Contents

Introduction to the Project

BRaSSS is the acronym for the project called 'Broadening Secondary School Science'. The project has been funded by a grant to UCL Institute of Education from the Templeton World Charity Foundation TWCF) as part of their 'Big Questions in Classrooms' initiative. This initiative seeks to develop teachers' and students' understanding and insight about 'how knowledge works'. This project, BRaSSS, seeks to do this by providing materials to help teachers of 11-16 year-old students to develop a broader understanding of secondary school science.

The biology materials have been written by Professor Michael J. Reiss, the chemistry materials by Professor Vanessa Kind and the physics materials by Dr Jonathan Allday. In this teachers' pack, 'Philosophy – a note' has been written by Professor Michael J. Reiss, 'History in Science Lessons' by Dr Catherine McCrory, 'Ethics in Science Lessons' by Professor Michael J. Reiss and 'Independent Scientific Research Projects for Year 8-10 students' by Dr John L. Taylor. Dr Tamjid Mujtaba is leading on the research component of the project.

Context

The place of science in the school curriculum, certainly in the secondary phase, is secure. Ironically, this leads to certain problems. In particular, unlike many other subjects (e.g. geography, design & technology, Religious Education (RE), this has led a degree of complacency among science educators who have not had to fight to defend their subject in the curriculum. It has also led to an unwelcome degree of insularity. It is all too easy for school science to make little effort to help students explore the ways in which science engages with other subjects. *It is the contention of this project that such engagement of school science with other subjects will be to the benefit of students and, ultimately, science itself.*

Almost everyone acknowledges that scientists, whether working in academia, in industry or elsewhere (e.g. health or the environmental movement), usually work in interdisciplinary teams. While each scientist nearly always needs a core, narrow area of conceptual knowledge in which they have deep knowledge, they also need, at the very least, to be aware of the boundaries of their own knowledge and of how their own knowledge relates to that of others and to the hopes and concerns that their work might raise. To give a concrete example, agronomists (collectively, not individually) need deep expertise in plant genetics, plant physiology, soil biology and related areas of the natural sciences. In addition, they also need to understand something of the concerns that members of the public may have about the use of pesticides or techniques of genetic modification, and of the arguments as to whether increased crop production is the key to alleviating world hunger or whether the problem is one of food distribution or human selfishness.

It seems clear that whatever the precise aims of science education, we want a curriculum that enables students to develop rich conceptual understanding in science, whilst also appreciating how science is undertaken, how it relates to other disciplines and the questions it raises about the world in which we live, and the human condition.

In England, there is a particular problem with post-compulsory secondary education (after age 16) and at university level with overspecialisation, given that most students in years 12 and 13 (ages 16-18) study only three subjects. It is therefore important that school subjects do not construe themselves too narrowly. Science is a subject where this danger is particularly apparent. Given this, and the importance of subject specialisation to teacher identity, if we want to see substantial moves towards interdisciplinarity in school science in large numbers of schools, the most likely way forward is to broaden school science so that teachers of school science see a revised curriculum and associated pedagogies as sufficiently close to their understanding of the subject for them to be willing to change their teaching.

Again, to give a concrete example, as a generalisation, most secondary science teachers are much more likely to be willing to include some history of science, applications of science and ethics of science in their lessons if they see this as part of science rather than as something that should be covered in history, design and technology, RE or philosophy classes.

Accordingly, the approach adopted in this project is to produce materials that do indeed permit this broadening of school science across its conventional disciplines (biology, chemistry, physics) and to support teachers in developing their pedagogies both when using these materials and more generally. We are helped in this in that, since the introduction of the National Curriculum in 1989, there has consistently been a place for history and philosophy of science (under various names/labels such as 'AT 17', 'The Nature of Science' and 'Working Scientifically') in the 11-16 science curriculum. This means that the project will be able to build on existing good practice.

Why the focus on Years 7-11 in science?

The TWCF's 'Big Questions in Classrooms' initiative aims to promote teaching and learning about the nature and relationship of different forms of knowledge taught and learned in primary and secondary school classrooms, so that students are better equipped to ask and find answers to big questions of meaning, purpose and reality. A core site where such teaching and learning can take place is in the science classroom. Indeed, unless school science is actively engaged, any attempts to bring together science, religion and other subject disciplines are likely to gain at best only modest purchase in most schools in England.

This project therefore focuses on how to help teachers and students in England explore and better understand the ways in which science relates to other subjects. Ultimately, the hope is that students appreciate that science is not an insular subject and there are benefits for science and other subjects when science is taught in a cross-curricular way.

This project concentrates on secondary schools. One advantage of this is that virtually all teaching of science in such schools is undertaken by teachers with at least an undergraduate degree in a science (or allied – e.g. engineering) discipline, whereas this is the case for only a small minority of primary teachers.

Organisation of the work

The three main research questions that BRaSSS seeks to answer are whether innovative teaching in school science that takes a more cross-curricular approach than is usual will:

1. Produce significant change among students in the perceived compatibility between science and other curriculum subjects?
2. Shift how students see science?
3. Make students more positive about their science learning and the possibility of continuing with science?

Overall, the project is being conducted in three phases, each of which lasts approximately one school year, though there will be some overlaps between the phases.

Phase 1 (September 2018 – August 2019)

In the first phase, an extensive bank of trial materials was developed for use in lessons in biology, in chemistry (including Earth science) and in physics (including astronomy/ cosmology). The materials are designed for use with 11-16 year-olds (separate materials for each year group) and are suitable for teaching aspects of science as defined in the current National Curriculum in England. Worksheets, suggestions to teachers for classroom and homework activities and links to useful websites have been developed.

Phase 2 (September 2019 – August 2021)

We identified and recruited six schools to trial from September 2019 to June 2020 the materials and associated pedagogical approaches developed in phase 1. The COVID-19 pandemic meant that we had to abandon the work before the teaching and research components had been finished. Accordingly, we repeated the 2019-20 school year in 2020-21. At this stage, our intention was not to attempt to have a representative sample of schools (hardly feasible with n = 6), but rather to ensure that a relevant range of schools were included within which to trial the pedagogical approaches and innovative lessons.

Phase 3 (September 2021 – August 2022)

As a result of phase 2, we made a number of refinements to our materials. In phase 3, we are formally evaluating the project in up to 20 schools, using revisions of the data collection tools devised in phase 2, and revisions of the materials and pedagogical approaches that were developed in phases 1 and 2.

We appreciate that there are already great demands placed on schools and that incorporating a research element requires some adjustment and modification to termly plans. Therefore, we do not expect any participating school to use the materials that we produce in more than twelve lessons (six lessons with a class in one of Years 7, 8 or 9, and six lessons with a class in one of Years 10 or 11) – though we would be delighted if you do! The materials are modular rather than linear in the sense that there is no particular order in which they need to be studied by students.

The materials

The materials have been produced to a common template, so that, for example, it is made explicit what the cross-curricular links are. It is worth mentioning that one can envisage two main ways in which school science might be made more interdisciplinary:

1. Science lessons can include *content* from other subjects – for example, history or philosophy.
2. Teachers of science can draw on *teaching approaches* more commonly used in other subjects – such as the more open-ended discussion one often gets in the humanities (e.g. RE), elements of role play (drama) and more emphasis on designing and testing objects (design and technology).

The materials for each lesson provide guidance for science teachers to enable science lessons to be more interdisciplinary. In addition, the rest of this teachers' pack has four further chapters, which we hope will be of general value across many of the materials:

- A very short chapter on philosophy ('Philosophy – a note');
- A chapter on the place of history in science teaching ('History in Science Lessons');
- A chapter on the place of ethics in science teaching ('Ethics in Science Lessons');
- A chapter on the value of using research projects in science teaching ('Independent Scientific Research Projects for Year 8-10 students').

Feedback

Tamjid Mujtaba will be contacting many of those of you involved in the project to get your feedback. At any time, feel free to e-mail either Tamjid t.mujtaba@ucl.ac.uk or Michael m.reiss@ucl.ac.uk.

Best wishes and many thanks!

Philosophy – a note

One of the pieces of feedback that we received after the pilot in phase 2 was that it would be useful to have something about philosophy that teachers could read and use.

The word 'philosophy' comes from the Ancient Greek for 'love of wisdom'. Philosophy is therefore the study of fundamental questions to do with such essential issues as existence, knowledge, values and language. For example, philosophy would seek to help people to think about and answer such basic questions as 'Why is there something in the universe rather than nothing?', 'What should we do to lead a good life?' and 'How can we attain reliable knowledge about the world?'.

It is clear that philosophy is related to science, but somewhat distinct from it. Science often takes more for granted than philosophy does. So, for example, science doesn't really attempt to answer the question 'Why is there something in the universe rather than nothing?', it simply starts from the observation that there is something (indeed, rather a lot of things) in the universe. Equally, science – as we will consider in more detail below in the chapter on ethics – doesn't seek to answer such questions as 'Is gene editing of humans a good thing?'. Instead, it is more likely to concern itself with the practicality of gene editing and questions to do with safety.

Just as science has certain methods that it uses widely (most famously, the idea of generating a hypothesis and then testing it through collecting objective data that are capable of falsifying the hypothesis), so philosophy has its methods. Perhaps the most famous method in philosophy is called the 'Socratic method' – after the Ancient Greek philosopher Socrates. Without wanting to simplify too much, what Socrates, from the records we have, seemed to do was to ask those who made claims probing questions about these claims. If they ended up contradicting themselves, it suggested that their claim was false.

Often, philosophy can help to refine our understanding about a topic. For example, supposing that someone claims that one should always stick by one's friend, Socratic questioning might lead to a refinement of the claim (one should not stick by one's friend if they are delusional or evil) and give rise to new questions; for instance, are the duties one has to a friend different from or the same as the duties one has to a stranger?

One thing that philosophy and science have in common is that they both seek after truth. Also, they both have a high regard for precision – precision of language and thought in the case of philosophy.

History in Science Lessons

Introduction

'Science' can mean a specific method of finding things out and a body of knowledge arising from the things found out. The scientist Richard Feynman (1999:15-16) attempts to demarcate science from other subjects when he writes:

> *[a scientific method is] … based on the principle that observation is the judge of whether something is so or not … The principle … imposes a severe limitation to the kind of questions that can be answered. … Questions like, "should I do this?" … are not of the same kind … This does not mean that those things are unimportant. They are, in fact, in many ways the most important. In any decision for action, when you have to make up your mind what to do, there is always a "should" involved, and this cannot be worked out from [science] alone.*

Feynman's definition could be challenged; for example, other disciplines are rooted in observation but are not science (e.g. art history) and some science only indirectly connects with what is observed (e.g. theoretical physics). Feynman's definition, however, raises two points relevant to this chapter; the question of how academics define their work relative to other disciplines and how teachers think of their disciplinary knowledge relative to their role as teachers.

