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NSW GOVERNMENT

Teaching poetry

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Scientific knowledge through argumentation

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Scan is a leading refereed journal, published monthly between February and November. Scan aims to bring innovative change to the lives and learning of contemporary educators and students. Through Scan, teachers' practice is informed by critical engagement with peer reviewed research that drives improved school and student outcomes across NSW, Australia and the world. Scan aims to leave teachers inspired, equipped and empowered, and students prepared.

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Teaching scientific explanation and argumentation in a post-truth era

Dr Kok-Sing Tang

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Dr Kok-Sing Tang concisely explains the meaning and importance of scientific literacy in the education of students K-12.

Science education is currently facing an unprecedented crisis. We are now living in a post-truth period where basic facts are contested by fake news and conspiracy theories. As public trust in science is declining, the goal of scientific literacy will increasingly be more important. The emphasis of science education in K-12 needs to shift from knowledge acquisition to a deeper appreciation of the nature of science that generates our knowledge of the world. After all, the challenge in an information age is not whether children know about the solar system, evolution, virus, climate change or any information that can be found easily on the internet. Rather, the challenge is to engage children in developing scientific habits of mind that could critically evaluate information based on sound reasoning and evidence.

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Current problem

A potent illustration of the current crisis is the flat earth movement where many sensible adults no longer believe the Earth is round, despite learning this fact in schools and seeing countless photographs and videos of Earth from space. Many of these Flat Earthers have developed piecemeal explanations for everyday phenomena such as sunsets, tides, moon phases and eclipses. Without a good understanding of how science works, it can be easy to fall prey to these 'alternative' theories and reject decades of scientific research based on conclusive evidence. The flat earth movement is only the tip of the iceberg, as the larger community of misinformed people also include COVID sceptics, anti-vaxxers and climate change deniers who are presently threatening our wellbeing and survival on this planet. Therefore, science education in this post-truth era needs to prepare young children to reason, debate and make conclusions following the inquiry process used by scientists.

Science has in fact developed a robust mechanism over the centuries that addresses alternative theories and peer debate in the process of reaching consensus. Unfortunately, not many science teachers and students are familiar with this process. Ask anyone about the key characteristic of science, and the most likely answer is the science experiment. No doubt experiment (or investigation in general) is an integral part of scientific inquiry, and this has been reinforced in most schools through laboratory-based practical work. However, many people tend to associate the science experiment with a recipe-like procedure along a fallacious 'scientific method' (Mody, 2015). A more accurate way to describe the process of science is through a set of scientific practices. In particular, explanation and argumentation are two of the practices that will be critical to mitigate the rise of science denialism, as I will elaborate further.

The Next Generation Science Standards (NGSS) developed in the U.S. provides a useful framework to understand the relationship among the scientific practices of investigation, argumentation and explanation, as shown in Figure 1 (Reproduced from National Research Council, 2012, p 45). Investigation involves an inquiry process of experimenting, observing and measuring to collect empirical data from the real world. Explanation involves the use of established or new theories and models to account for the data collected from investigation. Theories

