teaching of science and technology, although in one school (CS 4), an established program of collegial peer observation resulted in her observing generalist teachers within the school. Observations could be of science and technology lessons, and therefore expertise in the subject was available to generalist classroom teachers. In the first case study (CS 1), the specialist teacher co-taught with the regular classroom teacher and contributed to their becoming more engaged with, and more expert teachers of, science and technology.

A potential consequence of the first model, where the specialist takes full responsibility for all the teaching of science and technology, is that it may lead to a deskilling of generalist teachers in science and technology. This may impact on their employability at other schools and may make it difficult for the school to move to different organisational staffing models for the teaching of science and technology in the future. A concern for the second model, the generalist teacher co-teaching with a specialist teacher, is that it has significant staffing and cost implications.

The case studies provide examples of teaching and learning in contexts that may generate ideas for science and technology education in other school settings. The models presented here are not intended as models for adoption or implementation as described. No doubt there are other models which involve specialist and generalist teachers that were not evidenced in these case studies. If the case studies tell us anything, it is that there are a variety of ways to approach effective science and technology teaching and learning in different contexts. Therefore, each school should consider its own needs and resources in determining the strategies it considers for use.

CONCLUSION

What effective teaching and learning in primary science and technology looks like has long been a matter of national concern. Government, business and many educators consider the need to improve science and technology teaching, learning and engagement to be of critical importance for young learners in preparing them for the future. This is evident in the prioritisation of

STEM within education policy and discussion, including commentary on the importance of improving teacher efficacy in this area. This study provides a number of valuable insights into effective teacher practice within the independent sector that school leaders and educators may consider for use within their own contexts in order to improve the learning experiences of primary students in science and technology.

The variety of practices illustrated in these case studies highlights the multiplicity of approaches available for the effective teaching of science and technology. The lessons and learning sequences observed ranged across a variety of activities and strategies. However, common to all case studies was the contextualisation of the lesson and the active involvement of students in investigations to learn both science and technology skills and content.

Teachers emphasised inquiry approaches in the teaching and learning of science and technology, and their lessons were imbued with their professional and personal perspectives. They drew on similar pedagogical principles, but how these manifested in their classroom practice was particular to their individual context and the needs of their students. Each teacher displayed considerable PCK, was enthusiastic and passionate about science and technology, and demonstrated a strong desire to foster positive attitudes about the subject.

These teachers taught in supportive environments and their work in science and technology was valued by their school's leadership team. They engaged in a variety of ongoing professional learning activities to ensure that they continued to improve, and some endeavoured to support their colleagues in improving their practice. One teacher did this through co-teaching, and another participated in peer observation as part of the school's routine appraisal processes.

Although the teachers had much in common with respect to how they engaged in effective practices there were also many differences. Some were science and technology specialists and others generalists with a strong commitment to teaching the subject. Some taught in standard classrooms with relatively few resources, while others had access to a specialist classroom with extensive resources. Despite this variety of contextual and individual factors, all still managed to effectively teach science and technology in their classrooms. This suggests that although teaching and learning is greatly influenced by the environment in which teachers operate, the opportunities they have, the children in their classes, and the nature of the teachers themselves, there is still great potential for effective science and technology education to occur.

While keeping in mind the limits to generalising from these case study findings, it is clear from this research that there are general guiding principles and practices that appear pertinent to the primary school context. It is equally clear that there is capacity for teachers to make science and technology their own as they draw on their own strengths and capabilities, and mobilise their environments and opportunities. In doing so teachers can make science and technology teaching and learning a rewarding endeavour — both for practitioners and learners alike.

RECOMMENDATIONS

These recommendations draw on both the Quality Learning and Teaching in Primary Science and Technology Literature Review (Aubusson et al., 2015) and the case studies.

It is recommended that teachers:

1. emphasise inquiry based approaches when teaching science and technology
2. employ tools to gather data on the extent of inquiry based teaching and learning in their classes
3. reflect on their overarching pedagogy of science and technology and consider how to imbue it with their own professional and personal values and beliefs
4. embrace opportunities to learn with their students in science and technology
5. display an enthusiasm for science and technology.

It is recommended that schools conduct analyses focused on:

1. gathering information on the extent and richness of inquiry in science and technology teaching and learning. This will provide teachers with evidence as a basis for collaborative reflection on practice and guide development in science and technology. A variety of tools could be used to support this and, if combined with data analytics, would provide baseline and iterative data for teams of teachers to use to target actions that enhance practice
2. teachers' science and technology pedagogical capability. If required, schools could facilitate collaborative professional learning targeting identified needs. The professional learning could be part of the schools' existing professional learning processes, which could include creating opportunities for peer observation of practice
3. the organisational arrangements for science and technology. If required, schools could optimise the scheduling and timing of science and technology lessons
4. leadership support for science and technology. If required, schools could provide additional support for the teaching of primary science and technology such as resources, professional learning and emphasising science and technology in the school curriculum
5. connections with the community. If required, schools could implement strategies to engage with their communities in communicating about science and technology, as well as drawing on expertise in the community to enhance science and technology
6. the potential advantages of developing a science and technology champion to advocate for primary science and technology education throughout the school.

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APPENDIX

The Quality Learning and Teaching in Primary Science and Technology Literature Review (Aubusson et al., 2015) conducted in the first phase of the broader study suggests that the following features characterise quality science and technology learning and teaching:

1. foregrounding student inquiry
2. finding starter activities that arouse and engage students in investigations
3. identifying real needs or problems and seeking or building solutions
4. promoting student questioning
5. exploring ideas, developing designs, creating products
6. sharing and subjecting designs and ideas to scrutiny through evidence based discussions and in trial by experiment
7. failing and trying again
8. looking up information and finding out what is already known
9. engaging in authentic activities
10. connecting to students' life experiences
11. displaying and presenting products of learning and design
12. using formative assessment to diagnose needs and inform iterative changes to planned learning sequences
13. students creating and analysing their own representations and analysing standard technological and scientific representations
14. exploiting teachable moments for explicit teaching of science and technology principles, skills and processes
15. employing summative assessment to gather evidence of learning achievements
16. using a variety of strategies to communicate ideas with a range of audiences

16\. using digital technologies to enhance learning

17\. connecting learning experiences with local communities.

NOTES

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