Beyond a body of knowledge and a method for finding things out, Feynman (1999) also acknowledges that 'science' includes the things you can do when you have found something out. Yet Feynman becomes uneasy when discussion turns to the application of science, doubting the extent to which the scientist is qualified or obliged to consider the 'goodness' of how science is used. Feynman (1999:5-6) grapples with what he describes as the problem of the relationship between science and society thus:

> *Now the power to do things carries with it no instructions on how to use it, whether to use it for good or for evil. The product of this power is either good or evil, depending on how it is used. We like improved production, but we have problems with automation. We are happy with the development of medicine, and then we worry about the number of births and the fact that no one dies from the diseases we have eliminated. Or else, with the same knowledge of bacteria, we have hidden laboratories in which men are working as hard as they can to develop bacteria for which no one else will be able to find a cure. … We are pleased by the ability to communicate between nations, and then we worry about the fact that we can be snooped upon so easily. … The most famous of all these imbalances is the development of nuclear energy and its obvious problems.*

Feynman (1999:6-7) acknowledges how good and bad consequences can arise from the power to do something, but he also suggests that the scientist's knowledge somehow stands apart from that use. Feynman relays a story about a trip to a Buddhist temple where he was told that every man is given the key to the gates of Heaven; however, the same key opens the gates of Hell. Feynman believes that it is this way with science, a key that can open more than one gate without instruction as to which gate is which. Feynman continues:

> *All the major problems of the relations between society and science lie in the same area. When the scientist is told that he must be more responsible for his effects on society, it is the applications of science that are referred to. If you work to develop nuclear energy you must realize also that it can be used harmfully. Therefore, you would expect that, in a discussion of this kind by a scientist, this would be the most important topic. But I will not talk about it further. I think that to say these are scientific problems is an exaggeration. They are far more humanitarian problems. The fact that how to work the power is clear, but how to control it is not, is something not so scientific and is not something that the scientist knows so much about.*

The starkness of Feynman's demarcation between science and society, between having a power and using a power, arises partly from his belief in the moral neutrality of what we know and his narrow focus when defining science. He prefers to limit himself to 'scientific' questions. We can appreciate Feynman's distinction; a physicist's and a historian's explanation of why the World Trade Centre buildings fell on September 11th, 2001 differ. The physical forces causing the collapse of the buildings contribute to quite a different answer than the relative importance of the hijackers' motivations compared to other contextual features. The answers to some questions, however, are greatly impoverished if we do not cross traditional knowledge boundaries and some academics define their remit differently.

The medieval historian and author, Professor Yuval Noah Harari, identifies nuclear power, climate change and technological disruption as crucial concerns woven into the fabric of our daily choices as individuals. For Harari, where once we told stories of cataclysmic doom, now we have the capacity to realise global disaster. In the book, *Sapiens: A Brief History of Humankind*, Harari asks how humankind came to rule the planet. In *Homo Deus: A Brief History of Tomorrow*, he asks how power will shift in response to new technologies such as Artificial Intelligence (AI) and genetic engineering. Harari wants us to pause to consider the implications of how current advances differ from earlier knowledge.[1] Taking an example from AI, hypothetical scenarios presenting moral questions inviting your response (for example, do you pull a lever to change tracks whilst driving a trolley whose brakes have failed thus killing two people rather than five), previously served as an exercise to help us to think through difficult issues.[2] Yet, now such decisions are being made by people who write software for self-driving cars.

[1] Harari has written three books: *Sapiens: A Brief History of Humankind, Homo Deus: A Brief History of Tomorrow* and *21 Lessons for the 21st Century*. See https://www.ynharari.com/

[2] See, for example, https://www.youtube.com/watch?v=kBdfcR-8hEY&feature=youtu.be

The plausibility of Harari's arguments can be set aside for the purpose of considering how differently educationalists define their discipline and their role. Harari addresses 'big questions', in three senses. First, Harari's interest is 'big' in that it requires us to draw upon knowledge from multiple domains. Harari's thinking is full of boundary crossing; for example, scientific knowledge alone cannot help us to think about why more people die from obesity than from starvation or why more people die from old age than from infectious diseases, but neither can these questions be answered without secure scientific knowledge. Harari's answers would be impoverished, if not impossible, without Feynman's scientist explaining the causes of death, yet evaluative comparison over time requires historical thinking. Secondly, asking the 'so what?' question of how our manipulation of the world is different from before does not simply cross the traditional boundaries of knowledge domains, it is also 'big' in the sense of mattering because, from Harari's historical perspective, it appears as though we are on the cusp of profound and unprecedented change. Thirdly, Harari seeks to address how biotech and information technology, aligned with the interests of industry and nation states, may only be checked by a scientifically literate public because of how the sum of individuals' actions matters.

If we notice the role of individuals in determining change, 'big questions' also count as 'big' in the sense of mattering to people because they involve them; there are no bystanders. A rather remarkable example is the 16 year-old climate change activist Greta Thunberg, who attended a United Nations summit to protest about climate change by embarking on a two-week journey across the Atlantic to the US by sailboat to avoid contributing to carbon emissions by flying. Interestingly, our participation in 'big questions' need not be so remarkable. The topic of nutrition demonstrates the reach of science into almost every aspect of my day-to-day life[3]. An illustrative list of possible teaching ideas includes the role of advertising in the psychology of what we eat; the role of government in influencing malnutrition and obesity; the issue of animal welfare and lives worth living; the question of land use related to our impact on global biodiversity and climate change.

Reading this list, I am struck by my responsibility for understanding and making life- and world-changing science-related choices. To take the simplest of examples, we are only now beginning to appreciate the collective consequences of our individual use of throw-away containers. We can see how our ability to ask and answer 'big questions' contributes to the features and qualities of our own and each other's lives, now and in the future. What is perhaps most striking, these questions are already being answered without ever really being asked, through the collective consequences of our seemingly insignificant individual choices. So how do 'big questions' and our ability to handle small choices[4] relate? Might exploring the first offer one training ground for the second? Given how frequently, profoundly and pervasively science comes into my everyday life, I wonder how and to what end the science-related issues of my life come into the science classroom.

[3] See 'Healthy human diet'.
[4] Students could be supported to discuss their views on the issues raised here through sharing extracts from academics such as those included above.

How teachers define their discipline and understand it in relation to their role as teachers matters.

Feynman and Harari stand on either end of a spectrum of possible approaches to knowledge, one defining their interests narrowly, the other broadly. The mathematician, Dr Hannah Fry (2019) thinks explicitly about the question of education when defining her discipline and role[5]. In a national newspaper interview, Fry (2019) explained how she will use her upcoming 2019 Royal Institution Christmas lectures on the 'power and perils' of modern mathematics to:

> *…explore how algorithms that feast on data have infiltrated every aspect of our lives; what problems maths should be kept away from; and how we must learn when the numbers cannot be trusted. Fry said she got a sense of the ethical blindspots scientists can have while describing to an academic conference in Berlin the computer modelling of the 2011 riots she had done for the Metropolitan police. The audience, which understood the realities of a police state, heckled her from their seats. When Fry returned to London, she realised how mathematicians, computer engineers and physicists are so used to working on abstract problems that they rarely stop to consider the ethics of how their work might be used. The issue has become urgent now that researchers are building systems that gather and sell personal data, exploit human frailties, and take on life-or-death decisions. "We've got all these tech companies filled with very young, very inexperienced, often white boys who have lived in maths departments and computer science departments," Fry said. "They have never been asked to think about ethics, they have never been asked to consider how other people's perspectives of life might be different to theirs, and ultimately these are the people who are designing the future for all of us." The mathematician … said she also believed the public must take some responsibility for the products tech firms served up.*

Fry (2019) argued that, "We need a Hippocratic oath (in science) in the same way it exists for medicine". "In medicine, you learn about ethics from day one. In mathematics, it's a bolt-on at best. It has to be there from day one and at the forefront of your mind in every step you take." Fry is following in the footsteps of others who have also made the case for a Hippocratic oath for scientists before, including the philosopher Karl Popper. Fry is particularly concerned by the non-neutrality of scientists' or mathematicians' work and turns our attention to the matter of education, or the knowledge that people (scientists, the public) need.

Fry's comments are helpful because, while Feynman challenges the notion of whether some questions are indeed within the scientist's remit, our interest here is in science education. Educationalists quite rightly recognise the limits of their understanding but

[5] See https://www.theguardian.com/science/2019/aug/16/mathematicians-need-doctor-style-hippocratic-oath-says-academic-hannah-fry.

deciding that particular questions are not, for example, 'scientific' or 'historical' or 'philosophical' questions, and so fall beyond our specialist remit as subject teachers, risks neglecting many concerns that, as Feynman recognises, matter most. Our interest as educationalists is in how the good of our subject, in this case, the good of science, and the good of science education, is more than the extension of scientific knowledge. Fry, like Feynman, helps us to see how we can be educated in quite different disciplines, and how easily being trained up to do science or mathematics can leave us feeling unprepared to do life. There are important differences between disciplines, but some important questions, questions whose answers really matter to our future, require boundary crossing.

This project supports science teachers' thinking about 'science', understood broadly. This chapter asks how the discipline of history, from the perspective of a history educator, could contribute to the work of science teachers interested in thinking about how and why they might want to consider such 'big questions' in their teaching. Three themes run through the following discussion:

- How could history be incorporated into science education and how might it contribute to our thinking about 'big questions'? What can be gleaned both from the body of historical knowledge and the historical approach to investigation?
- Can the history teacher's approach to curriculum planning, in terms of the selection of 'big questions' and purposes of such selections, be of any value to colleagues in science?
- If 'big questions' do require more than 'scientific' knowledge and method, as Feynman (1999) would have it, can history teachers' pedagogical approaches be of any value to colleagues in science?

