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AUSTRALIAN SCIENCE TEACHERS ASSOCIATION

teachingscience

THE JOURNAL OF THE AUSTRALIAN SCIENCE TEACHERS ASSOCIATION

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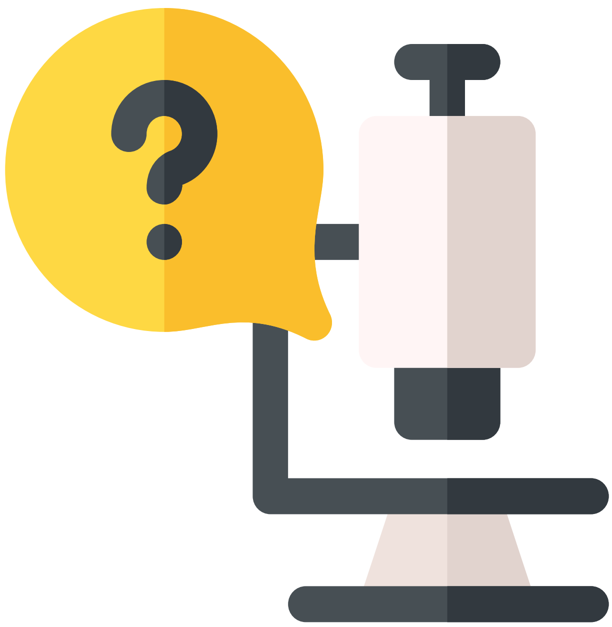

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Teaching Science is a quarterly journal published by the Australian Science Teachers Association. This journal aims to promote the teaching of science in all Australian schools, with a focus on classroom practice. It acts as a means of communication between teachers, consultants and other science educators across Australia. Opinions expressed in this publication are those of the various authors and do not necessarily represent those of the Australian Science Teachers Association or the editorial advisory committee.

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AUSTRALIAN SCIENCE TEACHERS ASSOCIATION

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Contents

EACH ISSUE

From the President

Rosemary Anderson

Teachers play a vital role in our society, often acting as role models for young minds and guiding them towards realising their potential. Nowhere is this fact more important than in the fields of Science, Technology, Engineering, and Mathematics (STEM). Therefore, it is vitally important that our teachers, especially those in primary and secondary schools, are well supported. Our mission at the Australian Science Teachers Association (ASTA) is to support all teachers in the STEM fields across Australia so that they can inspire young minds about the wonderful world of science and technology every day. In this issue of Teaching Science, I would like to share my perspective on inspiring young minds towards STEM.

Young children have a natural curiosity about the world around them. They are inquisitive, asking questions to anyone they think may have the answer. Teachers in primary schools are often faced with non-trivial, deep questions from a curious child. How a teacher reacts and responds in that circumstance often has a big impact on the child and may either encourage them towards or deter them from the path of curiosity and inquiry. Therefore, as a teacher, it is vitally important that we understand how to appropriately answer such questions, so as not to deter or subdue the flickering flame of curiosity within the child. Doing it badly often imprints the child with fear and negativity towards inquiry and prevents the development of a scientific mind.

Science is a field of inquiry into the world around us. Progress in science is made by observations and analysis of said observations; experimentation and curiosity are fundamental pillars of scientific thinking. The difference between a curious child playing with their toy and a scientist trying to understand how a protein functions inside the cell is in the approach and rigour of the latter, which comes from training. Curiosity shaped by understanding and knowledge propels science forward. They are both fundamental pillars of science, and both need to be cultivated simultaneously.

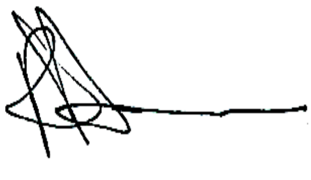
Not every student is naturally scientifically inclined. Internal variations aside, such biases come from upbringing. As stated earlier, imprints made at a young age are powerful motivators, and should be treated with care. Such thinking also comes from the portrayal of science and scientists in media and popular culture. There, the reality of scientific research is often misrepresented and for young minds this reinforces the misconception that science is about writing long, complicated equations with odd-looking symbols. It is, therefore, very useful to expose students to accurate representations and misrepresentations of science and scientific research.

Excursions to prominent research institutes provide an excellent way of doing this. This has proven true in my personal experience. Some years ago, the Australian Nuclear Science and Technology Organisation (ANSTO), ran a Big Ideas competition to encourage students to think about today's problems that the students would like ANSTO scientists to find solutions to. I encouraged two of my students to submit an entry and their entry was selected. At the time, the two students, who were the main participants in this project, were not particularly inclined towards science. One was a slightly above-average student in science but excelled in the arts. The other, was a below-average student in science who also displayed no interest in science. What was common in both these students was their passion for the environment. I used their passion to ask the question: "What would you like to see changed in your community? What do you think scientists should do?" I never mentioned the competition. In no time, I had the students coming up with all sorts of real issues facing our community that in their view could be solved by science. I then said, "What if you actually had an opportunity to tell the country's top scientists your idea?" As winning entrants, both students and I spent a week in Sydney working with scientists at the ANSTO laboratories. We all enjoyed the experience greatly. It was a great learning experience for all of us and indeed a privilege seeing cutting-edge experiments being carried out in a state-of-the-art facility. That excursion, and exposure to real-world science, was a turning point for both of my students. In senior secondary, they both elected to do science and then went on to become STEM professionals. This is one of many such situations where a positive experience and proper exposure to science motivated a student to pursue it further.

Nurturing curiosity and providing the right environment for the curiously minded leads to them being more interested in finding out the inner workings of the world around them, leading them to science. Some years ago, there was a disengaged student in my school whose teachers mostly classified as 'naughty'. The student would often end up in my office for being disruptive in their classes. The student did not show any particular interest in STEM, but I used to take them to my laboratory to keep them engaged while I got on with my work. I quickly realised that the student really enjoyed the experiments that we were doing during this time out, to the extent that they would deliberately get kicked out classes just so they could come and 'do science' with me. In senior secondary, to the surprise of their parents and teachers, they pursued science courses and eventually went on to study medicine and become a doctor. A gentle nudge in the right direction through engagement and fun helps grow interest and leads young students to pursue STEM courses and careers.

Not everyone is scientifically inclined, but experience shows that the right guidance may lead them down a path of STEM. We, as teachers, must take care not to inhibit the curiosity of a young mind, especially when they ask us questions that we have never thought of before and have no idea about. Science is fuelled by curiosity; and that questioning instinct will lead students to the fields of science. Of course, the curiosity and experimentation need to be supplemented with study, analysis and understanding. Practical investigations and excursions to science and research institutes are very useful in this regard. As teachers, it is our duty to guide our students into the wonderful world of scientific discovery and expose them to real-world science.

Rose Anderson
ASTA President



From the Editor

John Glistak

Welcome to the second issue of *Teaching Science* for 2022; the 68th year of this publication, in its various titles, since its inception.

The Editorial Advisory Committee is seeking additional members to assist with the peer review of manuscripts as they are received, to select the Most Valuable Paper for the previous year's journal, and to assist in other directions, as required. So, if you would like to join us on the Editorial Advisory Committee, please contact me at editor@asta.edu.au.

In this issue, Manolis Kousloglou, Anastasios Molohidis, Kleopatra Nikolopoulou and Euripides Hatzikraniotis present a case study of the integration of the Phyphox application that utilises a smartphones' integrated sensors in hands-on physics experiments on friction in an inquiry framework.

Nadya Rizk, Matt McKenzie, and Marya Samrout, in their article, describe a 90-minute lesson activity on coding that consists of three parts: an introduction, a competition, and a concluding discussion session. The activity aims at helping primary students develop their computational thinking skills, furthering their literacy in coding, and developing their appreciation for the ubiquity of algorithmic thinking and its applicability to a wide spectrum of contexts.

The topic of the motion of the Moon is covered in both primary and secondary schools in Australia. Students typically learn about the sidereal month, synodic month and the Moon's passage through the zodiac. The Sun is, by definition, always on the ecliptic. However, the motion of the Moon, as seen from Earth, can appear to be a considerable distance away from the ecliptic; if students observe the night sky, they may find a number of planets in line, but the Moon itself may be slightly out of this alignment. Keith Treschman's article represents an extension for students interested in the topic. It could be used as a class exercise to measure where the Moon rises and sets over time and its greatest elevation during the day or night.

In the second of a 3-part series, Keith Skamp and Jodie Green once again address the issue of Earth System Science Education and the Australian Curriculum: The way forward to sustainability. In this issue, how the most current Earth System Science understandings and abilities could lead to a far deeper understanding of the Earth System are considered and those that may need more attention from students and teachers are highlighted.

Also included in this issue are a range of smaller articles on a diverse selection of topics.

Until our next issue ...

Best wishes

John

From the CEO

Shenal Basnayake

Greetings all,

As I write this, the 2022 Australian federal election has just come to an end and, whilst several seats are yet to be decided, a new Labor Government is in place, with or without a majority in parliament. What this means for school science educators, and science in general, time will tell, but I hope the foundation I have laid over the past few years — directly engaging with all sides of politics — will bode well for our federation. I certainly have my work cut out for me with the large number of independents potentially holding a balance of power, which means more people to engage with and gain support from. Hopefully, given the priorities they backed, scientific, evidence-based decision-making is at the forefront of their minds, which I intend to capitalise on.

In the lead up to the elections, ASTA released a list of election priorities and we had fantastic engagement from our followers across our social media platforms. Whilst follower engagement was high, we did not get any political party committing to any of our priorities, which has been disappointing. I communicated our priorities across the political spectrum, and so far, the only positive news I had was a response from the Hon. Tanya Plibersek that she would do what she can to support our Science ASSIST service. This is some good news. It is not, however, a commitment to support our request, but one I will take and pursue with the new government. I do note that education was on the backburner this election, with very little being said or reported about it, and certainly not school education. This makes it even more important for ASTA to actively pursue our priorities so that we can continue to support our members.

If you have not heard or seen, I am pleased to announce the launch of our *Chrysalis* online learning portal (https://chrysalis.asta.edu.au/). This is something I have been waiting for, as I believe it will help bring school science educators access to greater flexible learning opportunities, whilst expanding the reach of our federation. We are slowly building up a bank of courses, and I thank the STAs that have put content on the portal so far and invite you to keep an eye out across our social media platforms and website as we announce more new content. In the space of the first 12 hours of the launch of the site, statistics across our social media channels indicated very strong engagement and interest in the portal. Therefore, I look forward to learners enrolling and undertaking programs with us, as the more the portal is utilised by learners, the more content we can build. I also encourage you to ask your STA for content that you would like to see, you may even want to work with your STA to develop and deliver such content. Whilst it will take time to build content and a learner base, I am confident that Chrysalis will go from strength to strength as we continue to offer high-quality content on a regular basis.

As you know, Science ASSIST — as a new federal government-funded project — has been going for a few months now. Teresa Gigengack, the Science ASSIST Manager, has had her hands full working with the government to finalise the project activity plan. I'm pleased to say now that the plan was accepted. As part of the plan, Teresa has recruited a number of new casual staff. The new team is made up of teachers and technicians with expertise across multiple learning areas and year levels, which will add to the expertise and experience we already have in place. As mentioned above, one of our election priorities was for ongoing baseline federal government funding for the continuation of the service and I am hopeful that we will secure this funding over the next few months. If not, then we risk losing the service at the end of the year. Whilst we await a decision on ongoing funding we are once more actively pursuing school subscriptions, which are steadily growing, but we need many hundreds more schools to subscribe. To find out more about subscribing you can head to https://www.asta.edu.au/science-safety/science-assist/

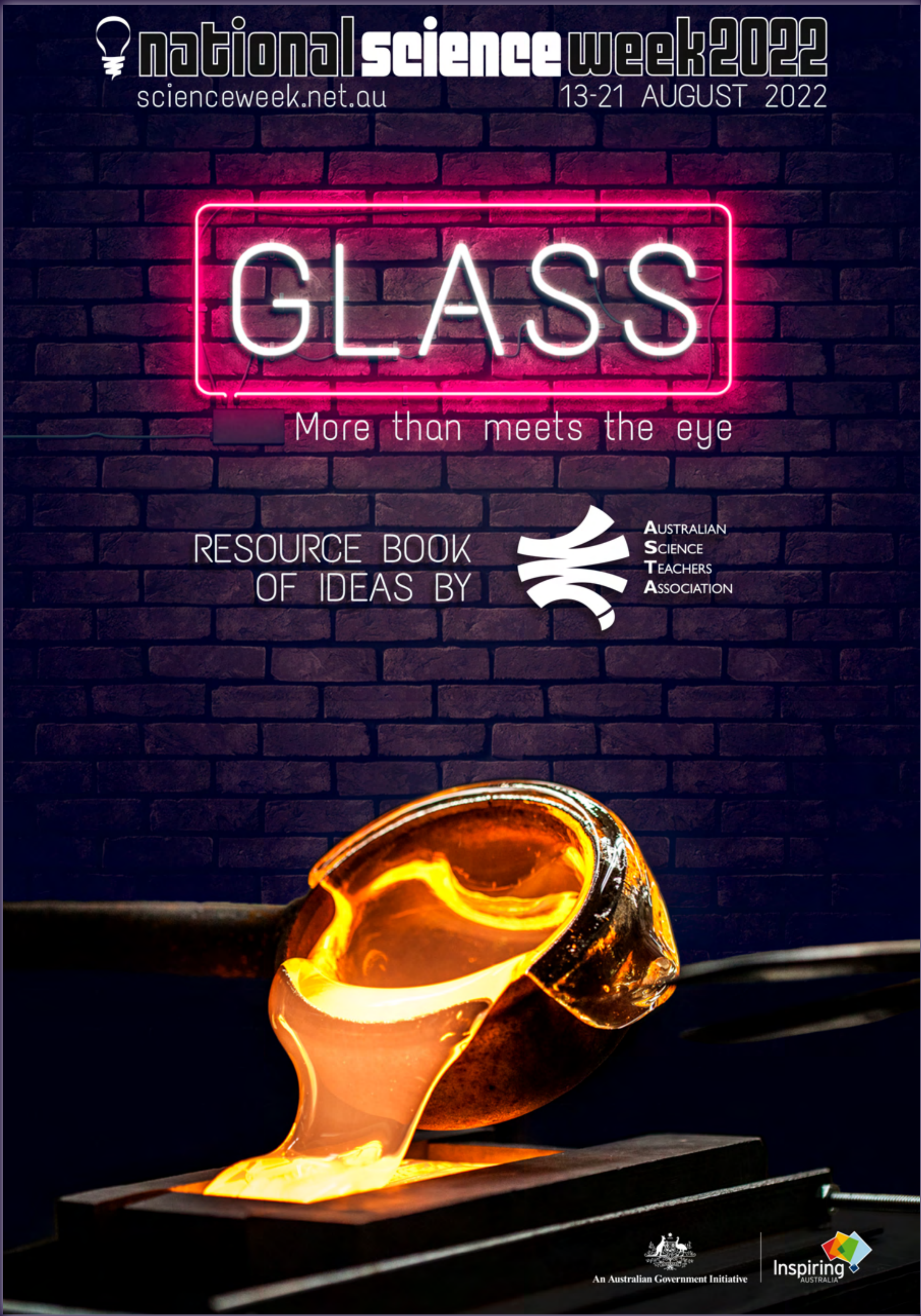
I recently spoke with the new Science Curriculum Specialist at ACARA about the release of the new curriculum and have organised a meeting for our STAs to find out more about the changes. There are several areas that ASTA raised concerns about during the development phase that were not addressed to our satisfaction, however, now that the curriculum is in place we need to look forward to its implementation as well as how we support teachers to adopt and adapt. As you may have seen, we raised implementation of the new curriculum as an election priority, including our approach to supporting teachers. I look forward to having discussions with the new government about this. As you may have heard, a new curriculum website has been launched and I encourage you to have a look at it and let your STA know your concerns or suggestions (https://v9.australiancurriculum.edu.au/).

On a final note, I attended the Associations Forum national conference in Melbourne in April, which was a great success. I was invited to present on the topic of 'Major Association Transformation' and I was pleased to have the STAV President and the STAV Executive Officer attend. It was great exposure for ASTA and recognition for the work we are doing in driving positive change and growing impact. The conference itself was very good with excellent topics and I met several other member association executives and board members. It was interesting to see the common threads we all share, regardless of size or the sector we represent. Associations play a vital role in supporting their members, but change is a constant and requires brave action from those responsible for driving them. It is imperative to understand and meet the needs of a varied and evolving demographic whilst recognising the actions of the past but not being tied to doing things the same way because that's the way they have always been done. It is important to encourage and foster emerging leaders, including those within staff, as it adds to the depth of expertise that is needed to address the challenges, particularly when trying to attract new members. Addressing these challenges will also require a long hard look at how best to structure and operate as an association. There is much to think about, but right now I am happy to celebrate the wins we have achieved.

