Science, engineering and big questions

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Prelude: Big questions in challenging times

We are experiencing unprecedented personal, social, environmental and economic challenges. Barely a day goes by without a change to something we once took for granted as part of our daily lives. But changes can also create opportunities and, fortunately for those of us in education, young minds are always looking for new ideas and new ways to think. And, importantly, many of them are relying on their teachers to help them to find accurate information. So, as education always matters, the prelude to this theme on *Science, engineering and big questions* looks at some ways to develop students' insight and understanding during these challenging times.

The big question we will ask is '*How do we as individuals and as a society work together to tackle and overcome the challenges of COVID-19?*'

We know that science – as a method of enquiry and as a source of knowledge – can help us. Science informs our thinking about every aspect of our lives today. Why is that? Well, science can often give us a high level of certainty. Wash your hands often and with soap – why? Because we understand very well what happens when we engulf the virus with soap and use water to hasten it from our skin.

So, stepping back, we can see this as a way to talk with students about what it means to work scientifically. Science begins with observations of the natural world and constructing ways to explain our observations. Science tests ideas by making predictions and carrying out systematic and objective observations… There are some questions, such as this one, that we can address by drawing on scientific knowledge that is well established and by testing predictions that are relatively straightforward for scientific methods to test. Engineers frequently capitalise on these 'sweet spots' of science to design products – such as bars of soap – that make our lives safer, better and easier.

There are many other questions being discussed in the news that do not have such clear answers. Talking about how science interacts with and compares with other disciplines helps many students to gain a richer and deeper understanding of the nature of science and also acknowledges that most real-world questions are too big for one discipline alone. There are also often opportunities to explain that different disciplines have different preferred questions, methods and norms of thought. Some of the graphics we are currently seeing in the news create an opportunity to talk about the power and limitations of mathematical models. Mathematics can help us to race through multiple scenarios to try to visualise how different rules and guidelines might affect how quickly the virus spreads. But behind a simple line graph in this case there is much that we do not know – such as what help to give people so that they can make the changes they are being asked to make. Scholars may draw on multiple strategies – such as in this case – to also study what is happening in other countries and the outcomes of different approaches as they unfold in real life.

Our social norms are changing – who'd have thought it would look OK to have TV presenters keeping their distance from each other by sitting at either end of a sofa? We are all wondering what we will keep and what we will gladly lose on the other side of this massive global investigation and response. The TV shows are also opportunities to highlight that we are seeing experts from many disciplines in the media. Each discipline has its preferred questions, methods and contributions to make. Scholars in all areas can speak to the value of openness and collaboration. Widening the frame still further, this is an opportunity to say that what will help us all to get through this problem will not only be the wisdom of our expert scholars – valuable though this is. We will also need to draw on our shared sense of humanity, empathy, moral reasoning, and common sense… in other words, there are some responses that we can make together and some that we can make as individuals, uniquely and in our own situations.

The theme in this special issue: Science, engineering and big questions

This issue of *School Science Review* has a sequence of eight linked articles which explore further examples of questions that bridge science and other disciplines and take on real-world contexts and problems. Teachers who choose to work with these types of questions will need strategies to develop their students' epistemic agency and confidence as researchers and learners. Key skills and understanding include an appreciation of how science and other disciplines work in real-world contexts and ways to work creatively within and across disciplinary boundaries.

Robotics and artificial intelligence are attractive contexts to explore. Can a robot be creative? Can a robot be held morally accountable for its actions? Can a robot own its own ideas? Schools and other education institutions have frequently struggled with where to put big questions about the nature and status of humanlike machines because they bridge curriculum areas and generally do not have simple agreed answers. Turned around, however, these topics can also be viewed as opportunities to clarify the nature, power and limitations of science in contexts that students find engaging. The strength of the natural sciences can be seen in their power to explain and predict; and in their respect for objectivity, repeatable observations and reproducible investigations. Our everyday lives are filled with applications of science, designed by engineers on the basis of scientific knowledge. Artificial intelligence (AI), however, draws inspiration from many disciplines. Its wider knowledge base is intended to overcome the challenge that human characteristics such as creativity cannot today be understood, modelled and tested scientifically.

A good science education encourages students to appreciate the distinctive characteristics of science. Alongside an account of the characteristics of science, students also need to appreciate what, if anything, differentiates science from other forms of enquiry. Researchers across several decades have noted that students frequently view science as a large body of proven facts and as a mode of enquiry that places a particular emphasis on learning right answers. These perceptions can be related to a tendency in science lessons to focus on questions that have well-established scientific answers. At the same time, it is important that students appreciate the strengths of science, and many teachers, rightly in my view, would have some reservations about unsettling students too far from this view. The science curriculum in England and in many other countries too asks teachers to draw students' attention to the nature of science and its powers and limitations. This can be addressed by helping students to appreciate what kinds of questions are suited to testing scientifically and what kinds of questions, in contrast, are less amenable to its methods. Since currently this aspect of the curriculum is often neglected, teachers are likely to become epistemic agents themselves, collaborating to construct and evaluate a research-informed and research-engaged approach to curriculum planning and teaching.