History as decoration

Professor of History and Philosophy of Science, Hasok Chang (2015), regrets how the history of science often appears in science textbooks in ways that distort and oversimplify history.[6] In a lecture to The Royal Society, Chang (2015) describes how history can appear in science as:

> *Stories of heroic scientists who overcame adversity. Tragic scientists hampered by human limitations and circumstances. Fortunate ones who made great discoveries by exploiting chance happenings. Strange ones who engaged in bizarre experiments or who devised fantastical theories.*

Chang's illustrative list includes: Newton's apple (gravitation), Kekulé's snake dream (the benzene ring), Fleming's mouldy Petri dish (penicillin), Franklin's kite (lightening as electricity), Galileo and the leaning tower of Pisa (free fall of bodies).

[6] Chang shared the following remarks during his lecture to The Royal Society, 'Who cares about the history of science?' as 2015 winner of the Wilkis-Bernal-Medawar Prize. See https://www.youtube.com/watch?v=EmrmikLbjHI&feature=youtu.be

History as 'garnish' (Chang 2015) seems to me to be of limited benefit. Just as our interest in relation to science education is in the good of science and not simply science for science's sake, so our interest in including history in lessons is also in the good of history. Whilst the historian may pursue historical questions purely for the sake of understanding the past, history teachers, and teachers of other subjects incorporating history into their teaching, do well to consider how the point of understanding the past is also in the present. They ask, "What good can come from knowing this?" As in science, 'this' refers to the method of finding things out and a body of knowledge arising from the things found out.

I can imagine ways in which historical content, and the history of science in particular, could enhance learning *in* science.

Historical content as a source of motivation

Student motivation matters. The teacher thinking only of the scientific or historic content of their lesson risks being right in vain. Historical content may be included in science lessons as a hook, engendering curiosity or inspiration. For example, historical content may be motivational as a window to the real-life consequences, and thus relevance, of science in application. Some students may find it helpful to feel the weight of how, as a consequence of science, one has power to do things. Rather than only teaching that something *is* the case, for example, some feature we now know about blood transfusions, we could explore whether some students find additional motivation in seeing how this knowledge has mattered. History can provide these case studies. For example, students could read extracts from the military medical historian Dr Emily Mayhew's book *Wounded from Battlefield to Blighty 1914-18*. Mayhew traces the journey of an injured soldier from the trenches to a hospital in Britain. The story is 'told through the testimony of those who cared for him – stretcher bearers and medical officers, surgeons and chaplains, orderlies and nurses – from the aid post in the trenches to the casualty clearing station and the ambulance train back to Blighty.'[7]

Concrete and personal cases of the peoples whose lives were changed by the science can help illustrate how it has mattered to society that we know something is the case. For some students, interest in the science behind the steam engine, light bulb, radio transmission, personal computer, space travel and so on, may be enhanced if understood in light of what each meant for generations of people, in order to better understand what it means now to them. History can help offer a view that includes the day before yesterday and the day after tomorrow. Film and documentary could provide an optional, supplementary homework, for example, the story of Alan Turing's work in *The Imitation Game*, or electricity in the upcoming *The Current War*, or space travel in *Hidden Figures*, or nuclear energy in *Chernobyl* (age restrictions apply). Nurturing these points of contact

[7] See https://www.amazon.co.uk/Wounded-Long-Journey-Home Great/dp/0099584182/ref=sr_1_1?ie=UTF8&qid=1504022029&sr=81&keywords=Wounded%20Emily%20Mayhew. watch?v=EmrmikLbjHI&feature=youtu.be

with learners' lives is not like teaching or testing student comprehension by transposing formulae into everyday scenarios. Nor is it quite like youth-friendly applications of science that might be made possible through projects. The pedagogical device here, a staple in many history lessons, is the interplay between the big story and the little story, the abstract and the concrete, the strange and the familiar. One reason to consider including history in science lessons is the potential for some students to become more invested in understanding the science.

Science's past as a resource for teaching science

Beyond motivation, perhaps including historical content, particularly content from the history of science itself, could help further students' scientific understanding as a body of knowledge and an investigative method. The point here is about the pedagogical role of science's past and whether the history of science might contribute to better science, or better science education, that is, to the better teaching of science. Does the way we have understood the world in the past and the temporal sequence of advances in scientific knowledge offer any insights or parallels that could be exploited in instructional design? Might lessons that adopt the pedagogy of direct and explicit instruction in what is already known in science be occasionally complemented by opportunities for students to encounter science's questions as their predecessors did?

In history, we clearly know what happened in the sense of battle outcomes or election victories and so on; nevertheless, there is pedagogical merit in teachers exploiting the fact that students do not yet know these things. For example, using a predict and reveal technique, history teachers might ask students, 'If you were Elizabeth I facing this dilemma, what would you prioritise and why?'. The power of the technique partly rests in what it can reveal of student reasoning, thus potentially enhancing the teacher's ability to be responsive to students' understanding. Students can also become motivated to find out how their answers compare to each other's and to what is true, that is, what did actually happen. The technique is subtle; students' stance on something is being used as a lever to leverage their better understanding of that thing. Designed well, the pedagogical approach can capitalise on the 'cliff hanger' technique favoured by television shows that end by enticing you to 'tune in next time' to find out what happened next.

I wonder if there might be two possible benefits to science teachers working through a selection of pertinent moments in the history of science related to the lesson's topic and the insights that unfolded over decades, if not centuries. I am imagining the science teacher engineering encounters in which students work through the issues pertinent to scientists before they discovered what we now know. I am not suggesting that we teach erroneous ideas, or that there is not benefit and skill in directly teaching students what is already known. First, considering the nature of learning, students arrive in lessons with conceptions of the world that are more or less helpful to understanding the body of scientific knowledge to be taught. This means that it is vital for teachers to discern students' current understanding, including modes of reasoning. Might there be parallels between the trajectory of understanding by the discipline and that of the individual learner? Could science's past inspire teacher instructional design that could reveal how students take the world to be and potentially add potency to the level of depth with which the scientific knowledge is grasped, perhaps through some sort of mimicking investigative scenarios?

Secondly, the generative aspect of science, for example, creating hypotheses, cannot be taught by explaining what is already known. Designing investigative scenarios, possibly inspired by the history of science, may afford students the opportunity to generate scientific thinking and to see the process of discovery modelled through the historic examples. As in the Elizabeth I example, the opportunity to create reasoned suggestions and then to compare one's own ideas to others, including the correct ideas, can be pedagogically powerful. Chang (2015) also suggests that it is possible to learn something of scientific method through the history of science. Knowledge 'of' how we have come to know what we know is not the same as the ability to build knowledge in science through experimentation, but if time limits students' opportunities to participate directly in experimentation, it is better than knowing nothing of how knowledge in science is built up.

There are many points of connection between history and scientific interests that go beyond the history of science. The simplest of ways to broaden the science curriculum is to include cases in which students can encounter the relevant content from other subjects whilst immersed in that topic in their science lessons. For example, students could learn some history-related facts connected to the science that they happen to be learning. The premise is that students could benefit from seeing how the topic they are studying in science is related to many other fields of study – nutrition, for example, has a historical dimension, a geographical dimension, and so on. The illustrative example of nutrition mentioned previously, included the suggestion that science could be broadened through:

> *the history of diets in England over the ages – not just a story of progress. Why most of us like more sugar and salt than is good for physical health. Social class and diet. Prison diets – why are they often worse now than in Victorian times?*

History-related resources that could support science teachers considering this approach are available on the internet.

History's potential contribution to science-related 'big questions'

Beyond the history of science and history as a support for students gaining scientific knowledge, how can history more generally, including methods of historical investigation, contribute to students' understanding of science-related 'big questions'?

[8] See https://worldhistoryconnected.press.uillinois.edu/12.3/engineer.html. Other resources include: https://school.bighistoryproject.com/bhplive.

History brings a temporal perspective to 'big questions'

The history educator, Dr Peter Lee (2011:68), wrote, *'For some purposes it may be appropriate to think of the present as the crest of a wave we are surfing. We are at the leading edge of a past which carries us with it on its face. Despite its faults, this analogy may help us avoid the temptation to assume that we live in an instantaneous present.'* Lee captures the idea that history offers perspectives that are not available to other subjects, most obviously, the understanding that comes from having a temporal perspective. This temporal perspective in history, the notion of zooming in and out on a sliding scale, taking in a year, decade, century or more on an imaginary timeline, is analogous to zooming in and out on maps using Google Earth. Why might teaching students the ability to scale-switch matter? Because we see different things and the things we do see look very different on different scales. The book *Zoom* by Istvan Banyai relays the idea of scale-switching memorably. The book starts with the image of a rooster and then the book zooms out and you realise that the rooster is actually in a barn and it zooms out again and you understand that the barn is on a farm, and then you see that the farm is a toy farm and a child is playing with it, finally, the child playing with the farm is the image on the cover of a magazine.

History helps us to play with perspective when making sense of the world and the relations we perceive, to look up closely and to zoom out, in time and place. How does this relate to science? Consider Malthus, the 18th century English cleric, demographer and economist. Writing about the population, Malthus postulated that population multiplies geometrically and food arithmetically and so population growth will outstrip food production leading to eventual starvation. For Malthus, *'The power of population is indefinitely greater than the power in the Earth to produce subsistence for man'*[9].His prediction was in accord with how the world had been but, in a changing world, what was true yesterday may be redundant today. Over time, in which scientific advances outpaced population growth, Malthus was thought to be wrong. But, on an even longer timescale, Malthus might yet be proven right. If behaviours do not change or if science fails to keep up with the changing dynamics of life, nature may well redress a population-food imbalance.[10] What good could come of taking a temporal perspective? How could history contribute to what Fry (2019) was referring to above when she advocated that scientists and the public are educated in science for more than 'scientific' questions, in Feynman's sense?

Professor Margaret MacMillan (2009) explores the value of history in her book, *The Uses and Abuses of History*. She shares the personal anecdote of growing up during the height of the Cold War and of expecting the dynamic between the two global powers to be a permanent and central feature of international relations for the remainder of folks' lives.

[9] Malthus, Thomas Robert. An Essay on the Principle of Population. Oxfordshire, England: Oxford World's Classics. p. 13.
[10] History provides many examples, for instance, understanding the significance of nuclear power.

But the world looked very different after 1989. MacMillan explains how the perception of living through turbulent times is one reason to look to history for guidance and precedent, especially when other sources of authority have declined. When landmarks seem to havegone, MacMillan says, we turn to history and ask, 'When was it like this?' She believes that as we try to navigate a confusing world, there is no way to guess what lies ahead other than consulting the past. However, seeing precedents is a tricky business. MacMillan explains how frequently the analogy of 1930s appeasement of Hitler is used by politicians, and how often, in her view, in error.