On a final note, CONASTA is happening this year in Canberra, and I encourage you to attend. It will be a wonderful opportunity to meet face to face with peers and friends from across the country. To find out more go to https://www.asta.edu.au/programs/events/conasta/

Cheers,

Shenal



National Science Week 2022 Teacher Resources

Available to download at:

www.asta.edu.au

The Teacher Professional Lifecycle Framework

By Margaret Shepherd, President of STANSW

In 2022, an ASTA working group researched the career life cycle of a science teacher from pre-service to retirement in order to better support professional learning programs for its members. The project resulted in the production of a framework showing the relationships between individual teacher contexts in their personal and workplace life and the various different levels of expertise or engagement. While the framework shows a non-linear pattern throughout the career journey, it does provide a way for professional development providers to cater to the various needs of P–12 STEM/science teachers.

With so many different research models suggested for the career life cycle of a teacher, for the purpose of this project, the amalgamated model was created. The work included segments from models developed by Aydin (2018), Fessler (1985), Huberman (1989, 2001) Steffy (2001), White (2008) and Hattie (2013).

The advisory panel for this project also strongly recommended that the major focus is on the Australian Professional Standards for Teachers and, as a result, the framework uses those standards as well as the national Professional Standards for Highly Accomplished Teachers of Science written in 2002 by ASTA in conjunction with ACER and Monash University (https://research.acer.edu.au/teaching_standards/9). Both of these documents align in the areas of professional knowledge, practice and attributes.

The framework then builds on a science teacher's organisational environment from both home and work, as it was recognised that motivation for undertaking lifelong learning is foundational to developing expertise. Some of these factors include wellbeing, collegiality, isolation and emotional intelligence to name a few (Fessler, 1985). The more recent issues that have added to this environment are remote learning, absences from school for both staff and students and the consequential on-costs to staff time, funding and resourcing issues, and media hyperbole about quality teaching. These points urgently need research as more recent information is essential.

The second component to the framework was career life stage, and all these can be seen in Figure 1.

This framework can now be used when planning and scoping professional learning opportunities for science teachers. It would inform the purpose and direction as well as the audience for the professional development (PD) and would better cater to the very wide range of teacher levels.

One example for using the framework would be Table 1. This planning would inform the presenter that the audience will be growing in their expertise and very enthusiastic but hesitant of their own capabilities. They are proficient teachers and are keen to learn more about chemistry pedagogical content knowledge.

Table 1: Scoping of PD for science teachers.

PD event	APST	Context	Life stage	ASTA standard
Chemistry workshop	Proficient	Science hesitant	Growing enthusiastic	Broad range and current knowledge of teaching, learning and assessment

There are many advantages for the state Science Teacher Associations (STAs) for using this framework. Experienced and expert teachers could be a resource for each STA. The mentoring arena is particularly useful in recognising expertise and providing a space to share it. There are also clear descriptions of levels of expertise that can be used to link to both teacher environment and the Australian Professional Standards for Teachers in a non-linear manner. Lastly, it opens the opportunity for tapping into emeritus or actively retired expert science teachers.

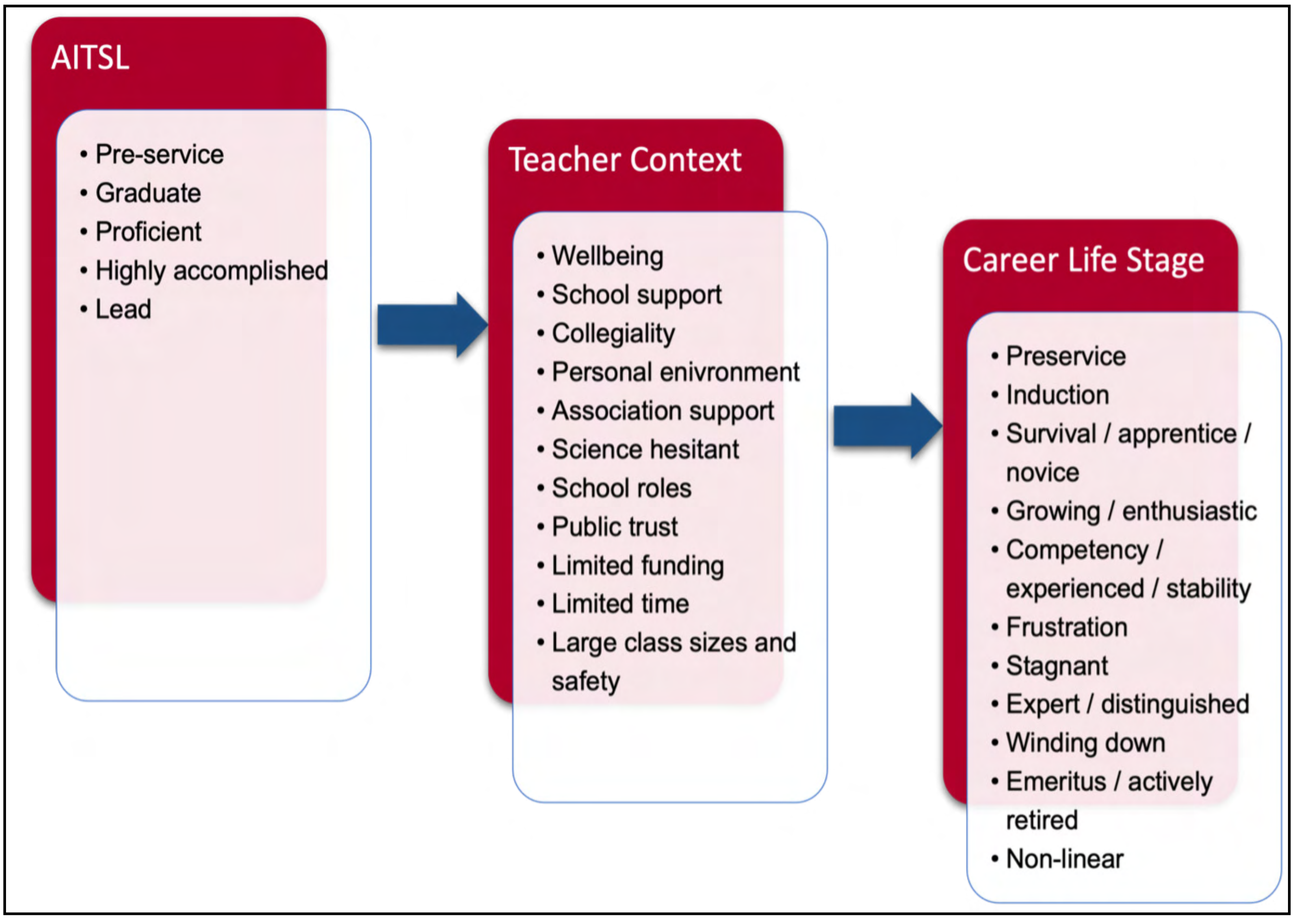


Figure 1: Teacher Life Cycle Framework

Limitations exist for this framework, as you would expect. Firstly, experienced does not necessarily mean expert; experienced teachers can be novices when learning something new. Secondly and perhaps the biggest issue is that the organisational environment has a huge impact that may extend beyond the factors listed. Care needs to be taken to open this discourse into the future and ASTA welcomes the opportunity to be involved.

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CSIRO and ASTA recognise standout teachers and students at the BHP Foundation Science and Engineering Awards

Building Australia's next generation of STEM professionals are an impressive line-up of teachers sharing their enthusiasm for STEM. They're educating, supporting, and inspiring students to achieve in STEM, both inside and outside of the classroom.

BHP Foundation
Science and Engineering Awards 2022

BHP Foundation Science and Engineering Awards

Since 1981, the BHP Foundation Science and Engineering Awards — managed by Australia's national science agency, CSIRO, in partnership with BHP Foundation — has recognised the outstanding contributions of STEM teachers, and celebrated students across Australia for their achievements in STEM research and innovation. Continuing this tradition, Australia's best and brightest STEM teachers and students were announced for 2022 at the virtual awards ceremony late last year.

Teacher Award recipients

The Teacher Awards recognise outstanding teachers who engage students in the study of open-ended investigations and work consistently within their school community and wider professional arenas to make an outstanding contribution to science education in Australia.

BHP Foundation Science and Engineering Award teacher finalists included:

- Bobbi Smith, Aranda Primary School, ACT
- Jessica Neilsen, Good Shepherd Lutheran College, Northern Territory
- Jodie Donaghey, Holy Rosary School, Victoria
- Daisy Kong, James Ruse Agricultural High School, New South Wales
- Peta Scorer, John Curtin College of the Arts, Western Australia
- Daniel Edwards, Montello Primary School, Tasmania
- Sue Monteath, Wavell State High School, Queensland
- Rachel Pillar, Kangaroo Island Community Education, South Australia
- Anna Nakos, Temple Christian College, South Australia (Joint CREST submission)
- Amanda Benger, Temple Christian College, South Australia (Joint CREST submission)

Bobbi supports students to explore the world around them.

Congratulations to this year's Award teacher finalists. Find out more about the 2022 teacher finalists at sciencawards.org.au.

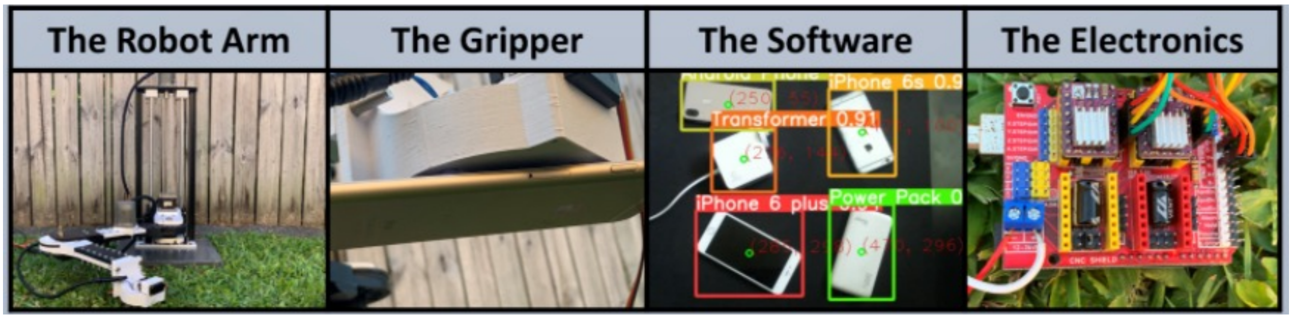
Student Award Finalists

The BHP Science and Engineering Awards also recognise and celebrate the next generation of school-aged STEM leaders who have undertaken innovative science or engineering projects.

Sam, from Proserpine State High School in Queensland, designed an Artificially Intelligent Electronic Waste Sorting Selective Compliance Robot Arm after identifying a growing area of environmental pollution.

"I'm passionate about reversing human environmental impact and am inspired by the pristine lands and waters of my remote hometown," Sam said.

"I created a waste-sorting robot arm, which improves on existing technology through using artificial intelligence to identify and sort electronic waste," he said.



Through mechatronics engineering and robotics, Sam developed a prototype device to segregate electronics autonomously in a waste sorting facility.

Charlotte, from Paynesville Primary School in Victoria, researched if sugar or sweetener affects mould growth.

Congratulations to this year's Award student finalists. Find out more about Sam and Charlotte's research projects, along with 24 other high school students and 16 primary school students' research projects at scienceawards.org.au.

Regeneron International Science and Engineering Fair

Seven of this year's BHP Foundation Science and Engineering Award finalists represented Australia at the Regeneron International Science and Engineering Fair (ISEF) held 7–13 May in Atlanta, Georgia (USA).

Attending virtually, along with more than 1,750 high school scientist and engineering students from around the world representing 63 countries, these finalists showcased their independent research projects on the global stage during the hybrid virtual and in-person event.

Visit the links below to find out more about this year's ISEF representatives and their projects.

- Environmental Engineering: 'Artificially Intelligent Electronic Waste Sorting Selective Compliance Robot Arm '
  Sam Rogers, Proserpine State High School, Queensland
- Robotics and Intelligence Machines: 'Weight Plate Loader'
  Skye Sriratana, Tintern Grammar, Victoria
- Plant Sciences: 'How do Flavanoids and Isoflavanoids Improve Nodulation in Legumes?'
  Abbey Curran, Daramalan College, Australian Capital Territory
- Energy: Sustainable Materials And Design: 'What Genre of Music Creates the Most Energy?'
  Tashan Kirubagaran and Alan Joju, Willetton Senior High School, Western Australia
- Earth and Environmental Sciences: 'Darwin Mangrove Ecosystem — Field Study'
  Reka Nemeth, Darwin High School, Northern Territory
- Physics and Astronomy: 'Does Altitude Affect the Quantity of Background Radiation?'
  Amelie Nanclares, Kirrawee High School, New South Wales

Sam (Qld), along with Alan (WA), Skye (VIC) and Tashan (WA), joined Abbey (ACT), Reka (NT) and Amelie (NSW) to showcase their research alongside students from 63 countries at the virtual Regeneron International Science and Engineering Fair (ISEF) 7–13 May 2022.

Students were evaluated based on their projects' creativity, innovation, and level of scientific inquiry, with almost US$8 million in awards, prizes and scholarships presented to finalists. ISEF followed months of preparation and presentations to an international judging panel.

Sam received a Special Award from the Association for the Advancement of Artificial Intelligence for his environment engineering research project, 'Artificially Intelligent Electronic Waste Sorting Selective Compliance Robot Arm'. Special Awards are provided by organisations representing government, industry, and education sectors, with all student entries considered for each prize, regardless of ISEF entry category.

Two Australian students received Grand Awards and were recognised with a cash prize. Grand Awards are presented in each of the 21 ISEF categories:

- 2nd place (US$2,000): Sam Rogers, Proserpine State High School, QLD, Australia
  'Artificially Intelligent Electronic Waste Sorting Selective Compliance Robot Arm'
- 2nd place (US$2,000): Abbey Curran, Daramalan College, ACT, Australia
  'How Do flavonoids and Isoflavonoids Improve Nodulation in Legumes'

The finalists thoroughly enjoyed the ISEF experience and the opportunity to enhance their future careers in STEM.

CSIRO and BHP Foundation extend their thanks to the Australian Science Teachers Association (ASTA) and the state and territory Science Teachers Associations (STAs) for supporting students in their journey through the Awards program, from state- and territory-sponsored submissions, onto the national BHP Foundation Science and Engineering Awards and participation at ISEF.

Mobile Inquiry-based Science Learning (m-IBSL): Employment of the Phyphox application for an experimental study of friction

Manolis Kousloglou[1], Anastasios Molohidis[1], Kleopatra Nikolopoulou[2] & Euripides Hatzikraniotis[1]
1 Aristotle University of Thessaloniki, Greece
2 University of Athens, Greece

Introduction

The natural sciences, by their very nature, are based on the exploration of the physical world, and digital mobile devices are considered appropriate to support this exploration (Suárez et al., 2018) since they offer the tools that make this investigation more accessible but also ubiquitous (Crompton et al., 2017). Inquiry-based learning is a process in which students propose questions or discover causal relations, formulate hypotheses, investigate and test experiments or observations (Pedaste et al., 2015). Mobile inquiry-based learning (m-IBL) aims to employ mobile technologies so as to facilitate the inquiry process and motivate learners to build and share their knowledge (Looi, 1998). Several researchers studied the application of m-IBL in the Sciences (m-IBSL), for example using the smartphones' sensors and relevant software in a laboratory environment without necessarily including their interventions within a specific theoretical framework (Kapucu, 2018; Pambayun et al., 2019). This article presents a case study of the integration of such an application (Phyphox) that utilises the smartphones' integrated sensors in hands-on physics experiments, in an inquiry framework.

Design of the Classroom Implementation

Seventy-one students (divided into 16 groups) aged 13–14 years old of the 3rd Junior High School of Kavala in Greece performed hands-on friction experiments by leveraging a mobile inquiry-based science learning (m-IBSL) methodology. The students were asked to install the Phyphox app (https://phyphox.org/) on their mobile phones. The worksheets were structured according to the inquiry-based learning phases: Orientation, Conceptualisation, Investigation, Conclusion & Reflection (Pedaste et al., 2015) and were designed so as to take into account that students were participating in inquiry-based learning for the first time. Students recorded their data on a Google sheet that had been created for this purpose, while data on students' participation in the m-IBSL procedure were collected by direct observation protocols.

It was expected, that students would:

- get to know and practice mobile learning, by applying their knowledge in daily life situations;
- practice scientific research skills, such as observation, selection and recording of useful information, comparison and interpretation, deepening an investigation; and,
- increase their motivation in physics, by using their smartphones.