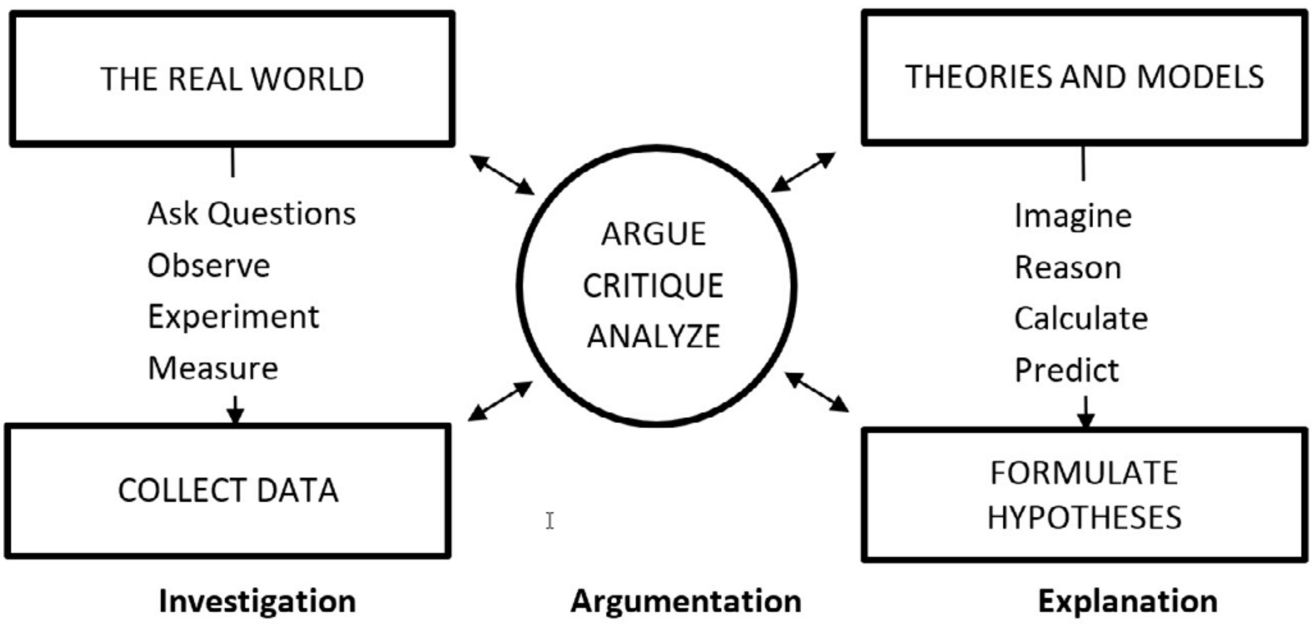

Figure 1. The relationship among investigation, argumentation and explanation

and models are important in science as they help us to reason, make calculations and formulate hypotheses, which could be further tested through investigation. Mediating the activities of investigation and explanation, as shown in the centre of Figure 1, is the core activity of argumentation. Argumentation involves the critique and debate of data and hypotheses. It frequently occurs among scientists internally within a research laboratory as well as externally in peer reviews, conferences and journal correspondences. The argumentation process often leads to further investigations or changes in the proposed theories, until a consensus is reached within the scientific community.

Explanation and argument

In the science classroom, explanation and argument are terms that are frequently used among teachers and students. However, their precise meanings are seldom clarified which often leads to confusion. According to philosophers of science, a scientific explanation is an account of why or how a phenomenon occurs according to a coherent theory (Braaten and Windschitl, 2011). There are many canonical explanations that students learn in school science, such as 'why did the dinosaurs become extinct?' or 'how is a shadow formed?' One of the issues in science teaching is that students often reproduce or regurgitate a 'standard' explanation instead of constructing an explanation on their own with some guidance. In a previous research, I developed a pedagogical strategy called premise-reasoning-outcome or PRO to support students in constructing scientific explanations (Tang, 2015). Premise is an accepted theory, model or fact that is used as the basis or 'first cause' of an explanation. Reasoning is the chain of events that follow logically from the premise, and outcome is the phenomenon to be explained.

By contrast, a scientific argument seeks to persuade others by justifying a claim in light of supporting or contradictory evidence. Unlike an explanation that seeks to account for something that has already happened or is not in dispute, an argument always has a degree of uncertainty over the claim to be argued, without which there would be no argument (Osborne and Petterson, 2011). According to the philosopher, Stephen Toulmin (1958), an argument minimally must consist of a claim (a tentative proposition), data or evidence to support the claim, and a warrant that connects the data to the claim. Because a claim is in dispute, argumentation is a process that involves dialogic exchange of arguments between two or more parties to defend or refute the claim (Cavagnetto, 2010). A good illustration to distinguish explanation and argumentation is the question of 'why did the dinosaurs become extinct?' The most common explanation given is based on the premise of an asteroid collision. This collision triggered a chain of casual events from the massive release of dust particles to the creation of an atmospheric cloud, which eventually led to the mass extinction of dinosaurs. Although this explanation is

$$r = \frac{360\,(Surface\ distance\ between\ Brisbane\ and\ Sydney)}{2\pi\,(Angle\ of\ elevation\ in\ Brisbane - \ Angle\ of\ elevation\ in\ Sydney)}$$