MacMillan commends US President John F. Kennedy for being guided during the Cuban Missile Crisis by two historical analogies rather than one: Appeasement and the outbreak of World War One. Kennedy was able to balance the need to stand up to powerful bullies, but of equal importance, the need to not blunder into war. MacMillan also believes that history can help us to explain certain attitudes and hostilities, for example, the Arabic Palestinian name for the birth of the state of Israel after the Holocaust of WW2 is 'The Catastrophe'. Many deep-seated reactions are born out of history. History, MacMillan believes, may also help us to formulate the right questions when thinking of taking action. She uses the example of the US-led invasion into Iraq after September 11th, 2001. If we look to history, in this case the British experience of trying to control the region through the previous century, we learn to ask what might happen if we take particular action, what evidence we need to take that action, and what we should look out for if we do take certain action. MacMillan thinks that history does not offer clear lessons, but she says that if we can learn anything from history, it is how to think things through, and humility, for in history we see clever people, people who knew a lot and who had a lot of power, make terrible mistakes. As educators, it would be good to know more about whether students learning these lessons in history, as distinct from science, influences their ability to apply the necessary insights in science-related 'big questions', and what we should do about that.

History's investigative method, when observation cannot be the test of knowledge

Feynman's point in the quotation above was that the methods appropriate to science are not those appropriate to non-scientific matters. Other methods are required in such cases. What contribution can history make to science teachers who are thinking about opening their lessons to 'big questions'?

McGill (1989, 2007) and Bevir (1994) have written both accessibly and authoritatively on the methods of investigation in history for readers interested in learning more about the methods of different disciplines. In the simplest of phrasings, from a history educator's perspective, I would say that it is important, yet often difficult, for all students to come to understand that when we are investigating something, just because we cannot say everything does not mean that we cannot say anything or can say whatever we please. Just because we cannot say conclusively, for sure, does not mean that we cannot say plausibly. Just because we cannot determine by observation or experiment does not mean that we cannot explore and express ideas in ways that accord with logic. By way of encouragement, history teachers often tell their students to go ahead and voice a view because there is no right or wrong answer and they have a right to their opinion. Although well-meant, both comments can be hugely unhelpful. There are wrong answers, even to open questions, and those that are plausibly right often exist along a spectrum of better to worse answers. Whilst I endorse the idea of encouraging anyone who feels that they do not have a voice to speak up, I fear the problems sown with this particular form of encouragement. As the philosopher Jamie Whyte explains below, we would do better to qualify what we mean when we claim we have a right to our opinion. Whyte (2004:76) argues:

> *Jack has offered some opinion – that President Bush invaded Iraq to steal its oil, let's say – with which his friend Jill disagrees. Jill offers some reasons why Jack's opinion is wrong and after a few unsuccessful attempts at answering them, Jack petulantly retorts that he is entitled to his opinion.*
>
> *The fallacy lies in Jack's assumption that this retort is somehow a satisfactory reply to Jill's objections, while, in fact, it is completely irrelevant. Jack and Jill disagreed about Bush's motivation for invading Iraq, and Jill gave reasons to believe that Jack was mistaken. She did not claim that he had no right to this mistaken view. By pointing out that he is entitled to his view, Jack has simply changed the subject from the original topic, the reason Iraq was invaded, to a discussion of his rights. For all it contributes to the invasion question, he may as well have pointed out that whales are warm-blooded or that in Spain it rains mainly on the plains.*

I believe that the qualities of the claim matter in history education over the notion that what counts is simply having something to assert. That there may be no single answer ought to increase, not decrease, the need for rigour. Other grounds of support should be found and offered as a source of encouragement for students who lack confidence.

It is not possible to say much more on the practices built up within history education when teaching what Feynman would describe as non-scientific matters; however, seeing these general principles seems to me to be a very good start. History teachers regularly struggle with the classroom implications of these epistemic principles. Being alert to them is a sure foundation and not a reason to fear venturing into discussion of questions where evidence is always partial and incomplete, where interpretation is always present and negotiated, and where there can never be one, provable right answer. The point for the teacher is to learn to infer how students seem to be taking the world to be through listening out for the qualities of student reasoning and through becoming more adept at drawing out students' conceptual frameworks and enhancing them.

History's pedagogical approaches

History teachers have a tradition of planting key considerations into lesson materials and activities such that pertinent issues and ways of thinking unfold rather than overwhelm students, and such that complexities are gradually layered into students' encounters using examples that allow them to grasp the issues. For example, in the biomechanics lesson intended for use when teaching the human skeleton to 11-12 year-olds, the knowledge domains needed include biology, design and technology, and possibly methodological or pedagogical approaches from a humanities subject such as history. In the suggested lesson ideas, students design a cast for a broken bone and then they design a wheelchair. Part of the learning entailed in tackling these questions might be for students to learn to discern which factors are pertinent to their task and to begin to explore the issues that arise when these factors are weighed against each other, hence impacting design choices.

A common pedagogy used in history lessons would entail students working through brief character cards (patient, parent, doctor, company supplying particular products, etc.) in which the teacher plants conflicting interests or concerns, such as the weight of the material, its cost, how itchy it is, the skill level needed to apply it, and so on. The teacher would direct students' attention using certain questions, perhaps varying the scenario to enable the students to see different considerations emerge or recede. The wheelchair task would then be used to both extend and assess student understanding. Again, character cards or unfolding scenarios might be used to afford students the opportunity to demonstrate their ability to appreciate conflicting needs (manoeuvrability, psychological wellbeing, cost, transportable, etc.) and the various priorities when attempting to resolve challenging tensions.

There is another approach that is gaining momentum and proving helpful in history education currently, which may be of interest to colleagues in science. The history education community has been building up a tradition of fostering collaboration between school history and academic history. This is commonly referred to as 'Bringing Historians In'. For example, historians and PhD candidates in history talk about their work, including the process of their investigation, either in person, visiting schools or virtually through recordings of digital technology.[11] One aspect of this is the potential benefit of students 'seeing' the practice of history, history as method, that history is done by people, and not simply encountering the product of historians' work. Apart from the obvious pedagogical benefits of modelling thinking, what we have found anecdotally in history classes is that while these ideas are obvious to us, teachers are surprised by just how revolutionary they appear to be to students. There may be parallels for science lessons.

Selecting questions in history

The puzzle of 'big questions' is a pedagogical device, designed to engender increased student participation and an epistemic consideration – the need to induct students into respecting knowledge as an enquiry and an endeavour. Having a worthwhile learning point, as discussed above, is not the same as succeeding in developing students' understanding of that point. From my experience in history education, there are various

[11] See https://londonhiesig.wordpress.com/2019/06/17/working-with-historians-and-historical-interpretations-in-schools-event-report/

reasons that teaching for open questions may fall flat, and there could be parallels here for science teachers thinking about incorporating 'big questions' into their teaching. Firstly, does the 'big question' need to be answerable, or is the 'big question' sufficiently satisfying by virtue of what is revealed in the attempt to answer it, for example, because of a greater understanding of the limits of our answering? Is there a range of plausible right answers arising from the 'big question', disputed for reasons other than a mishandling of evidence or an illogical argument? Would anyone care to dispute the issue at stake, or is student discussion falling flat because there really is nothing of much interest to be contested? Do students have access to the ideas they need for possible lines of argument to come into view? Can the students see their understanding develop as they engage in the process of answering the 'big question'?

Science from a historical perspective

When I think about science through time, the sorts of general ideas that strike me as interesting, ideas that might be worth exploring through 'big questions', include:

1) Understanding that science is a human activity and appreciating the role of co-operation and imagination in science; the role of mistakes and serendipity in science; the role of chance, patrons, personalities, purposes or contextual features in the making of science. History can help us:
    a. To see how we neglect contextual features such as the role of patrons in creating science and instead tell over-simplified stories such as science versus religion; for example, Galileo versus the Church.
    b. To recognise our over-simplified stories of the relationship between science and religion through examples such as Aristotle coming back into science in Europe via Muslim routes.
    c. To see the role of mentalities in science such as ideas about the supremacy or stewardship of humanity.
    d. To see the extent to which industry and economic interests influence science as it did not before; for example, the role of pharmaceutical companies or the American biotechnology company Monsanto reportedly developing sterile seeds, or the geopolitical forces, for example in Russia and the Middle East, influencing energy policies.

2) Understanding how scientific methods compare to other methods. History can help students to understand the limits of science, for example the role of objectivity, the idea of finding facts; but, as the size of the knots tied to make the fishing net determines the catch, so the theoretical and methodological approach contributes to the nature of the findings. Since history is about the stories, we tell ourselves, specifically the study of how and why we relate to the past as we do, history can

help us to examine to what extent and why we tell a romantic story of science compared to science as it actually is. History may help to combat hubris and teach us humility about what we know and what we can find out and do.

3) Understanding how science can be used for good or ill; or the role of the human element in the application of scientific knowledge including the unintended consequences in the application of scientific knowledge. I suggested above that case studies from history could support students' learning of science, motivationally; however, working with case studies could be a useful pedagogy if teaching for 'big questions' too. For example, *Chernobyl* provides a case study into the interdependence of knowledge domains as so much depends upon key individuals' abilities to think across knowledge boundaries. It could be interesting to explore how we could use other examples, providing case studies of how scientific and non-scientific knowledge are laced together through our lives. For example, in the film *Sully,* which is about the investigation into the decision of the airline pilot to land on the Hudson River in New York City, the findings from flight simulations cannot be interpreted correctly until the human reaction of the pilots is given due consideration. I am not suggesting that seeing these examples of the co-dependence of knowledge domains will enable students to integrate knowledge from different disciplines when facing 'big questions', but I am suggesting that these case studies provide models of people doing, or failing to do, just that, and examples of how and why it mattered.
4) Understanding how our perspectives on the merits of scientific knowledge or its use change in relation to the timescale that we adopt in our investigation. Students could see how the temporal perspective, say looking at the discovery or invention within a 10-year period, a 100-, 1,000- or 10,000-year period, changes our thinking about that knowledge. Or students could look at scientific breakthroughs from the perspective of the time, some subsequent period, or now.

Conclusion

The purpose of teaching and learning history is a source of heated discussion in my work with new student history teachers. We explore how, for example, someone with a good history education should know:

- about the lives of individual people and different-sized groups of people living in the past across different geographical and temporal scales;
- how to ask and answer questions of the past in historically authentic ways;
- how other people have handled, that is, how they've used and abused, the past.