The PHYPHOX app

PHYPHOX (PHYsical PHOne eXperiments) is an app for Android and iOS that includes many tools as shown in Figure 1 and uses the phone's built-in sensors (accelerometer, magnetometer, gyroscope, etc.).

For the needs of our implementation, the students used the Inclination Tool, which measures the angle of an inclined plane (Figure 2). Phyphox uses the orientation of the Earth's acceleration vector in order to calculate the inclination. As with all Phyphox tools, the Inclination Tool offers remote access via a laptop or another digital mobile device, and can export data in Excel compatible format so that data can be processed, produce graphs etc.

The implementation

The total laboratory intervention, with smartphones and conventional lab equipment, lasted 3 weeks. Smartphones were used to enhance inquiry-based experimental learning (m-IBSL) during the first week. The students worked in small groups of 4 or 5. During the whole process, the students filled in completed a Reflection Report at home.

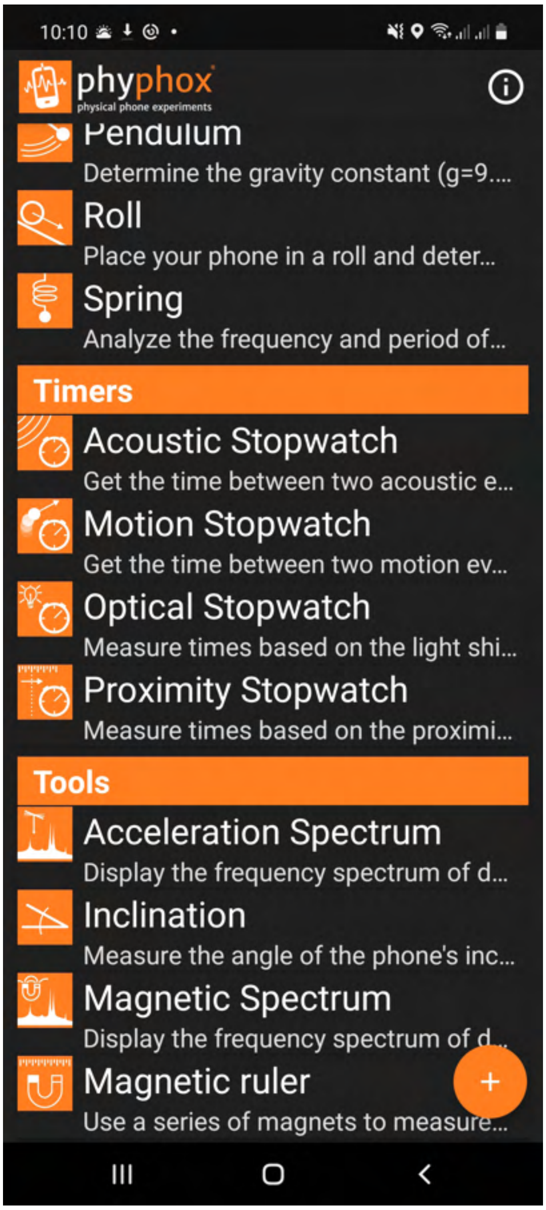


Figure 1: Phyphox' tools.

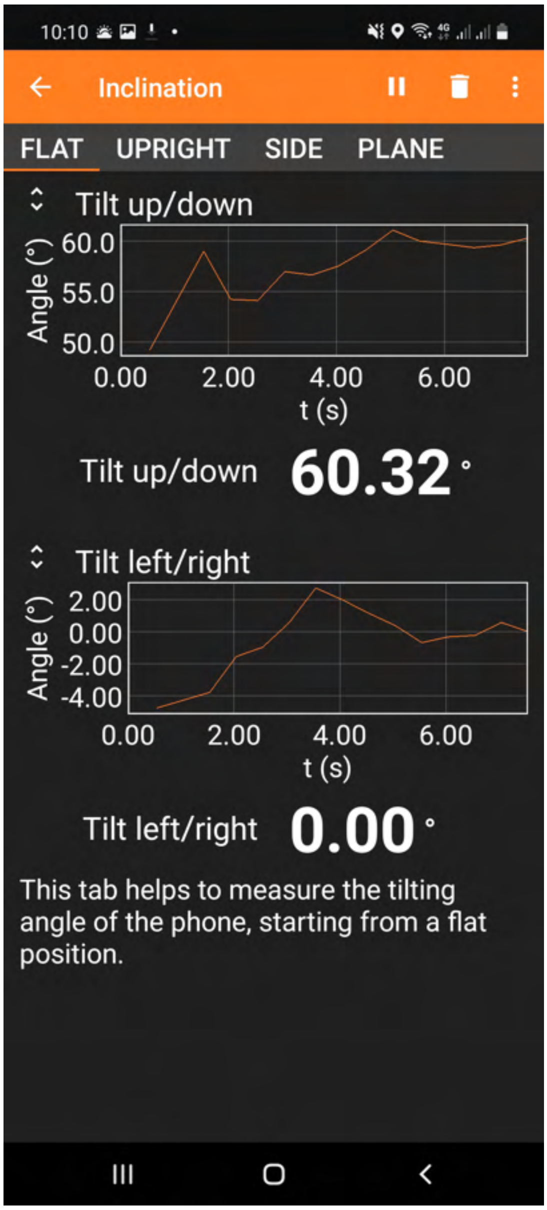


Figure 2: The Inclination Tool.

The worksheet started with a fictional story.

> It all started with an accident. In our house, on a chair, there were various objects, such as: a cup, a booklet-calorie counter, a kettle, even our mobile phone. We lifted the chair on one side so that our father could pull on the carpet underneath and there was great damage. Some objects slipped off the chair and fell to the floor. Fortunately, other objects slid slowly and were caught before they fell, while a few remained in place. The mobile phone was saved; it did not fall to the floor. This was fortunate because it had fallen in the past and we had already replaced a broken screen once...

The above fictional story from everyday life provided a trigger for students to repeat the incident using their mobile phones. The idea derived from Kapucu's (2018) study where a smartphone was used like an angle meter to determine the sliding angle and consequently to measure the maximum coefficient of static friction. We implemented this study in a real school environment. Before the experiment, the students discussed and recorded their predictions. Without giving any coherent reasoning, they thought that — like the objects of the fictional story — their mobile phones would slide at different inclination angles.

The experiment took place in the lab. For this purpose, each group of students used a chair with a wooden seating surface, on which a student's smartphone was placed. The Phyphox software was turned on at the moment the students started inclining the chair — very slowly — and the inclining was stopped when the smartphone just began to slide (Figure 4). It is noted that relevant safety measures were taken, such as the installation

Figure 3: Students experimenting and filling in their worksheets in small groups.

Figure 4: Students observing the slipping of the mobile phones in small groups.

of a safety cushion, in order to avoid accidents that might damage the smartphone (due to its sudden slipping). Test measurements were initially performed to familiarize the students with the experiment, so as to make the experimental data more reliable.

Each group (G) of students performed the experiment three times with the smartphone within its case and three times with the same smartphone without its case. Each time, they recorded the values of the angle at which the slide started (Table 1).

Also, after each experiment, they stored the data in .xls format and shared them through the "export data" capability of Phyphox using Google Drive, so that all students could have access and compare their data with other groups. The student groups had different types of smartphones, some of different size and weight. When the process was completed, the groups presented and compared the results of their measurements. The students observed that when they lift the chair, the mobile phones do not slide immediately. They also noticed that the sliding angle is in general smaller when the smartphone was without the case. The average value of the sliding angle was 9.2° when the smartphone was without the case, with the values ranging from 4° to 16°, and having a standard deviation of 3.6°. When the smartphone was left to slide with the case, the average value of the angle was 29.2°, with the values ranging from 11° to 49°, and having a standard deviation of 11.3°. The students were then asked to explain the difference(s) in their measurements (they were prompted to record only those hypotheses that could be tested, scientifically; i.e. with school laboratory equipment). The students stated that the different angles were due to the different mobiles' size (the surface area in contact), weight, and texture of their surface (the nature of the surfaces touching each other). The students were told that they would test these hypotheses during the next stage of the experiment — using lab equipment. However, before moving onto the next stage, the students reflected on the process and completed their reflection report at home.

Table 1: Mean values of the sliding angle (rounded to no decimal places).

Group	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16
Mean of angle values (without the case)	7°	4°	8°	6°	9°	16°	11°	8°	12°	11°	6°	7°	4°	10°	15°	13°
Mean of angle values (with the case)	14°	11°	35°	28°	34°	48°	49°	22°	30°	31°	28°	15°	23°	41°	36°	22°

Table 2: Reasons for not using personal mobile phone on the day of the experiment.

	Student percentage
The smartphone did not have the necessary sensor, in order for inclination to be active	11%
Lack of sufficient memory on their mobile (in order to install Phyphox)	9%
Mobile phone loss/problem, not own a mobile	8%

The process was part of the inquiry. Thus, the students predicted what would happen to their phones when they lifted the chair. Then they experimented and observed that when they lifted the chair the mobile phones do not slide immediately. They also noticed that the mobiles slid with different inclination angles of the chair. So, they questioned themselves why the mobile phones do not slide immediately and what factors influence the slide. They then hypothesised possible answers to their questions and recorded their hypotheses for further investigation. Then, they Reflected on the process in the Reflection Report (as homework).

We must note that some students either did not install Phyphox or they were not able to use their personal mobile phone in the experiment (reasons are indicated in Table 2). This was not a barrier as the experimental procedure was prepared so that one smartphone would be enough for each group.

Strengths and challenges

The process went smoothly over the three weeks. A key point was the fact that the intervention was designed in such a way that we could carry it out during the pandemic. That is, even if some classes were suspended for some period. Below, we present the strengths and the challenges of the intervention as reflected during and after its completion.

Strengths

The strengths of the intervention were:

- The students applied their knowledge in daily life situations connecting physics with their daily experiences;
- There was enthusiasm and a great willingness to participate in the experiments;
- The students used their mobile phones at home to download and study the Phyphox app, thus devoting time to topics related to the experimental process (at the expense of other activities such as online games and social media);
- Some students kept the Phyphox software permanently on their mobile phones and experimented with its tools; and
- No malicious use of mobile phones was observed (e.g., students photographing their classmates, accessing the internet). The students seemed to be very familiar with the use of mobile phones and did not disobey the rules that had been set.

Challenges

The challenges were as follows:

- The process, during the first hours of its implementation, revealed the difficulties involved in collaborative learning. Some 'weak' students hesitated to participate in group discussion. However, the change in their attitude, after 2–3 hours of engagement, was impressive;
- As we have already mentioned, some students were not able to use their personal mobile phone in the experiment. These students did not have the opportunity to get to know the app well, or to experiment at home (as did their peers);
- There was a great workload for the teacher (the principal author of this paper), during the preparation and implementation of the whole process.

Conclusions

This paper describes a mobile inquiry-based science learning intervention held during the school year 2020–21, at the 3rd Junior High School of Kavala in Greece. The implementation was on friction using the Phyphox app. Although some challenges were observed, the strengths were many and also important. We point out that students may have used their smartphones for the first time for constructive teaching purposes (not for online games and networking). Additionally, they showed great maturity in using their smartphones properly within the classroom environment.

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Carbon — the unauthorised biography

By Sonya Pemberton

Genepool Productions is an Emmy Award-winning production company based in Melbourne. We create global science films about the most consequential and polarising issues of our times — recently, we've made films about COVID-19, vaccination, and uranium. Our films are carefully designed and fact-checked to deliver insight and understanding, and to be used in schools as educational resources.

Our latest film, *Carbon — the unauthorised biography*, is our contribution to understanding the complex carbon cycles that drive our world, and our changing climate.

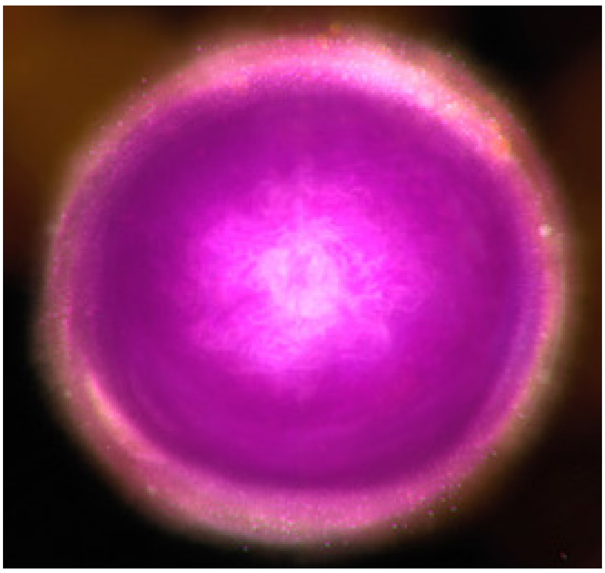
The film is available to schools and educators in a science-focused version (55 minutes) as well as the longer theatrical version (89 minutes). There are accompanying study guides for each. Short clips are also available. (https://www.thecarbonmovie.com)

Film Poster [Jeremy Saunders]

Our approach to filmmaking is backed by the emerging study of the 'science of science communication'. For several years we have worked with researchers at The Cultural Cognition Project at Yale and we now distil their massive academic endeavour to a few key ideas.

To start with, providing information or facts is not enough (the 'information deficit model'). Instead, we have to find imaginative and unexpected ways to incite curiosity. When dealing with subjects that provoke polarisation, we avoid signalling which 'side' we are on, and we never ridicule or dismiss the 'other' side. We also aim to tell our story accurately and with passion but avoid the triggers that spark conflict or shut down conversation.

Carbon — the unauthorised biography evolved as we were considering how we might apply these insights to the issue of climate change. Writer and co-director Daniella Ortega had a novel idea. Why not tell the incredible story of carbon, the story that underpins so much of climate change, and do it as if this element were a person? A biography of sorts.



Carbon Hero [Global Mechanic/ Bruce Alcock]

The genesis of this approach was a short story imagining the life of a single carbon atom by chemist Primo Levi in his book *The Periodic Table*. Our approach was to go further, to make Carbon a 'character' and visualise her multiple personalities and adventures. This was key to triggering surprise (We haven't seen *this* before!) and curiosity (Where did her story begin, how will her story end?).

In 2019, we partnered with co-director and co-producer Niobe Thompson, from Canada's Handful of Films, with whom we share a love of good science and a commitment to trying to cross the climate change divide.

Astrophysicist Neil deGrasse Tyson [Global Mechanic/ Bruce Alcock]

Astrophysicist Tamara Davis [Global Mechanic/ Bruce Alcock]

Backed by our broadcast partners at the ABC, CBC and the European Cultural Channel (ARTE) as well as a bevy of film agencies, production began in mid 2020. The key idea that won international support was that we were not framing this production as a traditional 'climate change film'.

This is a film about an element, about its role in shaping the natural and manmade world. We focus on the science — chemistry, biology, materials and environmental science — exploring what we know about the element and how it works. We also focus on history: the evolving story of carbon and humanity.

With enthusiastic experts like Neil de Grasse Tyson, Katharine Hayhoe and Tamara Davis; stunning landscapes; beautiful animation; and an epic score, this film is designed to excite wonder and curiosity about how things work.

Of course, the most startling element is the fact that Carbon speaks. This was the creative edge that allowed us to tell a very different, surprising, climate story.

By taking this approach we aim to reduce the fear, anxiety and guilt that's often triggered by climate change advocacy films and campaigns. The audience — regardless of their positions on climate change — can travel an extraordinary imaginary journey yet come to better understand our very real role in harnessing carbon. They discover for themselves how humanity's relationship to carbon shapes everything.

Left: Animation of volcano erupting — carbon cycle; Middle: Animation of tarsands/oil fields; Right: Animation of earth family [Global Mechanic/ Bruce Alcock]

Working with global expert advisors, we carefully illuminate the remarkable science and history of Carbon, telling a gripping and ultimately empowering tale, and importantly, we avoid the political and ideological climate change trigger points. For that reason, there are no images of polar bears on melting sea ice.

Carbon — the unauthorised biography is no dystopian vision of doom and gloom, nor a utopian dream of a world made right, but rather an inspired and illuminating exploration of the profound connections that bind our world.