There are weighty problems that students could research, such as driverless cars, and there are also lighter moments that can be used to stimulate interest at the start of a lesson. Consider, for example, the question of how our legal system should respond to claims by some that an AI can be creative and can be credited as the named inventor on a patent. 'DABUS' is an AI machine built by Stephen Thaler that creates solutions to problems. A team at the University of Surrey has filed patent applications for two inventions created autonomously by DABUS. One patent claims an invention for a new beverage container based on fractal geometry. The team at Surrey argues that it is improper to list Stephen Thaler as the inventor as he did not come up with the ideas nor direct the machine to invent them. The European patent office rejected the applications on the basis that DABUS is a machine, not a human being. The team behind the applications is planning an appeal.

Each of the eight articles in this theme on *Science, engineering and big questions* offers practical solutions for engaging students in learning about the nature of science by examining real-world problems.

To foster a good understanding of science, we need to give students not just the substantive knowledge that has traditionally been the foundation of science education; we also need to enable students to 'think like a scientist' – to know what kinds of questions are amenable to science and how to conduct a scientific enquiry. This framing of science as a discipline speaks to a direction of travel that is happening nationally and internationally. In England, the Office for Standards in Education, Children's Services and Skills (Ofsted) has implemented a new inspection framework for schools that shifts the emphasis from test results to a more holistic examination of a school's curriculum strategy. Their new inspection methodology considers two main categories of knowledge-related objectives. *Substantive knowledge* (sometimes called content or conceptual knowledge) is the knowledge that has been gained through a discipline, such as knowing about planetary motion, the parts of a plant and the properties of everyday materials. *Disciplinary knowledge* is knowledge about a discipline, such as knowing the preferred questions, methods and norms of thought within science. This type of knowledge is elsewhere called epistemic knowledge. Both types of knowledge are developed not only within individual lessons but also sequentially and coherently across a number of years.

In a similar vein, a position paper by the intergovernmental Organisation for Economic Co-operation and Development (OECD) as part of its Future of Education and Skills 2030 project (2018), identifies four kinds of knowledge that will help students to become wise and considerate scholars and citizens. Among these, it characterises *epistemic knowledge* as knowledge about a discipline, such as '*knowing how to think like a mathematician, historian or scientist*' (OECD, 2018: 5).

The importance of developing students' epistemic insight is already embedded in the national curriculum for science in England. As Billingsley and Windsor discuss in their article, timetables that only teach one subject or discipline at a time reduce the opportunity for students to think across the boundaries of science and other disciplines, to think like a scholar about a real-world context and to ask different types of questions in a multidisciplinary arena. Billingsley and Windsor's workshop looks at how science intersects with art and design in the real-world context of 'Renoir's painting' in order to explore the power and limitations of science in approaching an understanding of values in art and personhood.

In school, science is characterised as the natural sciences. A question that is designed by a teacher to bridge science and another discipline can prompt students to notice the boundary around the types of questions that (school) science prefers. In their article, Simpson, Abedin and Billingsley pose the question 'Why did the *Titanic* sink?' The workshop they describe builds students' substantive knowledge about the factors affecting buoyancy. This comes to light when we move into a lab and work with models and carefully controlled experiments. Science and history are both interested in causality, however. Expanding our disciplinary ways of knowing to include history reveals a richer and more complex explanation of what happened and who, if anyone, might be to blame. The next article in the series stays with a nautical context. Hampton takes the engineer's perspective to explain a hands-on, multidisciplinary workshop in which students apply science to solve practical problems in marine engineering.

In his article, Bentley shows how simple, miniature robots called 'Bristlebots' can be used in the classroom to stimulate big questions about what we mean when we say that something is 'alive' and whether robots can ever have a sense of curiosity or be creative. Bentley is an engineer, and, from his perspective, biology is a source of biological knowledge and biological ways of knowing. In the workshop he has designed, students critically examine the pros and cons of a biological definition of life as a way to judge whether an artificial entity is alive.

In the next article, Davies discusses the meaning and purpose of giving students a biological definition and explanation of life from the perspective of a biology teacher. The curriculum view of what children need to know in biology about being alive depends on their age. Ingram digs more deeply again by critiquing what we currently teach about life in biology through a historical lens.

The last two articles return to the context of robotics. Billingsley and Nassaji describe a workshop that prompts students to be critical of the language we use when we ascribe creative and intentional states to robots, for example, by saying that a robot 'hears' or 'thinks'. Oh and Lawson explain how they challenged students to consider whether a robot can make mistakes.

The Epistemic Insight Initiative consists of a growing group of teachers, tutors and student teachers who are carrying out research and designing strategies and workshops to offer as examples. The Initiative was launched in *School Science Review* in June 2017. Please get in touch with me by email or browse the website at www.epistemicinsight.com if, for example, you are interested in exploring these approaches and their impact with your students – whatever their current stage of education.

References

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