The student teachers consider how a good history education shapes our ways of seeing the world. For example, through the dates, events, states of affairs and lives that we study, a good history education should help someone come to know:

- that while the future can be other, we cannot make the future from scratch;
- that what we choose to say about the past says as much about us as it does about the past;
- that we cannot assume we know others un-problematically, but neither can we assume, that others are nothing like us;
- that a series of pieces of information that are individually true can nevertheless be arranged into an account that is false.

A pivotal moment in a history teacher's development is when they come to realise that there is not just lots of worthwhile information that we'd want someone with a good history education to know. We also want them to know what that information is worth, that is, how they can bring that information to bear upon the questions of their life. My experience, however, has led me to believe that such discussions, no matter how animated, are largely pointless if decoupled from what actually happens in lessons. For example, as a head of history in a state school when the National Curriculum was revised in 2008, I and the rest of the history department drew up a list of what we thought historical knowledge was good for and, hence, why we taught what we taught the way we taught it. Generally, we were pleased with how well our teaching aligned with our aspirations; however, we were not altogether satisfied. We included students understanding their local area as integral to understanding identity, and students understanding the present as crucial parts of our raison d'être. Despite doing so many things well, as we looked to the specifics of how we would recognise success in either of these ambitions, and when, where, how and through what we believed we deliberately taught for these possibilities, I am embarrassed to say that we came up short and had to go back to the curricular drawing board.

History teachers need to make choices about what to teach from a vast array of possibilities because it is impossible to teach everything and, compared to some other subjects, there is relatively little regulation, guidance or convention determining what they choose to teach. This freedom is for very good reason – fear of the distortion of the subject from enquiry into given narrative in the interests of political agendas, e.g. left- or right-wing. This level of freedom, and responsibility, means that many history teachers care about having a worthwhile point to their lesson sequences and care about getting that point across so that its value is felt by learners.

History teachers, thinking about their curriculum, often move back and forth between two complementary lines of enquiry:

1) What could I teach, why would it be worthwhile to teach that, what selection shall I make from the long list of possibilities of what I could teach?
2) I know that I want students to understand this worthwhile insight; what would understanding that look like and what cases could serve as a conduit for the development of that understanding?

How do science teachers think about curriculum planning? One reply to the question of what we are educating people for in science is so that some can go on to become scientists, but I imagine that colleagues also aim for all students to go on to be scientifically literate. Many non-scientists are involved in setting science's research agenda and in determining the appropriate application of scientific discoveries. What scientific understanding is needed of the politicians and entrepreneurs who help determine the goals and uses of science? What scientific understanding do people need whose everyday choices drive the governments and businesses that fund scientists' work? The scientific literacy of non-scientists matters. Crucially, however, as the case of my own curriculum discussion back in 2008 reveals, if science's (or history's) purpose in education is to be more than a theoretical discussion, teachers need to think hard about how their curriculum and teaching relates to this discussion. It is for science teachers to help us to see how the scientific knowledge taught in schools relates to scientific knowledge needed by people later in life, people who will grow up to be scientists and non-scientists alike. Much thinking has already been devoted to thinking through how curriculum provision serving the needs of future scientists may differ from a curriculum serving the needs of future non-scientists (Millar & Osborne, 1998). But the point of 'big questions' is that they include the untaught knowledge needed by all, future scientists included. As we saw in Feynman's discussion, many scientists rightly feel ill-prepared to face the 'big questions' that matter because their scientific knowledge alone does not speak to the peculiar demands of 'big questions'. What is the science teacher's role in helping students to ask and answer questions that go beyond the traditional remit of science, but which cannot be answered without a deep scientific understanding of the world?

To conclude, different disciplines exist for good reason, but students' lives do not compartmentalise so easily. There is a discussion to be had about how we prepare students to face questions that cross knowledge boundaries. History can offer more than 'garnish' (Chang, 2015) in science lessons. Historical content may be a source of motivation in science lessons. Science's past may be a resource for science teaching, potentially facilitating students' understanding of both scientific knowledge and methods. History may also contribute to science-related 'big questions' through its investigative methods and insights. Finally, as science teachers explore how to broaden their curriculum, there may also be something of value in the curricular planning and the associated pedagogical approaches of other subjects such as history.

Bibliography

Bevir, M. (1994). Objectivity in History. *History and Theory*, *33*(3), 328–344.

Feynman, R (1998) *The Meaning of it All.* London: Addison-Wesley.

Lee, P. (2011) in Davies, I., 2011. *Debates in history teaching / edited by Ian Davies*, London: Routledge.

MacMillan, M., 2009. *The uses and abuses of history / Margaret MacMillan*, London: Profile Books.

Megill, A. (2007) *Historical Knowledge / Historical Error: A contemporary guide to practice* Chicago: University of Chicago Press.

Megill, A. (1989) *Recounting the Past: "Description," Explanation, and Narrative in Historiography.* The American Historical Review, *94*(3), Oxford University Press.

Millar, R. & Osborne, J. (1998) *Beyond 2000: Science Education for the Future*. London: Nuffield Foundation.

Whyte, J (2004) *Crimes Against Logic: Exposing the Bogus Arguments of Poloticians, Priests, Journalists, and Other Serial Offenders.* London: McGraw-Hill Education.

Ethics in Science Lessons

Introduction

The intention of this chapter is to provide the following four things:

1. An introduction to the discipline of ethics, enabling science teachers more confidently and appropriately to include teaching about ethics in their science lessons, should they wish to.
2. Examination of the question of whether ethics should be taught in school science lessons.
3. Suggestions as to what student progression in ethical reasoning might look like – so that teachers can see whether students are indeed making progress.
4. Suggestions as to how student understanding of ethics in science might be assessed.

What is ethics?

Ethics is the branch of philosophy concerned with how we should decide what is morally wrong and what is morally right. Sometimes the words 'ethics' and 'morals' are used interchangeably. They can, perhaps, be usefully distinguished, though some languages do not allow for a distinction to be made. We all have to make moral decisions daily on matters great or (more often) small about what is the right thing to do: Should I continue to talk to someone for their benefit or make my excuse and leave to do something else? Should I give money to the WWF, to Oxfam or to cancer research charities? Should I stick absolutely to the speed limit or drive 10% above it if I'm sure it's safe to do so?

We may give much thought, little thought or practically no thought at all to such questions. Ethics, though, is a specific discipline that tries to probe the reasoning behind our moral life, particularly by critically examining and analysing the thinking that is or could be used to justify our moral choices and actions in particular situations.

The way ethics is done

Ethics is a branch of knowledge just as other intellectual disciplines, such as science, mathematics and history, are. Ethical thinking is not wholly distinct from thinking in other disciplines but it cannot simply be reduced to them. In particular, ethical conclusions cannot be unambiguously proved in the way that mathematical theorems can. However, this does not mean that all ethical conclusions are equally valid. After all most philosophers of science would hold that scientific conclusions cannot be unambiguously proved, indeed that they all remain as provisional truths, but this does not mean that my thoughts about the nature of gravity are as valid as Einstein's were. Some conclusions – whether in ethics, science or any other discipline – are more likely to be valid than others. *It is a common fault in ethics courses to assert that there are no rights or wrongs in ethics.*

One can be most confident about the validity and worth of an ethical conclusion if three criteria are met; first, if the arguments that lead to the particular conclusion are convincingly supported by reason; secondly, if the arguments are conducted within a well-established ethical framework; thirdly, if a reasonable degree of consensus exists about the validity of the conclusions, arising from a process of genuine debate.

It might be supposed that reason alone is sufficient for one to be confident about an ethical conclusion. However, there are problems in relying on reason alone when thinking ethically. In particular, there still does not exist a single universally accepted framework within which ethical questions can be decided by reason. Indeed, it is unlikely that such a single universally accepted framework will exist in the foreseeable future, if ever. This is not to say that reason is unnecessary, but to acknowledge that reason alone is insufficient. For instance, reason cannot decide between an ethical system that looks only at the *consequences* of actions and one which considers whether certain actions are right or wrong *in themselves*, whatever their consequences. Then, feminists and others have cautioned against too great an emphasis upon reason. Much of ethics still boils down to views about right and wrong, informed more by what seems 'reasonable' than what follows from formal reasoning.

The insufficiency of reason suggests that there may be an argument for conducting debates within well-established ethical frameworks, when this is possible. Traditionally, the ethical frameworks most widely accepted in most cultures arose within systems of religious belief. Consider, for example, the questions 'Is it wrong to lie? If so, why?'. There was a time when the majority of people in many countries would have accepted the answer 'Yes, because scripture forbids it'. Nowadays, though, not everyone accepts scripture(s) as a source of authority. Furthermore, a point of particular relevance when considering the ethics of contemporary science and technology, while the various scriptures of the world's religions have a great deal to say about such issues as theft, killing people and sexual behaviour, they say rather less that can directly be applied to the debates that surround many of today's ethical issues, for example those involving modern biotechnology and what energy sources we should use to generate electricity. A general point is that we are more conscious nowadays that we live in multicultural or pluralist societies. Within most countries, there is no longer a single shared set of moral values.

Nevertheless, there is still great value in taking seriously the various traditions – religious and otherwise – that have given rise to ethical conclusions. People do not live their lives in ethical isolation: they grow up within particular moral traditions. Even if we end up departing somewhat from the values we received from our families and those around us as we grew up, none of us derives our moral beliefs from first principles, *ex nihilo*, as it were. In the particular case of moral questions concerning contemporary biology, a tradition of ethical reasoning is already beginning to accumulate. For example, many countries have official committees or other bodies looking into the ethical issues that surround at least some aspects of biotechnology. The tradition of ethical reasoning in this field is nothing like as long-established as, for example, the traditions surrounding such questions as war, abortion, euthanasia and trade protectionism. Nevertheless, there is the beginning of such a tradition and similar questions are being debated in many countries across the globe.

Given, then, the difficulties in relying solely on either reason or any one particular ethical tradition, we are forced to consider the approach of consensus. It is true that consensus does not solve everything. After all, what does one do when consensus cannot be arrived at? Nor can one be certain that consensus always arrives at the right answer – a consensus once existed that women should not have the vote and that beating was good for children.