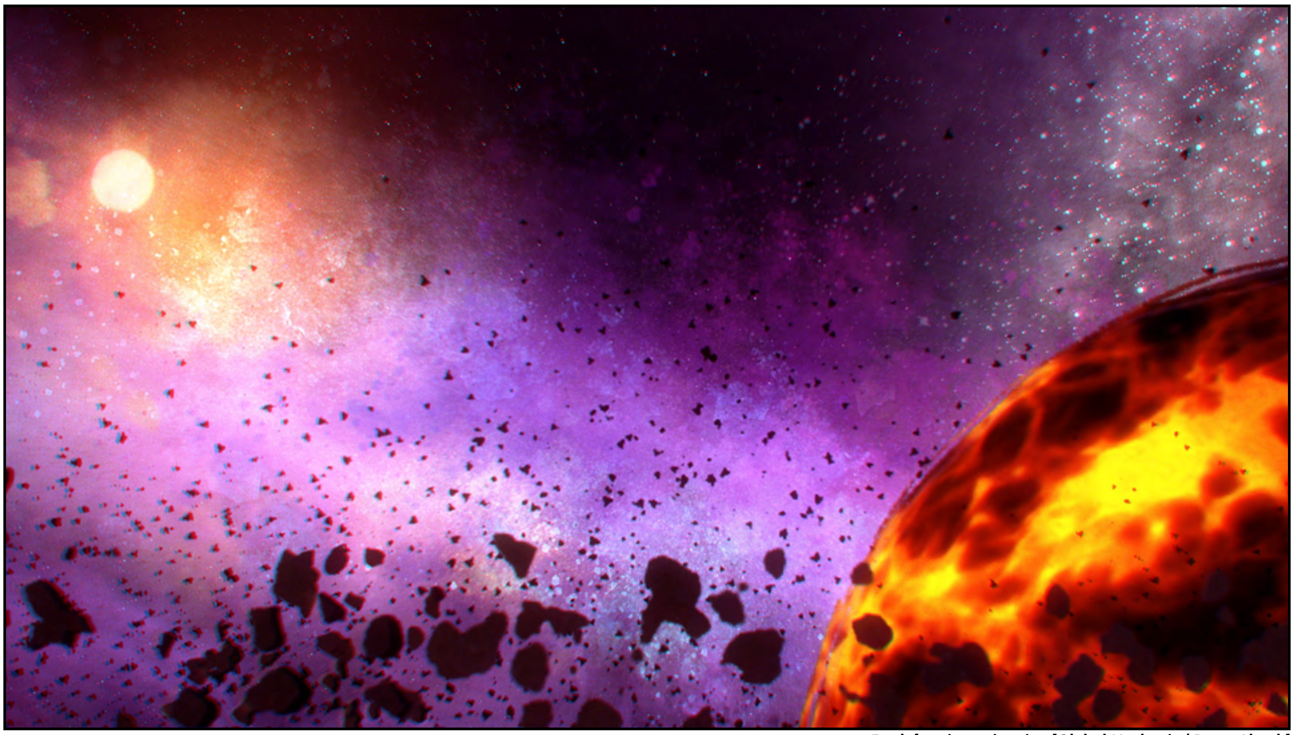
The film has screened in cinemas around Australia and New Zealand, and it's now screening on television on the ABC and around the world. Younger audiences tell how they become swept up in this unorthodox tale of a carbon atom, travelling the wild animated rides of photosynthesis and carbon burial, all guided by the young female narrator, Australian actress, Sarah Snook. Across the world, students appear to be embracing this unexpected and illuminating journey.

Carbon is so much more than a climate monster. Her life story illuminates something fundamental and profound — that we are all intimately connected to the planet and everything on it. Carbon is the common thread that binds us all.

Of course, deep down this is a film about understanding our changing climate, and about how we can all help give Carbon places to hide.

Carbon — the unauthorised biography is on ABC and iView from 8:30pm Tuesday July 12, 2022. 1 x 55-minute and 1 x 89-minute version, plus study guides, are also available through educational providers, such as ClickView, Enhance TV and Kanopy.

Sonya Pemberton, Executive Producer
Creative Director Genepool Production
www.genepoolproductions.com



Earth forming animation [Global Mechanic/ Bruce Alcock]

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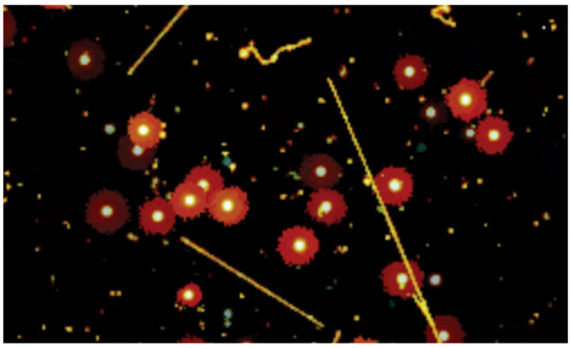

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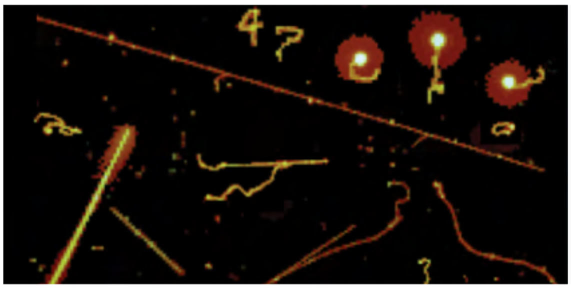

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Coding Race: Playing with Algorithms

Nadya Rizk, Matt McKenzie & Marya Samrout

Coding is a process often associated with computers. Nevertheless, coding is a thought process that can be mastered even without a computer. In NSW, primary students are introduced to computational and algorithmic thinking as early as Stage 1. Yet, teaching coding to young students is not always easy for teachers, mostly because the process is often invisible and abstract. The activity described here offers one way to teach coding to primary students in a fun, interactive, and stimulating environment. More importantly, it incorporates a play-based approach to engage students with the concrete skills of coding and to expand their views about algorithms and codes.

The concept of a 'Coding Race' was inspired by the show The Amazing Race: Australia. Accordingly, students compete in a race, and winners are awarded certificates and prizes. During the competition, students progress through eight stations where they are presented with coding challenges. Each challenge is an opportunity to further their understanding of the three pillars of coding: 'Code', 'Algorithm', and 'Output'. In each challenge, two of these pillars are given, and the students will need to work as a group to "develop" the missing pillar. In some stations, students will be using a Code to execute an Algorithm and develop an Output, while in other stations they will be working through a Code and an Output to develop the corresponding Algorithm. When completing these exercises, students will also learn the skills of 'Debugging', another term that is consistently used throughout this activity.

The activity described here is a 90-minute lesson that consists of three parts: an introduction, a competition, and a concluding discussion session. It aims at helping primary students develop their computational thinking skills, furthering their literacy in coding, and developing their appreciation for the ubiquity of algorithmic thinking and its applicability to a wide spectrum of contexts.

Part 1: Introduction

The teacher introduces the lesson as a fun competition about coding. Students' prior ideas about coding are explored. Teacher and students negotiate the idea that coding is a process that involves three pillars: a Code, an Algorithm and an Output. In order to reinforce a shared understanding of these three pillars, the teacher uses a simple coding activity (Figure 1) prior to starting the competition.

Teacher: "If I put my arm up, you all stand up and if I put it down, you all sit down; this is our code now! Observe the algorithm I'm going to perform. At this stage, observe only and don't perform the output. Remember, an algorithm is a fancy word that simply means: list of instructions using the code. So here's the algorithm for you to observe: arm up, arm down, arm up, arm down, arm up."
Students observe as teacher moves her hands up and down, up and down, and up.
Teacher: "Now you can execute the algorithm based on the code I introduced earlier"
Students execute the algorithm by standing up, down, up then down, and then up.

Figure 1: Activity to check students' basic understanding of the pillars of coding.

1) In this competition there is a central station where the gate keeper will be staying.
2) There are eight other locations (pointed out on a map) where students will need to go to in their groups.
3) At the beginning, each group will be sent to a specific location where they can find a folder with activity sheets in it. Each group member must take one of the sheets and group members need to work together to complete the coding activity.
4) Once a group completes an activity, all group members need to head back to the central station and share the results with the gate keeper. All members of the group should be present at the central station before the gate keeper can begin assessing their work. The gate keeper selects who will represent the group in sharing their work, therefore each group must ensure that everyone in the group knows how to present the correct answer.
5) Once the gate keeper verifies that the outcome is correct, they'll indicate the next location for that group. This process is repeated until each group has reached all eight locations.
6) If the group's answer is incorrect, they will sent back for debugging, that is working out what mistake(s) they have made and correcting them. Groups can have as many attempts at completing an activity as they need.
7) If one of the activities proves too difficult for a group, they get one chance (and one chance only) of swapping that activity for the mystery activity. There is no guarantee that the mystery activity will be easier.
8) The gate keeper will keep track of the locations that were visited by each group.
9) If a group completes an activity from a station where they are not supposed to be, then even if they complete the activity correctly, they will not get a score for that activity and will be redirected to their designated activity.
10) If a group comes to central station and there is a group in front of them, they will need to wait in line for their turn.
11) This is a competition. It means there will be awards and prizes for the first three groups to complete the race. As groups are competing against one another, group members are not supposed to help out other group members; Any person's loyalty is for their group!
12) Have fun!

Figure 2: Rules of the competition.

Part 2: The Competition

For this part of the lesson, the teacher established the rules of the competition (Figure 2). Students are allowed to ask questions to make sure the rules are clear for them. Next, students are assigned to groups. Each group is provided with an envelope which they are instructed not to open until permitted. The envelope assigns groups to their first station where they will find their first coding challenge.

The teacher, now referred to as the 'Gate Keeper', will be located in the Central Station, which is located at a fixed post for the entirety of the competition. The teacher will be assessing groups' outputs as clarified in the rules of the competition (Figure 2), and will be keeping track of the progress of each group. A progress recording sheet (Figure 3) outlines the projected trajectories that are unique to each group. Once a group completes a challenge successfully, the teacher crosses their previous location and instructs the group where to go next.

Each location or station presents a distinctive challenge. For example, one challenge consists of using a Code of Aboriginal symbols that students use to illustrate (the Output) a textual story (the Algorithm). Five other challenges are described next.

Team	Begin here			Location Name				
1	Dingo's Den	Wombat's Burrow	Platypus' Creek	Snake's Hole	Blue Tongue's Rock	Ants' Nest	Possum's Drey	Echidna's Log
2	Ants' Nest	Blue Tongue's Rock	Possum's Drey	Wombat's Burrow	Platypus' Creek	Snake's Hole	Echidna's Log	Dingo's Den
3	Snake's Hole	Platypus' Creek	Echidna's Log	Blue Tongue's Rock	Possum's Drey	Wombat's Burrow	Dingo's Den	Ants' Nest
4	Wombat's Burrow	Possum's Drey	Dingo's Den	Platypus' Creek	Echidna's Log	Blue Tongue's Rock	Ants' Nest	Snake's Hole
5	Blue Tongue's Rock	Echidna's Log	Ants' Nest	Possum's Drey	Dingo's Den	Platypus' Creek	Snake's Hole	Wombat's Burrow
6	Platypus' Creek	Dingo's Den	Snake's Hole	Echidna's Log	Ants' Nest	Possum's Drey	Wombat's Burrow	Blue Tongue's Rock
7	Possum's Drey	Ants' Nest	Wombat's Burrow	Dingo's Den	Snake's Hole	Echidna's Log	Blue Tongue's Rock	Platypus' Creek
8	Echidna's Log	Snake's Hole	Blue Tongue's Rock	Ants' Nest	Wombat's Burrow	Dingo's Den	Platypus' Creek	Possum's Drey

Figure 3: Recording sheet to track the progress of each team.**
****This set-up assumes 24 students competing in 8 groups of 3 (8 challenges +1 mystery challenge).**

1. Coding Challenge at Snake's Hole

For this challenge, students are given a Code and an Output. They need to decipher the Code in order to find out the Algorithm that produces the specified Output. They are provided the instructions below.

<u>Code:</u> Each specific arrangement of rocks and sticks is symbolised by a string of letters, and represents a letter of the alphabet as shown in the table below.

Symbol	Meaning		Symbol	Meaning
RRRRRS	A		RRSSSR	N
RRRRSR	B		RRSSSS	O
RRRRSS	C		RSRRRR	P
RRRSRR	D		RSRRRS	Q
RRRSRS	E		RSRRSR	R
RRRSSR	F		RSRRSS	S
RRRSSS	G		RSRSRR	T
RRSRRR	H		RSRSRS	U
RRSRRS	I		RSRSSR	V
RRSRSR	J		RSRSSS	W
RRSRSS	K		RSSRRR	X
RRSSRR	L		RSSRRS	Y
RRSSRS	M		RSSRSR	Z

For instance, the arrangement of rocks and sticks symbolised as RRR RRS represents the letter 'A'. Therefore, to write the letter A, place 5 rocks and a stick as in the following arrangement:

<u>Output:</u> The Output is the word: CODING

<u>Algorithm:</u> Using the Code above, produce an Algorithm that spells the Output.

Your Algorithm is an arrangement of sticks and rocks. Once complete, present your Algorithm to the Gate Keeper at Central Station to proceed to the next statio

Figure 4: Students completing the coding challenge at Snake's Hole.

2. Coding Challenge at Blue Tongue's Rock

For this activity, students are given a Code and an Algorithm. They need to execute the Algorithm, using the Code, to come up with an Output. They are provided the instructions below.

<u>Code:</u> Each letter shown on the left column stands for an action that you need to perform.

Symbol	Meaning
N	Move one cell in the northern direction
W	Move one cell in the western direction
E	Move one cell in the eastern direction
S	Move one cell in the southern direction

<u>Algorithm:</u> The northern direction is identified on the ground map. Starting at the marked "X" position on the ground, and moving within the matrix cells, use the code above to find out the number of the correct flag (Output) by executing the following Algorithm:

NEEEEESSSSSEEEENNNNNWWSSS

Note: Sixteen flags are drawn onto the map to reduce the appeal and effectiveness of guesswork and to reinforce systematic algorithmic thinking.

<u>Output:</u> The flag number: ------

Once complete, present your Output to the Gate Keeper at Central Station to proceed to the next station.

Figure 5: Students completing the coding challenge at Blue Tongue's Rock.

3. Coding Challenge at Platypus' Creek

For this activity, students are given a Code and several Algorithms. They need to follow the instructions to develop an Output. They are provided the instructions below.

<u>Code:</u> The following code has been used to develop four Algorithms.

Symbol	Meaning
→	Move 1 square to the right
←	Move 1 square to the left
↑	Move 1 square upwards
↓	Move 1 square downwards

<u>Algorithms:</u> Four Algorithms have been developed using the Code above. These are:

Algorithm 1:

→ → → → → ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ → → → → →

Algorithm 2:

→ → → → ↑ ↑ ↑ ↑ ↑ ↑ ↑ → → → → → →

Algorithm 3:

→ → → → → → → → ↑ ↑ ↑ ↑ → →

Algorithm 4:

→ → → ↑ ↑ → → → → → → ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ →

<u>Output:</u> To complete this activity, you need to refer to the grid and match each animal with the animal category to which it belongs. To do this, first you need to work out which animal belongs to which category. Next, test each Algorithm to see if it matches the animal with its corresponding animal category.

Present an Output where you correctly complete the following statements:

To match "Possum" with animal category "___________", use Algorithm number ____

To match "Lizard" with animal category "___________", use Algorithm number ____

To match "Rosella" with animal category "___________", use Algorithm number ____

To match "Frog" with animal category "___________", use Algorithm number ____

Possum ⟹											**Reptile**
Lizard ⟹											**Amphibian**
Rosella ⟹											**Marsupial**
Frog ⟹											**Bird/Aves**

Once complete, present your Output to the Gate Keeper at Central Station to proceed to the next station

Figure 6: Students completing the coding challenge at Platypus' Creek.

4. Coding Challenge at Ants' Nest

For this activity, students are given a Code and an Algorithm. They need to execute the Algorithm, using the Code, in order to come up with an Output. They are provided the instructions below.

Code:

Symbol	Meaning
→	Move right foot one step to the right
←	Move right foot to a standing position
<>	Clap your hands
Ω	Make a turn around yourself

Algorithm:

→ ← → ← <> <> → ← → ← Ω

→ ← → ← Ω <> Ω <> → ← → ← Ω <> <>

Output: You need to decipher the algorithm and collectively perform the Output dance in front of the Gate Keeper at Central Station in order to proceed to the next station.

5. Mystery Coding Challenge

For this activity, students are given a Code and an Algorithm. They need to execute the Algorithm, using the Code, in order to come up with an Output. They are provided the instructions below.

Symbol	Meaning
A	Play the A/6 drum for 1 beat
C	Play the C/8 drum for 1 beat
D	Play the D./2. drum for 1 beat
E	Play the E/3 drum for 1 beat
G	Play the G/5 drum for 1 beat
P	Pause for 1 beat

Code: The following code is used in this activity. Refer to the picture of the musical instrument to identify the drums by their names.