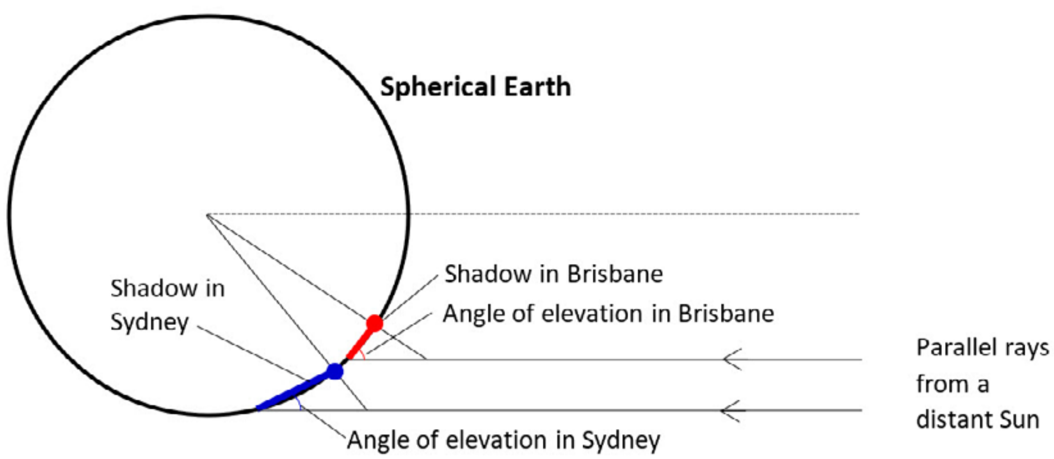

Figure 2. Explanation of shadow differences using a Spherical Earth model (not drawn to scale)

logical, the premise of a large asteroid collision has not been universally accepted among geologists and paleontologists. As such, this premise is currently a claim that requires more empirical evidence in order to convince the scientific community to accept it. Some of the best evidence supporting the asteroid collision so far are the Chicxulub crater (near Mexico) and the high concentration of iridium (a rare element) at the Cretaceous-Paleogene rock boundary. However, there are other possible claims competing with the asteroid collision claim, notably volcanic eruption and climate change, which are themselves supported by some empirical evidence. Only when the scientific community has conclusive evidence and no longer disputes a claim, then that claim will be accepted as a scientific fact (Latour & Woolgar, 1979).

I like to show how a controversial topic, such as the flat/spherical Earth debate, can provide rich opportunities for children to learn about scientific explanation and argumentation. The same method used by the ancient Greeks over 2000 years ago to determine the radius of a spherical Earth can be replicated as a real-world investigation for science and mathematics students. Using synchronous or asynchronous video conferencing, two classrooms in separate cities of roughly the same longitude, for example Brisbane and Sydney, can collaboratively measure the length of a shadow from a metre stick and its angle of elevation at a common time. Using some geometric reasoning, students in Years 7 and 8 can derive for themselves the equation shown in Figure 2 and use it to calculate the radius of the Earth.

The direct surface distance between Brisbane and Sydney is a verifiable fact at around 725 km. The angle of elevation in Brisbane and Sydney on 1st June at 12 pm are 40° and 34° respectively. I obtain these angles from SunCalc, which is a great resource for planning purpose. Students should however measure these angles to obtain the data empirically on any given day. From these data, the radius of the Earth is calculated to be 6923 km, which is within 90% accuracy. The experimental error is largely determined by the precision of the instruments used to measure angle and distance, at ± 1° and ± 0.1 cm respectively. If the measurements are taken on another day, the angles of elevation in both cities will change. However, their difference will always be 6°, thus making the radius of the Earth a constant (as it should be).

This investigative task should be used not only to calculate the radius of a spherical Earth, but also to convince students that the Earth cannot be flat. As an argumentation activity, there are two competing explanations based on a spherical Earth and flat Earth model. The flat Earth model can actually be used to explain why the length of shadows are different in Brisbane and Sydney. However, this explanation would require the Sun to be fairly near to Earth such that its light rays to Brisbane and Sydney are not parallel but will meet at a particular point (See Figure 3). Based on the empirical data of 40° and 34° angles of elevation