Nonetheless, there are good reasons both in principle and in practice for searching for consensus. Such a consensus should be based on reason and genuine debate and take into account long-established practices of ethical reasoning. At the same time, it should be open to criticism, refutation and the possibility of change. Finally, consensus should not be equated with majority voting. Consideration needs to be given to the interests of minorities, particularly if they are especially affected by the outcomes, and to those – such as young children, the mentally infirm and non-humans – who lack agency and are unable to participate directly in the decision-making process.

At the same time, it needs to be borne in mind that, while a consensus may eventually emerge, there is an interim period when what is more important is simply to engage in valid debate in which the participants respect one another, so far as is possible, and seek for truth through dialogue. In classrooms, teachers can mirror the processes by which societies can seek for consensus.

Is it enough to look at consequences?

The simplest approach to deciding whether an action would be right or wrong is to look at what its consequences would be. No one supposes that we can ignore the consequences of an action before deciding whether or not it is right. This is obvious when we try to consider, for example, whether imprisonment is the appropriate punishment for certain offences – e.g. robbery. We would need to look at the consequences of imprisonment, as opposed to alternative courses of action such as imposing a fine or requiring community service.

The deeper question then is not whether we need to take consequences into account when making ethical decisions but whether that is *all* that we need to do. Are there certain actions that are morally required – such as telling the truth – *whatever* their consequences? Are there other actions – such as betraying confidences – that are wrong whatever their consequences? This is a fundamental question and it might be expected by anyone who is not an ethicist that agreement as to the answer would exist among ethicists. However, this is not the case. There still exists genuine academic disagreement amongst moral philosophers as to whether or not one needs only to know about the consequences of an action to decide whether it is morally right or wrong.

Those who believe that consequences alone are sufficient to let one decide the rightness or otherwise of a course of action are called consequentialists. The most widespread form of consequentialism is known as utilitarianism. Utilitarianism begins with the assumption that most actions lead to pleasure (typically understood, at least for humans, as happiness) and/or displeasure. In a situation in which there are alternative courses of action, the desirable (i.e. right) action is the one that leads to the greatest net increase in pleasure (i.e. excess of pleasure over displeasure, where displeasure means the opposite of pleasure, i.e. harm).

Utilitarianism as a significant movement arose in Britain at the end of the eighteenth century with the work of Jeremy Bentham and J. S. Mill. However, its roots come from much earlier. In the fifth century BCE, Mo Tzu in China argued that all actions should be evaluated by their fruitfulness and that love should be all-embracing. In Greece, Epicurus (341-271 BCE) combined a consequentialist account of right action with a hedonistic (pleasure-seeking) theory of value.

Utilitarianism now exists in various forms. For example, preference utilitarians argue for a subjective understanding of pleasure in terms of an individual's own conception of his/her wellbeing. What all utilitarians hold in common is the rejection of the view that certain things are right or wrong in themselves, irrespective of their consequences.

Consider the question as to whether or not we should tell the truth. A utilitarian would hesitate to provide an unqualified 'yes' as a universal answer. Utilitarians have no moral absolutes beyond the maximisation of pleasure principle. Instead, it might be necessary for a utilitarian to look in some detail at particular cases and see in each of them whether telling the truth would indeed lead to the greatest net increase in pleasure.

There are at least two great strengths of utilitarianism. First, it provides a single ethical framework in which, in principle, any moral question may be answered. It doesn't matter whether we are talking about the legalisation of cannabis, the age of consent or the patenting of DNA; a utilitarian perspective exists. Secondly, utilitarianism takes pleasure and happiness seriously. The general public may sometimes suspect that ethics is all about telling people what not to do. Utilitarians proclaim the positive message that people should simply do what maximises the total amount of pleasure in the world.

However, there are difficulties with utilitarianism as the sole arbiter in ethical decision-making. For one thing, an extreme form of utilitarianism in which every possible course of action would have consciously to be analysed in terms of its countless consequences would quickly bring practically all human activity to a stop. Then there is the question as to how pleasure can be measured. For a start, is pleasure to be equated with wellbeing, the subjective experience of happiness or the fulfilment of choice? And, anyway, what are its units? How can we compare different types of pleasure, for example sexual and aesthetic? Then, is it always the case that two units of pleasure should outweigh one unit of displeasure? Suppose two people each need a single kidney. Should one person (with two kidneys) be killed so that two may live (each with one kidney)?

Utilitarians claim to provide answers to all such objections. For example, rule-based utilitarianism accepts that the best course of action is often served by following certain rules – such as 'Tell the truth', for example. Then, a deeper analysis of the kidney example suggests that, if society really did allow one person to be killed so that two others could live, many of us might spend so much of our time going around fearful that the sum total of human happiness would be less than if we outlawed such practices.

Intrinsic rights and wrongs

The major alternative to utilitarianism is a form of ethical thinking in which certain actions are considered right and others wrong in themselves, i.e. intrinsically, regardless of the consequences. Consider, for example, the question as to whether a society should introduce capital punishment. A utilitarian would decide whether or not capital punishment was morally right by attempting to quantify the effects that it would have on the society. Large amounts of empirical data would probably need to be collected, comparing societies with capital punishment and those without it with regard to such things as crime rates, the level of fear experienced by people worried about crime, and the use to which any money saved by the introduction of capital punishment might be put. On the other hand, someone could argue that regardless of the consequences of introducing capital punishment, it is simply *wrong* to take a person's life, whatever the circumstances. Equally, someone could argue that certain crimes, for example first degree murder, should result in the death penalty – that this simply is the *right* way to punish such a crime.

There are a number of possible intrinsic ethical principles and because these are normally concerned with rights and obligations of various kinds, this approach to ethics is often named 'deontological' (Greek for 'the study of duties'). Perhaps the most important such principles are thought to be those of *autonomy* and *justice*.

People act autonomously if they are able to make their own informed decisions and then put them into practice. At a common sense level, the principle of autonomy is why people need to have access to relevant information, for example before consenting to a medical procedure.

Autonomy is concerned with an individual's rights; justice is construed more broadly. Essentially, justice is about fair treatment and the fair distribution of resources or opportunities. Considerable disagreement exists about what precisely counts as fair treatment and a fair distribution of resources. For example, some people accept that an unequal distribution of certain resources (e.g. educational opportunities) may be fair provided certain other criteria are satisfied (e.g. the educational opportunities are purchased with money legally earned or inherited). At the other extreme, it can be argued that we should all be completely non-egoistic or nepotistic. However, as many have pointed out, it is surely impossible to argue that people should (let alone believe that they will) treat absolute strangers as they treat their children or partners. Perhaps it is rational for us all to be egoists, at least to some extent.

Rights are accompanied by duties but the relationship between rights and duties is often misunderstood. It is often supposed that, if I have rights, then I also have corresponding duties – as in the political slogan that 'rights entail responsibilities'. To see the logical error in this, consider a newborn baby. If ever a creature had rights, it is surely a newborn baby. It presumably has the right to be fed, kept warm, protected and loved. But what duties does it have? Surely none. A newborn baby is simply too immature to have duties. It is not yet responsible for its actions. However, *others* have duties to it – namely to feed it, keep it warm, protect it and love it. Normally such duties are fulfilled by the child's parent(s) but, if neither parent is able to undertake these duties, for whatever reason, the duties pass to others, for example other relatives, foster parents, adoptive parents or social services. *In general, if A has a right, there is a B who has a duty to ensure that A's rights are met.*

If it is the case that arguments about ethics should be conducted solely within a consequentialist framework, then the issues are considerably simplified. Deciding whether anything is right or wrong now reduces to a series of detailed, in-depth studies of particular cases. As far as modern science and technology are concerned, ethicists still have a role to play, but of perhaps greater importance are those who know about risks and safety, while sociologists, psychologists, policymakers and politicians who know about people's reactions and public opinions also have a significant role.

Much energy can be wasted when utilitarians and deontologists argue. There is little if any common ground on which the argument can take place, though some philosophers argue that there can be no theory of rights and obligations without responsibility for consequences, and no evaluation of consequences without reference to rights and obligations. The safest conclusion when teaching students is that it is best for them to consider both the consequences of any proposed course of action as well as any relevant intrinsic considerations before reaching an ethical conclusion.

Virtue ethics

A rather different approach to the whole issue of ethics is provided by *virtue ethics*. Instead of starting from particular actions and trying to decide whether they fail to maximise the amount of happiness in the world, are divinely forbidden or infringe someone's rights, virtue ethics focuses on the moral characteristics of good people. For example, think about a good teacher. What characteristics might we expect them to manifest? We might want them to know their subject, to treat all students fairly, to be able to maintain order in the classroom, to maximise students' chances of doing well in any examinations, to be able to communicate clearly, to have an appropriate sense of humour and so on. Some of these are skills – for example the ability to maintain order – but some are personality traits that we call virtues – notably treating all students fairly, rather than, for example, favouring males, white students, high-attaining students or those who support the same sports teams that the teacher does.

Virtue ethics has an ancient pedigree – receiving considerable impetus from Aristotle – and has undergone something of a revival since the 1970s. Part of the reason for this may be connected with a somewhat instrumental tendency in much of the training of such professionals as doctors, nurses, lawyers, accountants and so on, in which the idea of moral goodness features little. And yet many people who have to deal with such professionals (as patients and clients) want them to be morally good as well as technically skilled.

Widening the moral community

Traditionally, ethics has concentrated mainly upon actions that take place between people at one point in time. In recent decades, however, moral philosophy has widened its scope in two important ways. First, intergenerational issues are recognised as being of importance. Secondly, interspecific issues are now increasingly taken into account. These issues go to the heart of the question 'Who is my neighbour?'.

Interspecific issues are of obvious importance when considering biotechnology and ecological questions. Put at its starkest, is it sufficient only to consider humans or do other species need also to be taken into account? Consider, for example, the use of new practices (such as the use of growth promoters or embryo transfer) to increase the productivity of farm animals. An increasing number of people feel that the effects of such new practices on the farm animals need to be considered as at least part of the ethical equation before reaching a conclusion. This is not, of course, necessarily to accept that the interests of non-humans are equal to those of humans. While some people do argue that this is the case, others accept that, while non-humans have interests, these are generally less morally significant than those of humans.

Accepting that interspecific issues need to be considered leads one to ask 'How?'. Need we only consider animal suffering? For example, would it be right to produce, whether by conventional breeding or modern biotechnology, pigs or chickens unable to detect pain and unresponsive to their conspecifics? Such animals would not be able to suffer and their use might well lead to significant productivity gains: it might, for example, be possible to keep them at very high stocking densities. Someone arguing that such a course of action would be wrong would not be able to argue thus on the grounds of animal suffering. Other criteria would have to be invoked. It might be argued that such a course of action would be disrespectful to the animals, or that it would involve treating them only as means to human ends and not, even to a limited extent, as ends in themselves.