Algorithm: Below is an Algorithm representing a popular tune:

A A A C A A P P A A A C E E P P E E E D D D D D D D E D C A

P P P

A A A C A A P P A A A C E E P P E E E D D D D D D D E D C A

Output: Using the Code above, execute the Algorithm and play the Output tune.

Once complete, play your Output tune to the Gate Keeper at Central Station to proceed to the next station.

Part 3: Concluding Discussion Session

Some students will complete the competition earlier than others and are presented with extension activities while waiting for other teams to complete at least five challenges. At this point, the teacher concludes the lesson by presenting the awards to the three winning teams. A classroom discussion follows to address the following questions.

a. How were the activities different and how were they similar? Refer back to the 3 pillars.
b. How is the coding process similar to the way a computer code works?
c. What conditions should be met for the coding process to happen correctly? Unambiguous code; specific algorithm; correct execution of algorithm.

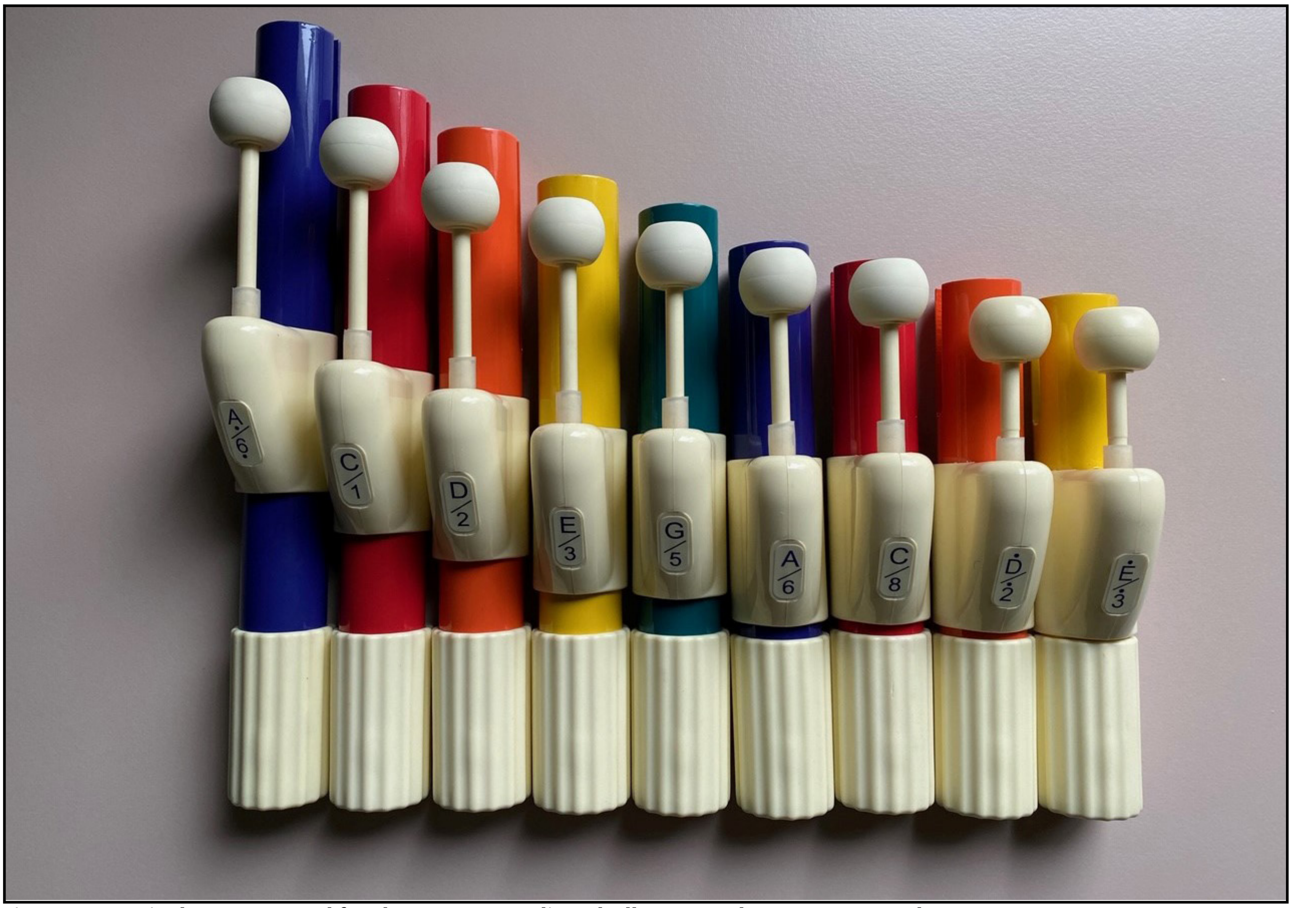

Figure 7: Exotic drum sets used for the mystery coding challenge at Blue Tongue's Rock.

Feedback from Participants

This activity was trialled with two groups of 24 Stage 3 students in a 2021 Science Week event, which took place at one Regional School in NSW (https://www.youtube.com/watch?v=4k7hifQfMEg). Students were asked to provide feedback about what they liked the most and the least about this activity.

Students overwhelmingly reported enjoying working in teams and bonding with classmates. Many expressed joy when solving the challenges, and on average, spent around 10 minutes per activity before asking for help when stuck. Students also expressed that they liked the diversity of codes and that each challenge was unique. They also found the competition format to be motivating, especially as it was set out on the school grounds, outside the boundaries of the usual classroom. In terms of improvements, most suggested that the teacher needed to provide some clues to support the groups when they asked for help on a challenge.

Anecdotal feedback from the two teachers who observed the activity suggested that some of the winners are not the "typical" winners and that this instructional style may have enabled students to demonstrate success where they would not have in a traditional setting. One teacher also commented on the adaptability of the activities in terms of adjusting their levels of difficulty. Both teachers found the activity were equally fun and challenging yet effective in terms of developing students' understanding of the coding process.

About the Authors

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Rungulla Rebooted

By Clea Hooper

In 2020, just as Covid-19 reached Australian shores, a group of enthusiastic teachers had been anticipating their imminent Bush Blitz TeachLive expedition to Rungulla National Park to take part in Australia's largest biodiversity survey. It took two years for their trip to eventuate, but it was worth the wait.

Painted grasshawk dragonfly — *Neurothemis stigmatizans.* Photographed at Rungulla National Park, Queensland [image — Chris Burwell, QLD Museum].

Three candidates from the deferred 2020 survey — Michael Tubby, Monica Lilley and Louise Edwards — along with past expedition applicant, Janet Price, finally realised their aspirations to work directly with scientists and to "teach live" from the field in May 2022 whilst on the latest Bush Blitz biodiversity survey to Rungulla National Park, Queensland.

Image courtesy Google Maps

After a full day's travelling by 4WD from Cairns over rough roads to Rungulla, the fabulous foursome spent the next eight days through both sunshine and downpours, sleeping in tents, hiking, helicoptering, exploring, and cataloguing their way around the rugged terrain, collecting specimens and documenting everything from tarantulas to fungi. They learned of the region's vast array of living things, nurtured and protected by generations of traditional ownership.

Caring for country

Rungulla (pronounced Roong-ala) National Park lies within the traditional lands of the Ewamian (pronounced Oor-a-min) people. Queensland National Parks and Wildlife Service rangers, in collaboration with Ewamian rangers, care for this environment through natural resource management, cultural heritage management, visitor management and education[i].

On Day 1, our teachers met with Ewamian Elders, Jimmy ("JR") Richards, Ken Georgetown and Barry Fisher, who took them on a tour of cultural heritage sites perhaps dating back 30,000 to 40,000 years.

Michael Tubby wrote that, "We saw grinding stones, axes, rock art and hand prints, and even an old digeridoo! We then had the honour of walking with these Ewamian men on their country as they searched for lost cultural sites. It was an amazing privilege to be present as at least three sites of cultural importance were rediscovered."

Before the end of the expedition, JR explained to our teachers that "it is extremely important work that the scientists are doing, because science and Aboriginal Peoples' knowledge work together to understand what is here on this Country."

Jimmy "JR" Richards, Ewamian Elder, cultural advisor and Senior Tour Guide [image — Bush Blitz Facebook].

Burnings and bugs

Rangers regularly undertake Indigenous cultural burning across the area, which not only fosters the landscape, but during this Bush Blitz also provides an opportunity for the survey team to collect a vast array of insect life, to assist the scientists in their studies.

Monica noted in her blog, "After the fire starts, it is the perfect time to keep collecting insects, as the smoke from the fire and the slow burn gives the insects and animals time to escape. We caught an enormous number of bugs, some which were very interesting. Including some beautiful green cockroaches which make hissing noises, and a spectacular stick insect."

The team also used a range of other methods to collect the insects, including "pooters", traps and pitfalls, and even creating "poo balls" to attract dung beetles. The work is often laborious, but clearly this is no barrier, as Janet observed: "What I have loved seeing is the passion shown for each person's field. From the Rangers to each Scientist they are always hard at work, either in the field, peering through the microscope, crawling along the ground, beating trees or arranging specimens."

Scientists use these collections to identify new species and subspecies of insects. Chris Burwell, one of the QLD Museum taxonomists, found 14 new species of dragonflies and damselflies for Rungulla National Park.

Left: Insect collection; Right: Dragonfly [Images — Monica Lilley]

And the Bush Blitz bravery award goes to…

However, not all new or undescribed species were quite as beautiful to some participants. A number of the discoveries were of the eight-legged kind. Arachnologist Dr Robert Raven collected specimens of an undescribed tarantula, Selenotypus, which Michael found somewhat intimidating.

"We gathered around as he used various odd tools to dig deep into the ground, swatting away biting termites as he worked until finally he found a female spider.

Undescribed female Tarantula — *Selenotypus* species [Image – Sabrina Trocini]

"A tarantula.

"A tarantula the size of a golf ball.

"A tarantula the size of a golf ball with a baby."

Michael, a self-confessed arachnophobe, had deliberately chosen to work with Dr Raven to confront his fear, and found it a fascinating experience — in particular the many unusual methods to lure them, including singing into webs or prodding webs with electric toothbrushes to create vibrations. He even managed a laugh or two.

Teachers Monica and Michael helping to trap tarantulas [Image — Sabrina Trocini].

Sneaky Sundews and fabulous fungi

Of course the work of the botanists is equally as important in a biodiversity survey, and oftentimes their research is intertwined with the rest of the team. On each of these expeditions, these scientists document native flora and seek to discover new species.

"One really awesome thing that scientists do is to collaborate. This means that while in the field they know what each other are researching and therefore if they come across it then they will collect that sample for their colleague. Awesome!" writes Louise.

"Zoe was able to help other scientists today by bringing back a scorpion and a cockroach, but not just any old cockroach, the world's largest. Common name Giant Burrowing Cockroach (Macropansthia rhinoceros)."

The teachers worked with botanists from the Australian Tropical Herbarium, James Cook University. Herbarium Ethnobotanist and Mbabaram man, Gerry Turpin, was able to provide much local knowledge of the plantlife, and gave them an opportunity to sample some of the native foods, such as dog's balls fruits, spear grass roots and native hibiscus seeds.

Drosera sonata **and varieties of fungi found at Rungulla National Park [Images — Left and Centre: Monica Lilley; Right: Janet Price]**

Other plants of interest included the carnivorous Drosera sonata (commonly known as Sundew), of which Charles Darwin once wrote, "...at the present moment, I care more about Drosera than the origin of all the species in the world."[ii] This innovative plant uses insects to supplement its source of minerals in poor soil conditions. A type of bug, which as yet is unnamed and undescribed, co-exists with the plant by living on its leaves and sharing in the plant's prey. Drosera sonata samples were collected and stored (in Monica's lunch bag, after the intended box was co-opted for spontaneous scorpion capture) to study this symbiosis.

Janet was excited that the team were able to record species of fungus that had not been seen in the park before: "Matt found an abundance of fungi on fallen logs ... some species recorded for the first time at this park and others he suspect may be new species. Such brilliant finds!"

On her last day, while out chasing butterflies with a net, Janet "picked up a log with fungi on it to bring back for Matt", which turned out to be the first sighting of that fungus type in the National Park. Impressive!

Records, reptiles and rainfall

Whilst this particular survey was focused quite heavily on insects and plants, other living creatures were researched, including mammals, birds, frogs and lizards. Several microbats were caught using harp traps, and an Owlet-nightjar was brought in by the Ornithologist. Monica found the documentation process fascinating: "[Will] had caught an owlet nightjar in the evening, and he showed us how he measures the bird, takes photos and draws a tiny amount of blood before releasing them in the same place he found it."

Lerista rochfordensis **[Image — Monica Lilley]**

Another target species was the Lerista rochfordensis, known as a legless skink. It has only (tiny) hind legs, hence the name "legless", although they still dart quickly, making them tricky to catch. Catching legless skinks with the Queensland Museum's herpetologist, Louise enjoyed reliving her youth. "Climbing escarpments and crawling on our knees through caves. I felt like a child again having the most fun ever." They succeeded in nabbing three as a good representative sample.

Whilst catching lizards was child's play, very little outdoor fun was able to take place during huge rainfalls that occurred during their stay. But the teachers didn't allow this to dampen their enthusiasm. Despite puddles in their tents, they made the most of their time at base camp observing the scientists cataloguing their samples.

Scientists working at the camp during heavy rain periods [Image — Janet Price].

Teacher Janet Price watching on as Dr Robert Raven examines samples [Image — Sabrina Trocini].

"While many people think these expeditions involve traipsing through scrub and collecting anything that moves, these scientists need to consider the purpose of the specimens they collect," writes Michael.

"The herpetologist from the Queensland Museum (Dr Andrew Amey) told us that as a collections manager, his job was very similar to a librarians — he maintained a research collection of specimens that people could view and borrow from. The specimens they collect during the trip contain information that becomes useless if they are not collected properly. Details around location, capture method, collector, date and environment must all be recorded as the specimen is registered into the museum's collection. Today's terrible weather gave the scientists time to make sure that all their notes and records were in good order."

When the weather allowed, travelling around became quite the adventure, and Louise was living what she described as "an Aussie classic".

"Rungulla National Park has an annual rainfall of 800mm but what happens when 170mm or 21% of the yearly rainfall falls in a day and a half? Four Wheel Drive (4WD) fun! Heaven for every Troopy owner (Toyota Landcruiser)." No prizes for guessing what Louise likes to do on her weekends.

The rain also brought with it spectacular sights, such as the flowing Gilbert River and the natural wonders of the plant and animal life in the region. "What I am seeing is so special, most people will never see it in their lifetime," wrote Louise. "Janet and I walked down to check out the Gilbert River in all its glory. What a site [sic]! And sound!" Taking in the sights from a helicopter enabled them all to truly appreciate the wild landscape.

An experience like no other

The savage beauty of the remote, protected Rungulla National Park was not lost on any of the teachers who had been selected for this Bush Blitz.

As Janet spent some silent moments chasing butterflies, she mused about how priveleged she was to be involved: "The silence of the forest, the trickle of a waterfall, the song of the birds and being amongst people with a focus and a passion for their particular animal or plant."

Left: Monica and Janet in the survey helicopter [Image — Sabrina Trocini].

Right: Michael and Louise in the survey helicopter [Image — Jock McKenzie].

Below: The team helicopter was grounded when the weather became too fierce. [Image — Sabrina Trocini].

But, in its inimitable way, nature offered Janet a reminder of the fragility of all living things: "We saw nature at work, an Assassin Bug injecting a bee with venom (it then is liquified so the bug can digest it) and two ants tearing apart a red-backed spider. It's a dangerous world down there."

Each day, the Bush Blitz scientists put their bodies to the test, and these four dynamic teachers determinedly joined them, taking each bite, scratch, bruise and muscle ache with bravado and revelling in their personal achievements. "What an incredibly long but rewarding day I had today! I can't believe how lucky I am to be here," noted Monica.

"In the spirit of collaboration this project has shown me the power of bringing like minded people together," writes Louise. "What I am really enjoying is seeing and hearing how these scientists love, I mean really love, what they do."

It's safe to say that following their adventure, our teachers were somewhat disappointed to be heading home. "It's sad to think that this experience will soon be over," reflected Michael on their last day. "We talk and collaborate and discuss our big plans for new projects, but it's optimism seasoned with sorrow."

ASTA and the Bush Blitz TeachLive team congratulate Michael, Monica, Louise and Janet for their efforts and hope that their students benefited from seeing them "doing" hands-on scientific research. You can read more about their adventures in their teacher blogs, at https://www.earthwatch.org.au/Blogs/teacher-blog.

Bush Blitz is a partnership between the Department of Agriculture, Water and the Environment; BHP; Parks Australia; and Earthwatch Australia. The Rungulla National Park Bush Blitz involved experts from Queensland Museum; Queensland Herbarium; Australian Tropical Herbarium; University of NSW and TERN. The expedtion was supported by QLD Parks & Wildlife Service; Ewamian Limited; United Aero Helicopters; and caterer Robbie Bayliss.