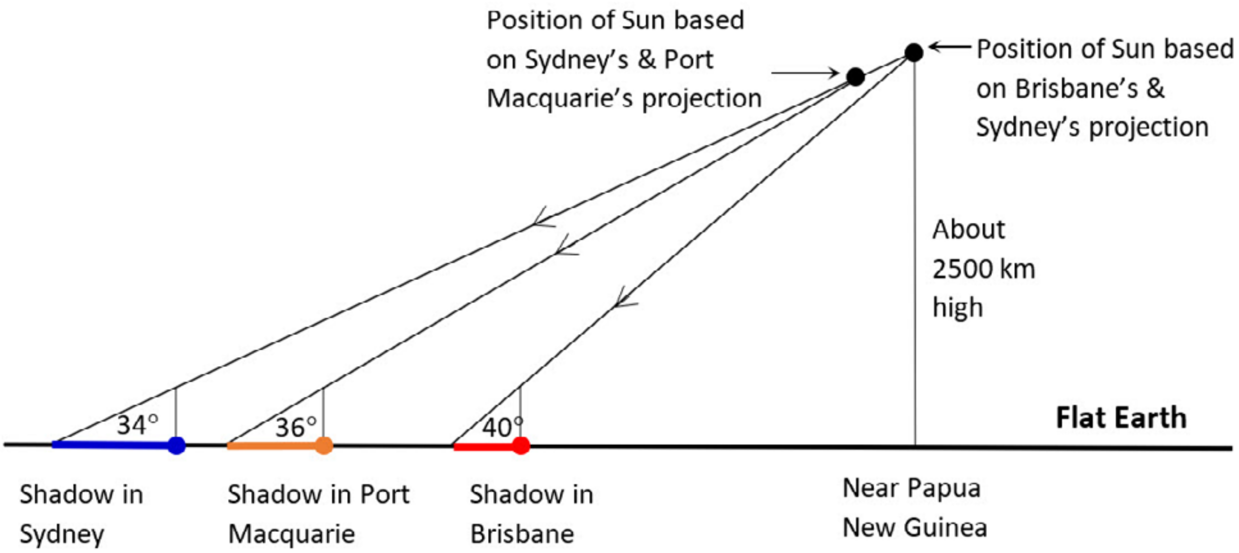

Figure 3. Explanation of shadow differences using a Flat Earth model (not drawn to scale)

in Brisbane and Sydney on 1st June at 12 pm, this would put the Sun at a vertical height of 2500 km and 2970 km North of Brisbane (somewhere off Papua New Guinea). Not only is this conclusion absurd, the flat Earth model also cannot accommodate a third data point. If another reading is obtained from say Port Macquarie, the lines projected from the angles of elevation in the three cities will never meet at a singular point, thus implying that the flat Earth model is untenable. Therefore, students can use these empirical data from the real world to construct explanations and engage in peer argumentation to support or refute various claims about the Earth's surface.

Syllabus links

This argumentation activity is suitable for secondary school students in a science, mathematics or integrated STEM classroom. It can also be attempted by primary school students, provided that someone does the mathematics for them. Students will learn disciplinary concepts and skills such as the solar system, light and shadow, measuring distance and angle, properties of circle and triangle, and trigonometry. But more importantly, they will also experience firsthand how scientific knowledge is constructed through the process of explanation and argumentation instead of just accepting it as an unchallenged fact from textbooks or the internet.

The increasing prominence of fake news, conspiracy theories and science denialism pose a significance threat to the functioning of a democracy. Science, as a human endeavour carried out for many centuries, has developed a unique way of knowing that counteracts the dangers of post-truthism through the scientific practices of empirical investigation, theory-driven explanation and evidence-based argumentation. As such, it is not only the knowledge of science that we need to pass on to the next generation, but also the rich cultural practices of science. This must be the vision of scientific literacy to ensure our future generation is able to use science to critically inform their personal decision-making, civic engagement and political discourse. As we witness the human cost due to numerous fake news reports during COVID-19, this vision of scientific literacy is not just a distant aspiration but is now an immediate priority that impacts our democracy.

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Writer biographies

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In her current role as a curriculum advisor at the NSW Department of Education, Lorri supports schools in curriculum implementation. Lorri's PhD research centres on 'Collaborative Teacher Professional Learning: Investigating Impact and Sustainability' (2015). Recent papers for teachers encompass publications and co-publications for English, including those focusing on the alphabetic principle, writing, spelling, collaborative teacher professional learning and teachers as researchers and practitioners. Lorri particularly enjoys collaborating with teachers on writing English units using the vehicle of quality texts.

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Cathy Sly is an independent researcher and writer. After teaching English in NSW Department of Education high schools for many years, she completed a PhD in Media, Communications and Creative Arts at Deakin University. Cathy has a keen interest in visual literacy and multimodal literature for readers of all ages. She has presented at academic conferences and contributed to scholarly publications both in Australia and overseas.

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