Intergenerational as well as interspecific considerations may need to be taken into account. Nowadays we are more aware of the possibility that our actions may affect not only those a long way away from us in space (e.g. pollutants produced in one country affecting another), but also those a long way away from us in time (e.g. increasing atmospheric carbon dioxide and methane levels may alter the climate for generations to come). Human nature being what it is, it is all too easy to forget the interests of those a long way away from ourselves. Accordingly, a conscious effort needs to be made so that we think about the consequences of our actions not only for those alive today and living near us, about whom it is easiest to be most concerned.

Should we teach ethics in school science lessons?

Not every science teacher will feel that we should teach ethics in school science lessons. For a start, there is the argument that the two disciplines of science and ethics occupy separate spheres of knowledge. It might be held that in claiming that ethics should be taught in science, one might as well claim that science teachers should teach aesthetics. The job of a physics teacher, it can be maintained, is to explain why we get rainbows, neither to pontificate on whether they are beautiful nor to urge us what we should do on seeing one.

Then there is an argument against the teaching of ethics in science that stems from a consideration of the consequences that would follow were such a practice to become common. This argument is somewhat speculative, but might go something like as follows. Science teachers are generally educated in science, not in moral philosophy. It is therefore unrealistic and unfair to expect them to teach ethics. If such teaching is required, it would/might (a) decrease the time they have available to teach science; (b) lead to lower quality teaching, since science teachers will be teaching outside their sphere of competence; (c) lead to lower levels of professional satisfaction amongst existing science teachers; (d) result in fewer science graduates wanting to enter teaching and more science teachers leaving the profession, thus exacerbating the shortage of science teachers that exists in many countries.

However, there are arguments in favour of teaching ethics in school science. For a start, it can be argued that ethics is inevitably and inexorably conflated with science in most cases. Both the scientists and those who fund them hope that production of a new vaccine will lead to more lives being saved (presumed to be a good thing), that the development of a new variety of crop will lead to increased food yields (presumed to be a good thing), that the synthesis of a new chemical dye will lead to greater cash flows, increased profits, improved customer satisfaction or increased employment (all presumed to be good things), that the construction of a better missile detection system will lead to increased military security (presumed to be a good thing), and so on. In each of these cases, the science is undertaken for a purpose. Purposes can be judged normatively, that is, they may be good or bad. Indeed, just beginning to spell out some of the intended or presumed goods (increased crop yields, increased military security, etc.) alerts us to the fact that perhaps there are other ways of meeting these ends or, indeed, that perhaps these ends are not unquestionably the goods that may have been assumed.

A different argument in favour of teaching ethics in school science is that it can enhance the motivation and interest of many students (but not all!). It may also help students better appreciate where science stops and other disciplines (like moral philosophy) begin.

Progression in ethical thinking

Jean Piaget was perhaps the first person to carefully to investigate the subject of moral development, i.e. how individuals progress over time in their ethical thinking. In the 1920s, he studied the ways in which children viewed the rules of the games they were playing. He concluded that morality was a developmental process. To a young child, morality is all about obeying rules. So, telling lies is wrong because a child has been told not to tell lies. I can still remember my father's surprise when, as a young boy, I confessed to him that biting my nails was a terrible thing to do and that if I continued, I should be punished. With hindsight, it was clear that I viewed biting my nails as being morally reprehensible along with other things I had been told not to do (stealing, telling lies, hitting my younger sister and so on). In time, I came to appreciate that biting my nails might transgress rules of etiquette but not principles of morality.

Piaget observed that as children age, and in interactions with others, they move to a more autonomous and less rule-bound view of morality. Piaget's conclusions were developed further by Lawrence Kohlberg who, while also accepting that moral reasoning proceeded in stages, argued that it can continue throughout our lives and that very few of us ever reach its ultimate conclusion. Kohlberg viewed the moral reasoning and practice of individuals as falling into one of six stages. Stage one, as for Piaget, is characterised by the acceptance of moral teaching because of a fear that one will be punished if one transgresses. At the other extreme, stage 6, rarely found in empirical studies, is characterised by abstract principles of moral reasoning in which the acceptability or otherwise of actions are judged against principles of ethical fairness that are established as such, not merely because the majority agrees with them, but because they result from universal, logical argument (as in Kant's *The Groundwork of the Metaphysics of Morals* or Rawls' *A Theory of Justice*).

Indicators of progression in ethical thinking

One of the problems in teaching ethics in science lessons is that there may be no clear expectation of progression. Figure 1 suggests a number of indicators of progression in ethical reasoning (Figure 1). It should not be read rigidly. It is not the case that individuals progress uniformly from left to right, nor would it be altogether surprising to find individuals who, in some cases, were situated at the left and, in others, at the right of the figure. Furthermore, any individual's position on Figure 1 will be affected by the individuals around them, the particular scientific or technological issue being considered, their motivation and a range of other factors. Nevertheless, there may be value in considering how teaching in this area should help individuals move from the left to the right of Figure 1.

Novice → Advanced

Personal → Peers → National → Global

Egocentric → Follows social rules → Holds reasoned principles

1 framework → 2 frameworks → 3-4 frameworks → Evaluates usefulness of framework for different situations

Considers humans only → Considers all sentient animals → Considers whole ecosystems

Immediate consequences – 'now' → Long-term consequences

Uses existing knowledge only → Uses taught knowledge → Researches new knowledge

Scientific knowledge and ethical principles are separated → Scientific knowledge and ethical principles are intertwined

Analysis conducted with one's own values → Understand and empathise with values/worldviews of others

Acceptance of ethical frameworks → Critical ethical frameworks

Explicitly refer to frameworks → Remember frameworks → Frameworks become internalised

Figure 1: Indicators of progression in ethical reasoning.

Such movement, indicating progression in ethical thinking, entails the following:

- An individual moving from viewing an ethical issue (e.g. eating meat from intensively farmed animals) in terms of its effects for oneself (e.g. the meat tastes delicious) to one's peers (e.g. how does the rest of one's family feel about this?) to others in one's country (e.g. consequences for national employment) to people globally (e.g. effect on world trade).
- A shift from seeing oneself as the moral universe (egocentrism) to following social rules (e.g. one should stick to the speed limit) to holding reasoned principles (e.g. one should adjust one's car speed for the benefit of other road users even if that means driving below the speed limit).

- A progression from only being able to use one ethical framework (e.g. consequentialism) to using two to using three or four to evaluating the usefulness of the frameworks for different situations (e.g. considering the frameworks of consequentialism, rights and virtues when considering whether or not to terminate a 20 week-old fetus with Down syndrome).
- Moving from considering humans only (e.g. when determining how to manage a park) to considering all sentient animals to considering whole ecosystems.
- A progression from considering ethical issues (e.g. climate change) solely in terms of the 'now' to the long-term.
- A development from relying solely on existing knowledge (e.g. when discussing how to deal with animal pests) to using knowledge they have been taught to researching new knowledge.
- Moving from a situation where scientific knowledge and ethical principles (e.g. about whether money should be spent conserving endangered species) are considered in isolation to one where they are drawn together.
- A shift from considering socio-ethical issues only within one's own set of values to considering them within others' too.
- A progression from simply accepting standard ethical frameworks to being able to critique them.
- A development from needing to consult frameworks before using them to remembering them to internalising them.

Assessing ethics in school science

As every teacher knows, good teaching is helped by good assessment. A Nuffield report[12] into how ethics might be assessed in school science came up with eight recommendations:

1. When teaching about ethics is included within science curricula, it should be made clear that there are differences between ethical reasoning and scientific reasoning and that the methods used to arrive at scientific knowledge are therefore not the same as those used to reach ethical conclusions.
2. Those responsible for devising science courses with a significant component of teaching about ethics should be considerate of the demands placed on teachers, for instance by providing clear guidance about what is and is not expected, carefully prepared worked examples and materials that can be used for professional development.
3. Science specifications that include ethics should indicate what progression in knowledge and understanding is expected, for example when grade descriptions are provided.

[12] Reiss (2009).

4. Assessment of students' understanding of ethics is unlikely to be best achieved when questions are worth only a very small number of marks. Students need to be given time and space to show what they know and to develop an ethical argument.
5. Those who are responsible for devising mark schemes to accompany question papers in science that assess knowledge and understanding of ethical issues should familiarise themselves with best practice in subjects, such as philosophy, with a well-established history of assessing ethics.
6. The way in which ethics is assessed should reward good teaching, and students should be provided with regular feedback on their learning.
7. Teaching about ethics should be seen as important across the disciplines of science and not restricted to biology.
8. Professional science organisations and other bodies involved in improving the quality of school science education should examine what they can do to enhance the teaching and assessment of ethics in science.

Some of these recommendations apply to Awarding Bodies and other organisations rather than specifically to schools, but many apply to science teachers attempting to include more ethics in their lessons.

Bibliography

Beauchamp, T. L. & Childress, J. F. (2013) *Principles of Biomedical Ethics, 7th edn*. New York: Oxford University Press.

Jones, A., McKim, A. & Reiss, M. (Eds) (2010) *Ethics in the Science and Technology Classroom: A New Approach to Teaching and Learning*. Rotterdam: Sense.

Levinson, R. & Reiss, M. J. (Eds) (2003) *Key Issues in Bioethics: A Guide for Teachers*. London: RoutledgeFalmer.

Mueller, M. P., Tippins, D. J. & Stewart, A. J. (Eds) (2017) *Animals and Science Education – Ethics, Curriculum and Pedagogy*. Dordrecht: Springer.

Mullan, S. & Fawcett, A. (Eds) (2017) *Veterinary Ethics: Navigating Tough Classes*. Sheffield: 5M.

Reiss, M. J. (1999) Teaching ethics in science. *Studies in Science Education*, 34, 115-140.

Reiss, M. (2009) *Assessing Ethics in Secondary Science: A Report of a Seminar held at the Nuffield Foundation*. London: Nuffield Foundation. Available at http://nuffieldbioethics.org/wp-content/uploads/Assessing-Ethics-in-Secondary-Science.pdf.

Singer, P. (2011) *Practical Ethics, 3rd edn*. Cambridge: Cambridge University Press.