For more information about upcoming expeditions, and how to apply, visit http://asta.edu.au/national-programs/bush-blitz-teachlive on the ASTA website. For information about the full Bush Blitz program visit https://bushblitz.org.au/

The entire Bush Blitz Rungulla National Park team [Image — Helen Cross]

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i Ewamian People Aboriginal Corporation, *Ranger Program*. Ewamian Aboriginal Corporation. Retrieved May 27, 2022 from https://www.ewamian.com.au/rangerprogram

ii Ellison, A. M., & Gotelli, N. J. (2009). Energetics and the evolution of carnivorous plants—Darwin's 'most wonderful plants in the world'. *Journal of Experimental Botany*. *60*(1): 19–42. Retrieved May 31, 2022 from https://en.wikipedia.org/wiki/Drosera

AUSTRALIAN SCIENCE TEACHERS ASSOCIATION

Teaching Science is a quarterly, digital-only journal of the highest integrity produced to support the members of the state and territory science teacher associations that make up the Australian Science Teachers Association.

The aim of *Teaching Science* is to promote the teaching of science in Australian schools with a focus on classroom practice and contributing to the professional development of teachers of science.

Free to members, non-members can purchase *Teaching Science* direct from ASTA as an annual subscription. To find out more about subscribing, click on the following link.

https://www.asta.edu.au/resources/teaching-science-journal/

Science ASSIST: Bringing the pieces together

By Teresa Gigengack

Announcing new government funding

We are delighted to announce that the Australian Government Department of Education, Skills and Employment has provided one-off funding to support the operation of Science ASSIST for 12 months, until 27 February 2023. This funding is provided under the Emerging Priorities Program.

The objective of Science ASSIST is to support school science teachers and laboratory technicians by providing consistent and authoritative advice on all aspects of school laboratory safety, management and design, plus expert, up-to-date information on educationally sound and safety compliant practical activities to improve the educational results of all school students in all sectors across Australia.

The Science ASSIST service

The Science ASSIST website provides a wealth of support for practical activities in science as detailed below.

Questions and Answers (FAQs)

Where else can you go to get customised, timely advice and support for experiments, safety and compliance from current and experienced teachers and technicians who are working, or have worked, within a broad range of Australian school sectors?

- There are hundreds of questions submitted by teachers and technicians that our team of experts have answered and published on the website. They cover a wide range of topics relating to experiments and safety.
- You can find the complete list of these published Q&As by clicking on the FAQ tab in the red menu bar across the top of the site's web pages.

- You can gain an overview of the questions by downloading the [Quick links to technical questions].
- We are progressively reviewing previously published Q&As to provide the latest up-to-date information for you.
- **ASK A QUESTION**: this facility is only available for subscribers to the service. Send us your question and our team of experts will respond in a timely manner to provide your answer.

Connected Learning Experiences

- Connected Learning Experiences (CLEs) are curriculum resources designed to support teachers implementing learning experiences that are linked to the Australian Curriculum: Science and that embody an inquiry approach to scientific investigations.
- CLEs are comprehensive resources providing teacher background information, lesson plans, digital resources such as video clips and interactive simulations, student workbooks, and support for the assessment of student learning outcomes.
- This collection of thirty resources were developed by the Science ASSIST Team and cover topics from Foundation Year all the way through to Year 10.
- You can find the CLEs by clicking on the 'CLE' tab in the red menu bar across the top of the site's web pages.
- You can also gain an overview of the CLEs' year level and subject matter by downloading the [Quick links for Connected Learning Experiences].

Technical Resources

- Technical resources have been developed by the Science ASSIST Team and cover a broad range of topics relating to practical activities in school science.
- Comprehensive information can be found in major resources such as:

  The Chemical Management Handbook for Australian Schools — Edition 3;

  Guidelines for Best Practice for Microbiology in Australian schools;

  Guidelines for the Design and Planning of Secondary School Science Facilities in Australian schools; and

  The List of Recommended Chemicals for Science in Australian schools.

- You can find ASSIST Information Sheets (AISs) and Standard Operating Procedures (SOPs) by clicking on the AIS or SOP tab in the red menu bar across the top of the site's web pages.
- You can also gain an overview of the technical resources by downloading the [Quick links to technical resources].

Curated resources aligned with the Australian Curriculum: Science

- These external and Science ASSIST-created resources have been tagged with the codes and descriptors from the three strands of the curriculum: Science Understanding, Science as a Human Endeavour, and Science Inquiry.
- You can currently search these resources using the relevant codes from Version 8.4 of the Australian Curriculum: Science.

We are progressively including the updated codes for the Australian Curriculum, Version 9.0.

Seeking subscriptions from schools

For those of you who have been following the status of Science ASSIST since its beginning in 2014, you will be aware that we have had several ups and downs with our funding. For Science ASSIST to continue and to grow, we are seeking the support of schools in Australia in the form of subscriptions.

We invite you to subscribe to Science ASSIST to keep the service operational and also gain access to new resources and the ability to 'ASK A QUESTION'.

You can subscribe by following the instructions on the ASTA website (see: https://www.asta.edu.au/science-safety/science-assist/) Click on the 'Subscribe Now' button, then select the button for 'Australian Schools' and complete and submit the online form.

You will have the option to request an invoice or pay using a credit card. If your school needs to use a purchase order, once submitting your form online, simply send your purchase order number through to accounts@asta.edu.au.

Don't delay, subscribe now and help us to sustain this important service.

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- Sign up for the Science ASSIST e-newsletter by emailing labsupport@asta.edu.au
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Teresa Gigengack, Science ASSIST Manager

Science ASSIST: Supporting safe and engaging practical activities in school science

MODEL OF MOTION OF SUN

Dr Keith Treschman

The topic of the seasons is covered in both primary and secondary schools in Australia. It may be difficult for some students to comprehend how the Sun alters its position throughout the year. The following shows how to calculate the changing rising and setting positions of the Sun for one's locality and the extremes of its elevation near noon over a year. A model to show these changes may be constructed.

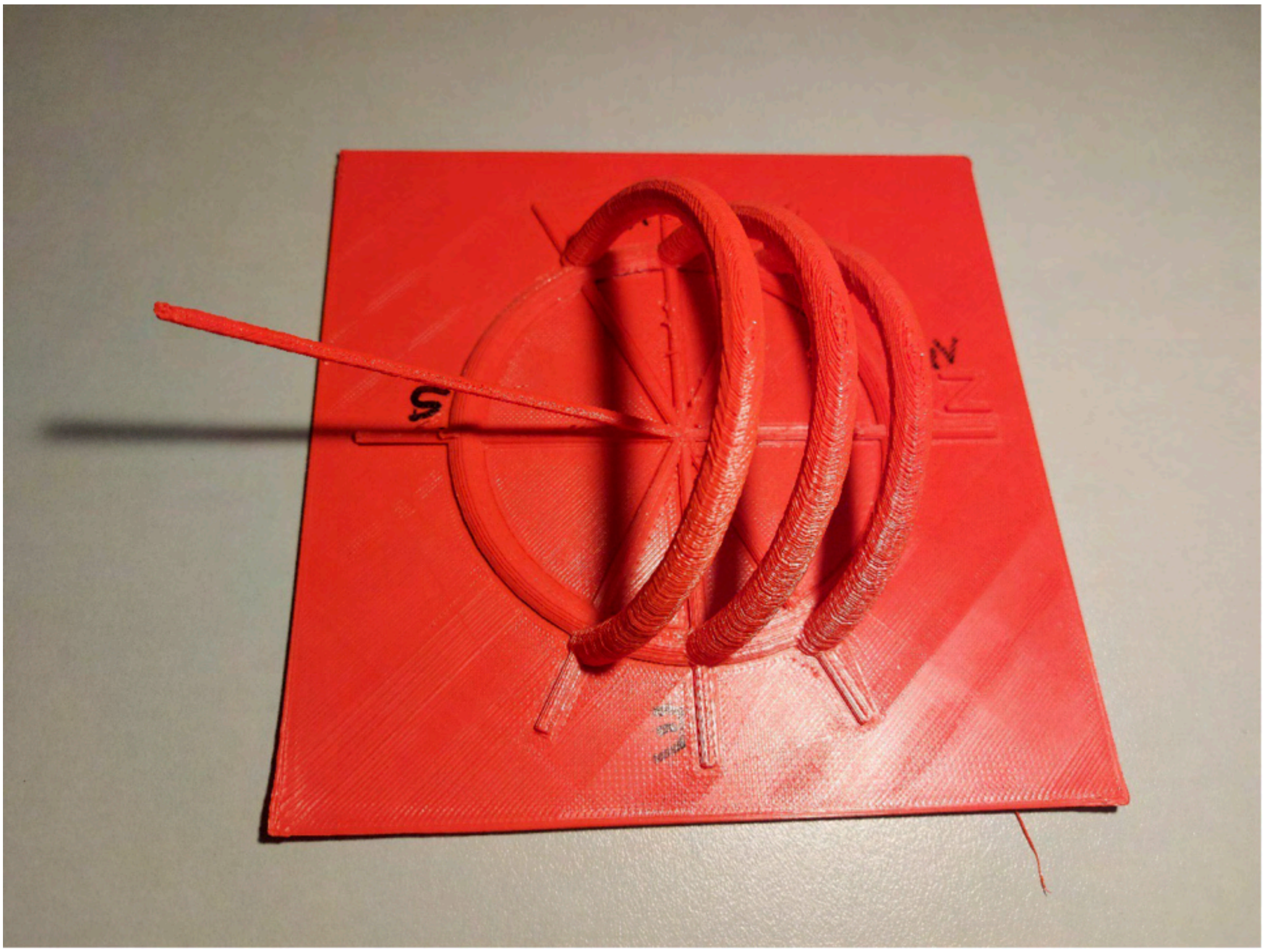

Figure 1: 3D Model of Sun's motion for Brisbane.

Introduction

The South Celestial Pole is an extension of the South Pole of Earth into the sky. It is the same angle above the southern horizon as one's latitude. The pointer in Figure 1 has been constructed for Brisbane, the latitude of which is 27.47° S (decimal of degree, not arcminutes). N, E, S, W are also on the model to show the cardinal directions.

The angle between the axis of Earth's rotation and the perpendicular to its orbital plane is 23.45°. Declination is the angle on the celestial sphere between the centre of Earth and the celestial equator, similar to latitude on Earth. It displays positive for north and negative for south. From geometry, the extremes of the declination of the Sun are ±23.45°.

Azimuth is the angle on the horizon of the Sun, in this case, from north at 0° in a clockwise direction.

Calculation of changing azimuth for Brisbane

In the southern hemisphere, the extreme azimuths of the rising and setting of the Sun occur on the June solstice (shortest amount of daylight) and the December solstice (longest amount of daylight). At both the March equinox and September equinox, the Sun rises due east and sets due west with 12 hours of daylight.

To calculate the position of sunrise or sunset, spherical geometry gives cosine (azimuth) = sine (declination) / cosine (latitude) and will give 2 solutions.

For a latitude of 27.47° S (use positive value),

- for declination = +23.45°, azimuth = 63.35° and 296.65°, each **26.65**° away from 90° (east) and 270° (west)
- for declination = 0°, azimuth = 90° (**east**) and 270° (**west**)
- for declination = -23.45°, azimuth = 116.65° and 206.65°, each **26.65**° away from 90° (east) and 270° (west)

Calculation of changing elevation for Brisbane

Elevation is the angle above the horizon. From geometry, for the greatest elevation of the Sun at Brisbane,

- for declination = +23.45°, elevation = 90° - (27.47° + 23.45°) = **39.1**°
- for declination = 0°, elevation = 90° - 27.47° = **62.5**°
- for declination = -23.45°, elevation = 90° - (27.47° - 23.45°) = **86.0**°

Calculation of azimuth and elevation for one's latitude

Table 1 lists these calculations for the capital cities of Australia along with Townsville in Queensland to give some spread for northern sections of the country. These are guides, as the calculations may be performed for any locality, and one may compare the latitudes either side of one's own locality to judge whether one has performed the calculations correctly.

All localities south of the Tropic of Capricorn (23.45° S) will always look north to see the Sun. However, those above the tropic may see the Sun either to the north or south of them. For the two entries in Table 1 marked with an asterisk, they are subtracted from 180° to give 79.0° for Darwin and 85.8° for Townsville, both above the southern horizon.

The arcs on the model are parallel to each other, and their planes are at right angles to the pointer (or its extension). They are parts of circles, which show the path of the Sun at different times in the year for the portion above the horizon.

The arc closest to north is for the path of the Sun at the June solstice, when it is above the Tropic of Cancer. For Brisbane, it rises **26.65°** north of east, reaches an elevation of **39.1°**, and sets **26.65°** north of west and has a smaller arc above the horizon than it would below.

The middle arc is for the path of the Sun at either the March or September equinox when it is above the Equator. It rises due **east**, reaches an elevation of **62.5°**, and sets due **west** and has half the arc above the horizon.

The arc closest to south is for the path of the Sun at the December solstice when it is above the Tropic of Capricorn. It rises **26.65°** south of east, reaches an elevation of **86.0°**, and sets **26.65°** south of west and has a larger arc above the horizon than it would below.

Length of daylight

As an extension, students may wish to calculate the length of daylight for their locality.

To calculate the length of daylight, spherical geometry gives cosine (semidiurnal arc) = - tangent (declination) x tangent (latitude). Only one solution is relevant. This arc is from either sunrise or sunset to the highest point in the sky. It is doubled to give the arc from sunrise to sunset This is calculated as a fraction of 360° and converted into time as this fraction of a 24-hour period.

For Brisbane (use -27.47° for this formula, that is, a negative value rather than the positive one previously.

Table 1: Azimuth spread north and south of east and west and elevation for the solstices and equinoxes

City	Latitude S in °	Spread of azimuth	Elevation at June solstice	Elevation at equinoxes	Elevation at December solstice
Darwin	12.43	24.05	54.1	77.6	101.0*
Townsville	19.26	24.93	47.3	70.7	94.2*
Brisbane	27.47	26.65	39.1	62.5	86.0
Perth	31.96	27.97	34.6	58.0	81.5
Sydney	33.87	28.64	32.7	56.1	79.6
Adelaide	34.93	29.04	31.6	55.1	78.5
Canberra	35.31	29.19	31.2	54.7	78.1
Melbourne	37.81	30.25	28.7	52.2	75.6
Hobart	42.85	32.87	23.7	47.2	70.6

Table 2: For the solstices, diurnal arc, arc fraction and length of daylight for selected Australian cities.

City	Latitude S in °	Diurnal arc in ° for June solstice	Arc fraction above horizon	Time in hours. minutes	Diurnal arc in ° for December solstice	Arc fraction above horizon	Time in hours. minutes
Darwin	12.43	169.0	0.47	11.16	191.0	0.53	12.44
Townsville	19.26	162.6	0.45	10.50	197.4	0.55	13.10
Brisbane	27.47	153.9	0.43	10.16	206.1	0.57	13.44
Perth	31.96	148.6	0.41	9.54	211.4	0.59	14.06
Sydney	33.87	146.1	0.41	9.45	213.9	0.59	14.15
Adelaide	34.93	144.7	0.40	9.39	215.3	0.60	14.21
Canberra	35.31	144.2	0.40	9.37	215.8	0.60	14.23
Melbourne	37.81	140.7	0.39	9.23	219.3	0.61	14.31
Hobart	42.85	132.5	0.37	8.50	227.5	0.63	15.10

- for declination = +23.45°, semidiurnal arc = 77.0°, diurnal arc = 153.9° = **0.43** of 360° = **10 hours 16 minutes**.
- for declination = 0°, semidiurnal arc = 90.0°, diurnal arc = 180.0° = **0.50** of 360° = **12 hours 00 minutes**.
- for declination = -23.45°, semidiurnal arc = 103.0°, diurnal arc = 206.1 ° = **0.57** of 360° = **13 hours 44 minutes**.

Table 2 shows the length-of-daylight calculation for the sample of Australian cities.

Conclusion

As an aid to students having a better appreciation of the movement of the Sun over a year at their locality, calculations are shown. A model with stiffened plasticine may be demonstrated for the solstices and equinox positions.

I performed the calculations but wish to acknowledge the contribution of Mr Anthony Lumsden, senior laboratory technician at Brisbane Girls Grammar School, in translating the figures into a software package that enabled him to construct the 3D model.

About the author

Dr Keith Treschman has a PhD in astronomy on astronomical tests of general relativity. He has taught science for 50 years.

Earth System Science Education and the Australian Curriculum

The way forward to sustainability

Part II: Curriculum implications

Keith Skamp and Jodie Green

Abstract

This paper, the second in a series of three, explores the representation of Earth System Science (ESS) in the Australian Curriculum (ACARA, 2018a)) through the Cross Curriculum Priority area of Sustainability and the Australian Curriculum: Science (F–12), with a focus on F–10. Part I (in *Teaching Science, 68.1*) overviewed the current understandings of the Earth System and the relatively recent interdisciplinary field of Earth System Science (ESS). Here, in Part II, an analysis of the Cross Curriculum Priority area of Sustainability and the Australian Curriculum: Science (F–12) revealed that several key ESS understandings and system-thinking skills were present. How the most current ESS understandings and abilities could lead to a far deeper understanding of the Earth System are then considered and those that may need more attention from students and teachers are highlighted. Part III (in a forthcoming issue) outlines several research-informed pedagogies to help learners develop more scientific understandings of the Earth System, and appropriate related abilities. These Earth System goals and pedagogies needed to be considered in the ACARA review of the Australian Curriculum: Science and the Sustainability Cross Curriculum Priority area — to that end, this paper was submitted to the appropriate committees. We believe the suggested ESS additions and emphases could comprise one pathway toward a more comprehensive and confident Earth System literacy and a stronger engagement in the Earth and other sciences at every school level, and to the curriculum as a whole. Better-informed, sustainability decision-making and actions by students as today's, and tomorrow's, citizens is the hoped-for outcome.

Earth System Science in school curricula

As outlined in Part I, there is a strong case for embedding Earth System Science in school curricula. Many have argued that planet Earth needs to be studied, by learners at *all* levels, as an "integrated system, characterised by dynamic interactions" rather than only as a limited number of separate systems and 'spheres' (Manduca & Kastens, 2012, p. 93, adapted; Shepardson et al., 2014). As Figures 2 (see the 'Anthroposphere') and 4, in Part I, indicates, such an 'Earth science' must involve the social sciences (Gilford et al., 2010), although the Science Learning Area (ACARA, 2018b) is the main focus here.

Mayer's seminal papers (1995, 1997), referring to 'the Earth System', formed the foundation for the later development of Earth System Science as a necessary inclusion within school science curricula (Orion & Libarkin, 2014). A key role was to advance Earth Literacy (www.earthscienceliteracy.org); this source referred to nine 'Big Ideas' and supporting concepts with a geoscience emphasis — Big Idea 6, for example, is "Life evolves on a dynamic Earth and continuously modifies Earth'. In Mayer's papers, seven Earth Systems Education understandings were articulated (e.g., The Earth System is comprised of the interacting sub-systems of water, rock, ice, air and life [Mayer, 1995, p. 384]). These earlier developments led to Earth System Science being recognised as a major idea in the 2013 Next Generation Science Standards (National Research Council, 2013) in the USA (Orion & Libarkin, 2014, p.482).

Revisiting the Earth System Science-Sustainability link

Images such as Figure 1 (the Earth from Space in Part I) have helped humanity appreciate the Earth as a single system and inspired many to care for the Earth. Now, Earth System Science, through the planetary boundaries framework (Figure 3 in Part I), has provided a "compass for the journey to a sustainable future… (It) is designed to keep us on the right path" (Attenborough, 2020, p. 126). However, "overshoot" has already occurred in the boundaries of climate change, biodiversity loss, excessive use and run-off of fertiliser and land-use change (e.g., deforestation). In addition, overshoot in one boundary affects all the boundaries and subsystems, as they are all connected in various meaningful physical ways. A missing link in this compass is that it does not address the unsustainable distribution of the Earth's resources with only about 16% of the human population responsible for an estimated 50% of humanity's impact on the living world (Attenborough, 2020, p. 126; Hickel, 2018). This is where the Doughnut model adds so much — representing a reconceptualization of sustainability — in that it "recognises that human wellbeing depends on enabling every person to lead a life of dignity and opportunity, while safeguarding the integrity of Earth's life-supporting sub-systems" (Raworth, 2017, p. e48). It depicts both ecological and social boundaries (see Figure 4 in Part I); in between these is the "ecologically safe and socially just space in which humanity has the chance to survive" (Raworth, p. e48). Apart from addressing the ecological overshoots humanity also needs to overcome the social shortfalls. Earth System Science, therefore, helps us to appreciate not only the interdependence of planetary processes, but also the "complex interdependence of human wellbeing and planetary health" (Raworth, p. e49). As Attenborough (2020, p.128) comments, "sustainability in all things" is the goal with the Doughnut model as the (more complete) compass for a way forward. This view of sustainability is consistent with "systems… support(ing) all life on Earth and our collective wellbeing" (ACARA, 2018a, emphases added).

This Earth System Science — Sustainability link is a strong justification for Earth System Science in school curricula. It develops "environmental insight" — an appreciation of the two-way interactions between humanity and the interacting physical and biological processes that comprise the Earth System (Ben-Zvi Assaraf & Orion, 2009) — and 'environmental science literacy' without which, Mohan et al. (2009) posit, students would not be able to interpret findings such as those provided in the assessment reports from the International Panel on Climate Change. Earth System Science, therefore, has a distinctive education for sustainability role both in, and beyond, the classroom.

Status of Earth System Science in schools

Orion (2019, p. 2, parentheses added) noted "worldwide Earth science education (within the context of Earth System Science) has retained the same low profile (in schools) that was noted in the previous century", despite a "strong theoretical foundation" for its, and Earth System Science's, inclusion. This is consistent with geoscience being "largely absent in Australia's school system" (National Committee for Earth Sciences,, 2018, p. 31). Earth System Science (as discussed here) is, therefore, probably not a significant inclusion in school science in Australia.

For students to engage with Earth System Science they need to comprehend the nature of the Earth System (and its sub-systems) and use system thinking (Orion & Libarkin, 2014). Since Mayer's (1995, p. 384) list of 'Earth Systems Education' understandings, there have been several iterations of the original Earth Systems Education / (now) Earth System Science Education framework — note the different nomenclature from 1995 to the present. Table 1 is a revised set of understandings based on Steffen et al. (2004, 2015, 2020) with input from the National Academies of Science, Engineering, and Medicine (2020). It also includes reference to Earth Literacy Big Ideas (Earth Science Literacy principles, 2010: www.earthscienceliteracy.org) and social science connections (Finley et al., 2011): here, as elsewhere in this paper, further details are available from the authors.

Mayer's (1995) Earth Systems Education understandings (see 1 and 8 in Table 1) are included to emphasise "the aesthetic values of planet Earth as interpreted in art, music and literature… stress(ing) creativity of the human spirit… essential to the proper conduct of science" (1) and the "immediate concerns and interests of the student" (8) (Mayer, p. 385, parentheses added). When ESE 8 was formulated, there was scepticism about the "practical use" of Earth System Science — for example, "[O]f what strategic or economic benefit is the evidence or concern about global warming?" (p.378)!; understanding ESE 8 brought the focus back to students' lives and futures — how much more so in 2022 in light of the recent extreme and dangerous bushfire seasons on the east and west coasts of Australia.

ESS understandings in the Australian Curriculum

The Australian Curriculum: Science was analysed to determine the presence of the Earth System Science (ESS) and Earth Systems Education (ESE) understandings in Table 1. Apart from the obvious connection of ESS with science curricula, evidence suggests 'sustainability' initiatives and resources are implemented more often by science teachers than teachers of other subjects (Barnes et al., 2017), even though there are more Sustainability Cross Curriculum Priority

Table 1: Major Earth System Science (with Earth Systems Education) understandings.

Earth System Science (ESS) (2–7) and Earth Systems Education (ESE) (1, 8) understandings	'Essential' natural systems (N) concepts (Finlay et al., 2011)	Earth Literacy Big ideas (BI)	Comments
1. The Earth is unique, a planet of rare beauty, and great value.			Earth Systems Education framework (Mayer, 1995, p. 384).
2. The Earth is an active, dynamic, open system in which all components interact to shape the state of the planet.	N3, N4, N5 & N6	BI 1 & 2	The changes are complex, frequently involve biological processes, and not explained by simple cause and effect. Dynamism refers to more than weather and tectonics. (Life is also a cause of Earth System dynamism: see 'Life as a driver below' [ESS 5].)
3. Earth sub-systems (geological, geochemical, geophysical, and biological processes that govern Earth System interactions) operate on wide temporal and spatial scales.	N1, N2, N7, N8–14	BI 2, 3, 6	The hydrological (water) cycle can be considered as part of the biogeochemical cycle (as can the carbon, nitrogen, phosphorus cycles). There can be tele-connectivity: matter and energy connections can interact over long distances. Modes and states can be relatively stable over time but with abrupt changes modifying or shifting these states.
4. How the Earth currently works as an integrated system (including people as geological agents) and how it has worked in the past is central to predicting how present-day changes, both natural and anthropogenic, are likely to influence human society.		BI 7, 8, 9	Global change is much more than climate change. Earth scientists use repeatable observations and testable ideas to understand and explain our planet. Modes and states of the Earth System can be relatively stable but can abruptly 'flip' to another mode.
5. Life as a driver. The Earth is a system that life itself helps to modulate.		BI 6	Biological processes (interactions with physical and chemical processes) have a much stronger role on the functioning of the Earth System than previously thought (Steffen et al., 2004, p. 256).[1]
6. Human activities are significantly influencing the functioning of the Earth System in many ways that could be irreversible and catastrophic.	Can be related to Finley et al.'s, (2011), 'Essential social systems' concepts[2]	BI 9	The Earth System is operating in a no-analogue state. i.e., in conditions outside the range of at least the last half-million years (Steffen et al., 2004, p. 262).
7. Resilience, tipping points, and surprises: Earth's dynamics are characterised by critical thresholds and abrupt changes and mode shifts.			Tipping points (TPs) are when "large scale discontinuities occur" in Earth processes (e.g., the climate system) (Lenton et al., 2019, pp. 592–593). Exceeding a process TP: could result in "abrupt or risky change" (Gifford et al., 2010, p. 2); can occur at different levels (e.g., regional to global) but there could be a 'global tipping point'; and could cross over to other processes (Lenton et al.,2019 p. 594–595).
8. There are many people with careers and interests that involve study of the Earth's origin, processes and evolution.			Earth Systems Education framework (Mayer, 1995, p. 384).

1. Examples of biological processes that interact with physical and chemical processes include: the formation of the early atmosphere and ozone layer (and the ocean getting rid of all its dissolved iron) through the great oxidation event driven by cyanobacteria stromatolites (from Earth's early history); the global oceanic carbon pump driven by oceanic coccolithophores and foraminifera; cloud formation being linked to organisms and biological products in numerous ways, from 'dusts' and excretions (see e.g., Steffen et al., 2004, pp. 29, 40, 49).
2. Of Finlay et al.'s (2011) eight concepts, examples include: humans are dependent on the Earth's materials; the primary social systems are agricultural, economic, legal, communications, transportation, moral, political and cultural (p. 107).

(Sustainability CCP) examples ('elaborations') in the Australian Curriculum: Humanities and Social Sciences (ACARA, 2018c). It is, therefore, hoped that science teachers see the opportunities that ESS provides for enriching their teaching with a sustainability emphasis.

In the following, the presence of ESS (and ESE) understandings are outlined in: (1) the 'Key concepts' in the Sustainability CCP area and their representation in the Australian Curriculum: Science; (2) the 'Key Ideas' and the 'Understandings' and 'Elaborations' in the Science curriculum (F–10); and (3) associated Scootle resources for these areas.

The Sustainability Cross Curriculum Priority: Key Concept Organising ideas

Earth System Science (ESS) is most apparent in the key concept of 'systems', which "explores the interdependent and dynamic nature of systems that support all life on Earth and our collective wellbeing" (ACARA, 2018f). Of the nine Sustainability CCP organising ideas, the three system ideas (0.1.1–1.3) overlap ESS understandings 2 to 5 in Table 1, although only the biosphere and ecological systems are specified, while other systems (as in Figure 2 in Part I) are absent. A 'futures' idea (01.8) overlaps with ESS 4 and 6 that refer to environmental impacts on achieving a sustainable human society; the potential serious implications of these impacts are not stressed.

Sustainability and the Science Curriculum

In the Australian Curriculum: Science, the Sustainability CCP refers to students "investigating and understanding chemical, biological, physical and Earth and space systems" that "operate at different time and spatial scales" (ESS 3). "Relationships between systems and system components and how systems respond to change" are explored so that students can appreciate "the interconnectedness of Earth's biosphere, geosphere, hydrosphere and atmosphere"; this includes various "relationships including cycles and cause and effect" (ESS 2, 3). In examining these relationships, students can learn to make "decisions (that) can impact on the Earth System" and "predict possible effects of human and other activity" (ESS 4, 6) (ACARA 2018e, parentheses added). Students are therefore expected to encounter all Earth System 'spheres', although recent research would support including the 'Anthroposphere'.

The only location in which the essential concept of a single 'Earth System' is found in the Australian Curriculum: Science (F–10) is in the Sustainability CCP learning area statement (ACARA, 2018e). At the senior secondary science level "Earth System" is mentioned in the overview of the Sustainability CCP for all science subjects. Furthermore, within the Earth and Environmental Science Curriculum the "Earth System model" is referred to in the summary of each of its four units (ACARA, 2018d). In these units, it is a significant concept (mentioned several times and with numerous references to Earth systems [plural]). We would argue that because the 'Earth System' construct is transdisciplinary, that all the senior sciences (and social sciences as well, obviously, through the Sustainability CCP) need to refer to appropriate Earth System understandings as adopted by Earth System scientists (as in Table 1). The cue from the Sustainability CCP needs to be heeded; 'Earth System', after all, is an underlying core idea and needs to be prominent in teachers' minds.

'Key ideas' in the Australian Curriculum: Science

Of the six science Key ideas, the 'systems' construct has the strongest overlap with ESS understandings. It is recommended that 'systems' be introduced from the earliest years (see Table 2) and that "relationships between components within simple (living and non-living) systems" occur in upper primary. Included in Years 7 to 10 are the "the processes and underlying phenomena that structure systems" and that there are "interactions between components (which) can involve forces and changes acting in opposing directions" — conditions for a steady state in systems are mentioned. Older students are expected to become "increasingly aware that systems can exist as components within larger systems, and that one important part of thinking about systems is identifying boundaries, inputs and outputs" (ACARA, 2018b, parentheses added). Although 'systems' are referred to in a generic sense, an analysis of science content statements and elaborations (F–10) (available from authors) indicates ecosystems and the carbon cycle are the examples mentioned. This Systems 'Key idea' description strongly aligns with ESS 2 and 3 (and possibly 5). The reference to boundaries, inputs and outputs could embrace the Anthropocene concept and the planetary boundaries framework (ESS 4, 6).

Table 2: Science 'Key Idea' statements and Earth System Science understandings.

Year level	Key Idea statements and ESS understandings (©ACARA, 2018, material in parentheses added)
F–2	**"From Foundation to Year 2, students learn that observations can be organised to reveal patterns, and that these patterns can be used to make predictions about phenomena."**
2	**"... students describe the components of simple systems (ESS 2) ... They ... are introduced to the idea of the flow of matter when considering how water is used."**
3–6	**"Over Years 3 to 6, students develop their understanding of a range of systems operating at different time and geographic scales (ESS 3)."**
3	**"... students begin to develop an understanding of energy flows through simple systems (ESS 3). In observing day and night, they develop an appreciation of regular and predictable cycles ... They use their understanding of relationships between components of simple systems to make predictions (ESS 2, 3)."**
4	**"... They begin to appreciate that current systems, such as Earth's surface, have characteristics that have resulted from past changes and that living things form part of systems (ESS 5). They understand that some systems change in predictable ways, such as through cycles. They apply their knowledge to make predictions based on interactions within systems, including those involving the actions of humans (ESS 2, 3 4)."**
5	**"... Students begin to identify stable and dynamic aspects of systems, and learn how to look for patterns and relationships between components of systems (ESS 2, 3). They develop explanations for the patterns they observe."**
6	**"... students ... continue to develop an understanding of energy flows through systems. ... They develop a view of Earth as a dynamic system, in which changes in one aspect of the system impact on other aspects (ESS 2, 3); similarly, they see that the growth and survival of living things are dependent on matter and energy flows within a larger system (ESS 3, 5)."**
7–10	**"Over Years 7 to 10, students develop their understanding of microscopic and atomic structures; how systems at a range of scales are shaped by flows of energy and matter and interactions due to forces, and develop the ability to quantify changes and relative amounts."**
7	**"... They use and develop models such as food chains, food webs and the water cycle to represent and analyse the flow of energy and matter through ecosystems and explore the impact of changing components within these systems (ESS 3, 5) ... They investigate relationships in the Earth-sun-moon system and use models to predict and explain events. Students ... analyse relationships between system components (ESS 2)."**
8	**"... students ... describe the role of energy in causing change in systems, including the role of heat and kinetic energy in the rock cycle. Students use experimentation to isolate relationships between components in systems and explain these relationships through increasingly complex representations (ESS 3)."**
9	**"... students consider the operation of systems at a range of scales. They explore... the interdependencies between biotic and abiotic components of ecosystems ... They begin to apply their understanding of energy and forces to global systems such as continental movement (ESS 2, 3)."**
10	**"... students explore systems at different scales and connect microscopic and macroscopic properties to explain phenomena (ESS 2, 3). Students explore the biological, chemical, geological and physical evidence for ... theories, such as the theories of natural selection and the Big Bang (ESS 2, 4)."** **"... They learn about the relationships between aspects of the living, physical and chemical world that are applied to systems on a local and global scale and this enables them to predict how changes will affect equilibrium within these systems (ESS 2, 3, 5)."**

Table 2 includes the science 'Key idea' statements (F–10) that directly refer to ESS understandings. Teachers with an Earth System mind set would 'see' many opportunities to develop students' appreciation of these understandings. An F–6 example would be, using the soil in school gardens as a stimulus, the meanings of 'Earth' as our home and as in soil, and 'life' as 'active' on both scales (from global to macroscopic to microscopic) could be illustrated. In fact, across the Australian F–10 Science Curriculum, concepts such as gravity, buoyancy, flow and energy dynamics (and more) are all able to be demonstrated and interrogated through an Earth System lens. Furthermore, there are generic science understandings mentioned that would assist students' comprehension of ESS understandings such as 'patterns', 'cause and effect relationships', 'components of simple systems', and developments in students' ability to think at the particulate level (e.g., atoms and molecules) as well as science inquiry skills such as making observations and collecting data to accumulate evidence for models that could explain phenomena.

As stated, the main focus here is on Years F–10. When we do look at the senior secondary level, it is only in the Earth and Environmental Science curriculum document that the Earth as a single system is mentioned (see earlier): in it "four interacting systems" are identified that can impact each other over "temporal and spatial scales". Energy transfer and transformation between these systems are investigated and the enhanced greenhouse effect and climate change overviewed (ESS 1–4, 6 and to some extent 5). Tipping points and related phenomena, such as abrupt changes and modes, are not obviously present. The senior secondary Biology curriculum document does make significant reference to interacting systems, "from ecosystems to single cells and multicellular organisms" (ESS 5 to some extent) but not to the Earth System (as above). Content and exemplars with an Earth System focus is not present in the senior secondary Chemistry and Physics curricula (ACARA, 2018e), even though the Sustainability CCP guidance for these subjects requires it. This inevitably results in leaving these content choices open for teachers to select, and it sends a mixed message regarding the importance of such learning. Without help to include it, Earth System Science could be inadvertently omitted, thought of as an optional inclusion or, in a sense, have lower 'non-core' status for many teachers and learners. If these issues are not addressed, many future teachers (and other professionals) may complete senior secondary science without the holistic view of the Earth that Earth System Science engenders. It can be added that if an integrated senior secondary science curriculum existed, it could ensure that students appreciate that all science subjects contribute to Earth System Science.

Science understandings and elaborations (F–10) and ESS understandings

An analysis of the science understandings and elaborations (available from authors) found that most ESS understandings are reflected in the 'Earth and space sciences' sub-strand, followed by the biological sciences. Earth System Science understandings were absent in the physical and chemical sciences but several of these subjects' concepts are necessary as they underpin (ESS) constructs such as 'energy' and 'matter'. The analysis found that all ESS/ESE understandings (except 1, 7 and 8) are directly mentioned; ESS 2 and 3 are introduced at the primary level and further developed in later years, while ESS 4 and 6 directly emerge at Years 9 and (especially) 10.

'Life as a driver' (ESS 5) may be implied in Years 9 and 10, although there is a tendency to stress a misunderstanding of the Earth System that El-Hani & Nunes-Neto (2020, p.79, comments in square brackets added) comment is prevalent at school level, namely:

> ... [the misunderstanding that] geophysical and geochemical structures, processes and conditions we find on Earth [are] merely a result of astronomic or geological events [rather than] such geo-physical and geochemical structures, processes and conditions [being] (partially) effects of the functionality of biological organisms, gathered in populations and ecological communities. (For examples of 'Life as a driver' see Table 1).

Finally, there are no direct references to tipping points (ESS 7), complex systems, feedback loops (ESS 2, 3 and others) and system thinking (see below) although it is probably implied.

Associated science curriculum (F–10) Earth System Science resources

With the absence of some Earth System Science concepts in the Australian Curriculum: Science (e.g., feedback loops) a keyword search of Scootle resources (https://www.scootle.edu.au/ec/p/home) indicated (as shown in Table 3) that:

- 'Tipping point' was mainly associated with climate change although global water systems was a focus in one resource;
- No resources were located with 'complex system' mentioned in the descriptor, although one resource referred to 'feedback loop' (related to climate change).

For some ESS understandings (e.g., tipping point) teachers of science may find suitable resources are limited and time-consuming to locate or in some instances virtually non-existent (e.g., complex systems and types and role of feedback loops including the role of biological processes).

The most comprehensive of the Scootle resources is Big Systems (Wilde et al., 2018) in the Science by Doing program (https://www.sciencebydoing.edu.au). This resource acknowledges the 'Earth system' construct, refers to 'systems thinking' and the attributes of systems (open, closed and isolated). It also indicates how the various Earth systems (e.g., biosphere, lithosphere) can influence each other — the anthroposphere is not mentioned although reference is made to anthropogenic gases. These systems (biosphere, etc.) are considered to be components of the Earth System and are illustrated at the local environment level as well as on a planetary scale. It is emphasised that Earth sub-systems' processes can be studied separately

Table 3: Scootle resources — a specific ESS keyword search*.

Keyword	Number of resources	Learning area (Year level)	Resources (accessible)
'Earth System'	18	Science (Year 9)	***Big systems*** **(Teachers' and students' guides): focus on four principal Earth sub-systems (lithosphere, hydrosphere, biosphere, and atmosphere) with a climate change emphasis (Wilde et al., 2013; Wilde et al., 2018).**
		Other	**Mainly science and geography (e.g.,** ***Explaining our catchment;*** **'Clean energy council' [7 resources: types of energy])**
'Tipping point'	25	Science (Year 9)	***Try maintaining your shell in an acidic ocean*** **(an ABC Splash resource): Ocean acidification and the development of an early warning system.**
		Science (Year 9/10)	**Three resources directly address this construct:** ***Water security: A 'tipping point'; Melting permafrost: A sign of climate change;*** **and** ***Greenhouse effect tips towards catastrophe.***
		Others (21)	**Others that did not refer to tipping point in the resource descriptors included:** ***The Greenhouse Effect*** **(interactive) (Year 10); many geography resources about greenhouse gas emissions associated with types of vehicles.**
Feedback loop	1	Science (Year 10)	***First signs of climate change*** **(refers to a positive feedback loop when sea ice is lost).**

*These were the resources listed on Scootle in 2020 (https://www.scootle.edu.au/ec/p/home)

"as long as [it is] recognise[d] [that there is a] high level of interactions between them" (p.3). Climate science is encountered from an Earth sub-systems perspective but with a focus on the carbon cycle (e.g., impacts on ocean acidification and biodiversity). Big Systems stands out as an available middle secondary resource that addresses many aspects of ESS 2 to 6. Although systems' boundaries are mentioned, the notion of 'planetary boundaries' is not overt and direct reference to tipping points and alternative Earth System modes and abrupt changes (ESS 7) is not made (although how Earth avoided a catastrophe by reducing ozone depletion is included). The aesthetics of planet Earth (ESE 1) are not covered, but students are encouraged to interact with Antarctic scientists (and learn about ESS careers) (ESE 8).

Systems thinking

Intimately related with learning Earth System Science understandings is the ability to be a system thinker (system thinking is overviewed in Shepardson et al., 2014, p.334–5). Empirical data suggests a hierarchy of system thinking abilities (associated with learning about the Earth System and Earth systems); one representation is in Table 4 with a climate system example. Ben-Zvi Assaraf and Orion (2010b, p.1255) provide another example for the (global) water cycle; abilities include displaying the web of processes and relationships occurring in the oceans and on land (Organising systems' components, processes and their interactions within a framework of relationships) and appreciating that the quality of drinking water in an area depends upon past events and processes in geological and

Table 4: Hierarchy of system thinking abilities.

System thinking abilities[1]		Meaning in a climate system[2]
Analysis of system components	Identify the **components** of a system and **processes** within the system	Identifies land, life, ice, atmosphere, oceans, clouds, humans, sun (components); water and carbon cycles and energy transfer (processes)
Synthesis of system components	Identify **simple interactions** between or among a system's components	Identifies relationships within and between components; usually cause–effect relationships
	Identify a system as a dynamic entity (**dynamic thinking**)	Identifies relations between three or more components
	Organize the systems' components, processes, and their interactions, within a **framework of relationships**	Understands how changes to a component affects other components and processes within a component
Problem-solving	Identify cycles of matter and energy within the system (**cyclic thinking**)	Understands that water and carbon cycle through the system and that energy is transferred — absorbed, radiated, reflected — among components of the system
	Identify patterns (**generalisations**)	
	Recognize **hidden** dimensions of systems	
	Think temporally: forward and backward	

1. Adapted from Ben-Zvi Assaraf & Orion (2010a, p. 541) and Orion & Libarkin (2014, p. 490, emphases in original).
2. Adapted from Shepardson et al. (2014, p. 347).

human time (Thinking temporally). The system thinking hierarchy in Table 4 omits 'identifying feedback loops within systems' (Orion & Libarkin, 2014, p.490).

This System Thinking model could guide teachers' Earth System Science lesson development. Based on Year 4 students experiencing a 30-hour unit (excluding field trips) about the "process of water transportation through Earth's systems" (Ben-Zvi Assaraf & Orion, 2010a, p.543) and in Year 8, 45 hours of "laboratory and outdoor learning inquiry-based activities" with a similar focus (Ben-Zvi Assaraf & Orion, 2005, p.524), with both sequences aiming to develop system thinking skills, it was found that:

- Most Year 4 students could analyse components and processes and recognise connections between system components, with about half noting dynamic relationships but far fewer demonstrating higher-level abilities (about 20% appreciating cyclic thinking), although some achieved at even higher levels (e.g., identifying hidden parts of the hydrological system).
- Year 8 students displayed similar improvements in system thinking abilities but with up to a third thinking in a cyclic manner and appreciating hidden system features and processes.

In these studies students' prior system-thinking abilities were very low (even at Year 8). Various inferences can be drawn. Teachers cannot assume that system thinking is an intuitive ability; such abilities "need to be learned if they are to improve" (Ben-Zvi Assaraf & Orion, 2010a, p.558). Furthermore, teachers need to be familiar with system-thinking concepts and abilities (the teachers in these two studies were) and appreciate significant time is required for students to acquire system-thinking abilities.

Integrating Science with Earth System Science understandings and system-thinking abilities

For students to develop "an integrated picture of the Earth" takes time, requiring a spiral curriculum that regularly revisits Earth Systems Education concepts and abilities (American Association for the Advancement of Science, 1993, p.66; also see Chang, 2005, p.626). This is possible if teachers look for connections between their existing science curriculum and key Earth System Science (ESS) understandings and abilities. Chang (2005) described how this was done with the Taiwanese Science and Life Technology (SaLT) curriculum (Years 1 to 9), in which the objectives and content of this curriculum were met within Mayer and Tokuyama's (2002) Earth Systems Education framework (which overlaps with most ESS/ESE 1 to 8 in Table 1). The SaLT understandings of 'Composition and characteristics of nature' (sub-understandings of 'Earth environment', 'Lives on the Earth' and 'composition and properties of matter') and 'Interactions in nature' (sub-understandings of' 'change and stability', 'interactions' and 'structure and functions'), for example, correlated with (in this paper's Table 1) ESS understandings 2, 3 and 4 (Chang, 2005, p.632). How similar ESS connections could be made with the Australian Curriculum: Science have been outlined earlier. Interestingly, Chang reported secondary students experiencing this modified curriculum achieved higher science achievement scores and expressed more positive attitudes towards the science content — a result worth reflecting on.

These findings suggest that, to begin with, primary and secondary teachers need to have, or develop, an Earth System Science mindset (which embraces a system-thinking perspective). A way forward would be for teachers to look for, and share, correlations between science understandings on which they are focusing and one or more ESS understandings (as in Chang, 2005). Earth sub-systems learning (say, about the water cycle), for example, could be enveloped, at an appropriate level, within an Earth System model (as in Figure 2 in Part I). This could be done by continually scaffolding student thinking from an Earth System perspective. In fact, this approach is analogous to that followed in the Year 9/10 Big Systems unit (Wilde et al., 2018) in that some ESS (and ESE) understandings (1 to 8) were introduced first and then Earth sub-system cycles studied, but with strong scaffolding. To what extent this deductive introduction would be effective with upper primary students is problematic; even so classroom dialogue could reflect the Earth System Science perspective.

Conclusion

Earth System Science investigates how the single Earth System operates. As Part I (see *Teaching Science, 68.1*) indicated it is a paradigmatic shift in how we 'see' our planet. Teachers need to 'take on board' this mindset when teaching science (and, where appropriate, other subjects). Learning science, through the lens of Earth System Science, will help students see why it is necessary to learn about the Earth System so that we can better protect our planet. The recent developments in Earth System Science need to be reflected in the Australian Curriculum (especially the Science [but also the Humanities and Social Sciences] curriculums). How this can occur has been described in this paper (Part II). Specific Earth System Science pedagogies will be introduced in the next issue of *Teaching Science*.

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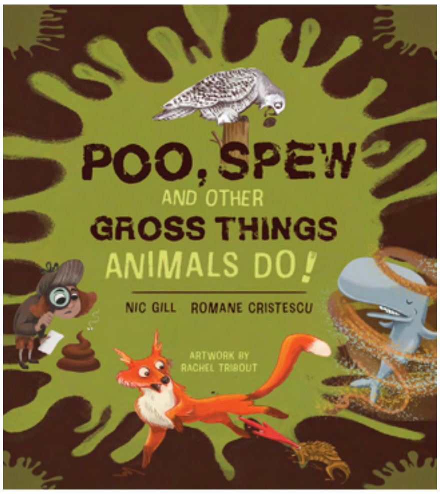
Poo, Spew and Other Gross Things Animals Do!



Written by Nic Gill & Romane Cristescu

Illustrated by Rachel Tribout

Published by CSIRO Publishing

(https://www.publish.csiro.au/book/8021)

Recommended for ages 8 to 12.

Poo, Spew and Other Gross Things Animals Do! is a thoroughly engaging non-fiction text written by Nic Gill and Romane Cristescu and supported by beautiful illustrations of Rachel Tribout. Nic Gill is an environmental writer and conservation dog handler and Dr Romane Cristescu is a researcher and the director of Detection Dogs for Conservation. Both authors have overlapping interests in conservation ecology, where they devise solutions to help wildlife.

The book consists of eight well-defined chapters with over three dozen detailed photographs depicting gross outputs of different animals, ranging from microscopic demodex mites that live near/on the hair follicles of mammals (including humans) to large animals like sea cucumbers, spiders, frogs, fish, owls, chickens, zebras, elephants and whales. The book also contains interviews with a number of scientists so that the science is presented as a creative human activity that fulfils our natural curiosity. The first chapter provide details on how excreta, mucus, vomit, and the flatulence of animals are produced and how they aid the survival of the animal in its habitat. I particularly liked how the first chapter (p. 16) addressed the alternate conception on bee honey being bee vomit. The rest of the chapters outline in a thought provoking and fun manner how animals use their excreta to: maintain a healthier balance in gut microbiota, achieve homeostasis, escape predators, attract potential mates, build homes, and nurture their young. The final chapter explains the significance of animal excreta on maintaining the flow of energy and matter through the ecosystem.

The comprehensive text — well supported by the images and a scientific glossary — and the extensive teacher notes available online from CSIRO Publishing makes this book a valuable resource for primary classrooms to explore several key learning outcomes in science, English and the design and technology curricula. I believe the teacher notes also contain adequate details that can be easily expanded into a complete set of lessons. The book contains a particularly entertaining scientific key (pp 58–59) to help differentiate animal excreta based on their physical properties, which could be a powerful tool for an inquiry-based, primary science learning activity during a nature excursion.

The content, language and typography of the book is perfectly aimed at middle and upper primary students. However, I was also thoroughly intrigued and immensely enjoyed reading the book and looking at the wonderful photographs, which I think makes the book an engaging reading choice for both adolescents and adults, if you are not put off by the title or the grossness.

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