Taylor, J., Swinbank, E., Reiss, M., Harrison, D., Ellis, P., Cartwright, J. & Allday, J. (2007) *Perspectives on Science: The History, Philosophy and Ethics of Science>* Oxford: Heinemann.

Independent Scientific Research Projects for Year 8-10 students

The value of project work

Recent summaries of research into the ongoing discussion about the relative merits of 'instruction' and 'inquiry' as teaching approaches have tended to confirm what thoughtful teachers will perhaps always have suspected, namely that both have their place.

For example, in the McKinsey 2017 report *Drivers of Student Performance: Insights from Europe*, Etienne Denoël, Emma Dorn, Andrew Goodman, Jussi Hiltunen, Marc Krawitz and Mona Mourshed made a careful analysis of OECD PISA results and reached this conclusion:

> *Our research found that student outcomes are highest with a combination of teacher-directed instruction in most to all classes and inquiry-based teaching in some classes.*[13]

It should be clear from the outset that in recommending the inclusion of more project work in science lessons for year 8 – 10 students, our purpose is emphatically not to deny that there is an essential role for instruction. On the contrary, as any teacher who has sought to use a project approach to facilitate rich and effective learning knows, students need to be taught the skills required for successful project development work. Perhaps we would do better to think in terms of 'learning-based projects' rather than 'project-based learning'.

Project work can provide a valuable setting within which students can begin to develop the skills they need in order to become more independent learners. It is commonly noted by those concerned with the 'outputs' of the educational process that successful achievement of high examination grades is of questionable value if it has been accompanied by a deterioration or even destruction of such valuable educational traits as curiosity, independent-mindedness and willingness to engage with challenging questions. Here is how one admissions tutor put it:

> *While not a 'skill' in its own right, one of the key perceived gaps in some students' outlook when arriving at higher education was intellectual curiosity or a 'love of their subject'. One interviewee referred to it as a lack of the "sheer love of investigation". While few interviewees believed this is something that can be taught, many thought that it was something that tended to be better developed in the past because upper secondary school pupils had the space to do so. Many were of the opinion that the number of exams taken within A levels meant that pupils had no opportunity to gain a love of their subject and had encouraged a "joyless little bean counter" approach to learning, whereby they thought that learning was simply a matter of knowing the right answer. However, it was noted by this interviewee and others that this utilitarian approach to learning and exam-passing is something that is embedded in the entire education system and not solely an issue in the A level system.*[14]

[13] *Drivers of student performance: Insights from Europe,* McKinsey. https://www.mckinsey.com/industries/social-sector/our-insights/drivers-of-student-performance-insights-from-europe. See also Hmelo-Silver, C. E., Golan Duncan, R. & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: a response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist* 42.2 (2007): 99-107 and Scott, David M. et al. (2018) Examining the efficacy of inquiry-based approaches to education. Alberta Journal of Educational Research 64(1).

[14] *Fit for Purpose? The view of the higher education sector, teachers and ...* 1 Apr. 2012, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/377930/2012-04-03-fit-for-purpose-a-levels.pdf.

Project work can provide an antidote an exam-driven approach to learning, offering a context for the development of the capacity of students for independent – or collaborative – thinking.[15] This guide for teachers offers advice about how project work can be embedded within science lessons.

Teaching independence

The capacity for independent learning is not innate, and if we are to expect our students to begin developing in this domain, we will need to point the way. Specifically, students need to be taught some of the skills they will employ in the course of project work, and they need to know something about the topics they will grapple with.

One of the biggest obstacles in the path of those who wish to teach science in a broader, more exploratory, inquiry-driven fashion is the sheer volume of material to be covered in most programmes of study. It is not uncommon for teachers to express sympathy with the aspiration of moving towards a mode of classroom engagement that affords more time and greater priority to student-led inquiry, but to despair of finding the time to progress in this direction, whilst simultaneously doing justice to the imperative to 'tell them what they need to know'.

In response, we may note that to the extent that this pressure is all-pervasive, it is perhaps marginally less so during the years that precede the onset of examination preparation, so that there are better prospects for developing independent project work in or around Years 8–10.

That said, many schools, under pressure from assessment and accountability targets, are moving the teaching of examination content earlier, so that the window for opening science up, such as it is, begins to look more like a crack in the wall.

With this in mind, the models described in this guidance will be framed with a dual purpose: they should serve to foster a richer, broader, deeper sense of engagement with science as a process of active inquiry whilst also enabling the topics of the curriculum to be addressed.

Teaching syllabus content and research skills concurrently

A simple exercise that serves as a starting point for teaching research skills whilst simultaneously enabling students to begin exploring curriculum content is to set a series of syllabus learning objectives as topics for research. A scaffolded Google Doc template with prepared headings can be issued to students, along with guidance about the use of the Google EXPLORE research tool. Depending on the confidence of the class in using Google Docs, you could either set this as an individual assignment, or set a group activity in which students collaborate to create the notes jointly on a single Doc.

See the video on 'Learning to Research using the EXPLORE Tool' for further guidance.[16]

[15] For a recent review of the evidence of impact, see Bennett, J., Dunlop, L., Knox, K. J., Reiss, M. J. & Torrance-Jenkins, R. (2018) Practical Independent Research Projects in science: A synthesis and evaluation of the evidence of impact on high school students. *International Journal of Science Education*, 40, 1755-1773.

[16] https://youtu.be/uVxz_s0LJFs.

Promoting inquiry through philosophical discussion

Our aim is to encourage a deeper form of learning of science, one that goes beyond simply 'knowing the right answer' (i.e. the one that will get marks in the exam). Our aim is also to encourage a broader understanding of scientific knowledge – a form of understanding that connects it to the questions we ask in other fields, questions about the meaning of scientific knowledge, the right way to use it, and the implications it has for our wider beliefs about reality.

Classroom philosophical discussion can provide a helpful starting point for the process of encouraging students to think more deeply and broadly about science. We will understand philosophy to mean: thoughtful exploration of the meaning of ideas used in everyday and scientific discussion.

Philosophical reflection has a valuable role to play when it comes to thinking more broadly about scientific knowledge, and the way in which this knowledge relates to other disciplines. One simple way to introduce a philosophical element into science classes is to invite the class to participate in a group discussion of questions about science and its boundaries.How many sciences are there?

The boundaries of science

Run a classroom discussion activity, choosing one or more of the following questions as a stimulus to discussion. It is unlikely to be productive to try to engage the entire class in discussion, so break into sub-groups, and invite one member of each group to feed back to the whole class in a plenary. Alternatively, you can use the 'fishbowl' arrangement, with half of the class sitting in a larger circle, auditing the discussion of the rest of the class as they sit in an inner circle.

- Why should the government pay scientists to do scientific research?
- What is science?
- Why do we do science?
- Does science rule out religion?
- Could there be a scientific explanation of love?
- Can science provide us with certainty or just theories?
- Does science disprove the existence of souls?
- Does evolution disprove creation?
- What is the difference between science and mathematics?
- Is history part of science?
- How many sciences are there?
- Could there be a science of ghosts?
- Could science come to an end?
- Could science explain why there is a universe at all?

Can science teachers teach philosophy?

The suggestion that science lessons should incorporate some philosophical reflection raises a concern for some science teachers as to whether they have the subject knowledge required to teach philosophy.

To the extent that the aim of including philosophical discussion is simply that of raising awareness of interesting puzzles about the nature and boundaries of scientific knowledge, a deep knowledge of philosophy is not required. However, some acquaintance with the methods of philosophy and important philosophical ideas can be helpful in providing a framework for broader, deeper scientific inquiry. The following framework provides a basic set of categories and questions that can be used to help provide clarity for both science teachers and their students when addressing philosophical questions arising from scientific knowledge.

Philosophical field	Areas within field	Questions that can be asked	Examples of application within a science lesson
Ethics	Areas within field Questions relating to right and wrong; matters of value	How should we live? What should we do about ...? What is the right thing do to? What are the good and bad consequences of an action?	Discussion of the ethical use of gene editing What policy on the welfare of farm animals should we adopt?
Metaphysics	The exploration of the most general ideas about reality	What is ultimately real? How does one part of reality relate to another? Which parts of the world are objectively real?	What is energy? Is heat a thing? What is the relationship between individual animals and a species? Is gender a biological fact or a social construction?
Epistemology	The limits of knowledge	What do we know for certain? What is the difference between knowledge and belief? How do we know things?	Do we know where the universe came from? Is it reasonable to doubt the evidence for climate change? Is all scientific knowledge based on evidence?
Semantics	The meaning of language	What is the meaning of a word? What misunderstandings of a concept arise?	What is the difference between mass and force? What is the meaning of 'evolution'? Is the everyday concept of power the same as the scientific concept?
Logic	The structure of arguments	What are the assumptions of an argument? What follows from these assumptions? Does the evidence provided prove, or support, the conclusion?	What arguments can be given for and against the use of performance-enhancing drugs in sport? What are the assumptions of these arguments?

Managing discussion in the science classroom

Since our aim is to promote thought about open-ended questions related to scientific topics, a solely didactic approach is clearly not appropriate. The aim is to equip students with the knowledge they need in order to enable them to engage in meaningful inquiry. This means that there needs to be some didactic teaching, of core knowledge and inquiry skills, but that wherever possible, teachers should exploit opportunities for engagement in discussion, dialogue, debate, inquiry and investigation. The rationale for activities like these is that they are appropriate given the open-ended nature of the questions being explored.

So, for example, since there are different possible reasonable answers to the question, 'Should performance-enhancing drugs be allowed within sport?', instead of the teacher lecturing the students, it makes sense to invite students to research, explore, investigate, discuss and debate such a question amongst themselves. In short, we are inviting students to engage in a form of 'citizen science' – enacting within the classroom the same process of communal deliberation that should characterise exploration of open-ended questions in a mature democracy.

A variety of modes of classroom discussion can be utilised to facilitate engagement with open-ended questions.

Activity	Description	Example of use	References
Philosophical starter	An open-ended question designed to stimulate thought at the outset of a lesson	A physics lesson begins with the question, 'Which direction is up in space?'	https://www.slideshare.net/cranleighschool/cranleigh-thinking-world-philosophy-day
Question bouncing	A technique for drawing a number of students into exploration of a question	The teacher asks the question 'Are all forms of radiation dangerous?'. When one student has argued yes, the teacher asks for a student who disagrees to give their argument	https://www.theguardian.com/teacher-network/2011/nov/17/lessons-good-to-outstanding-afl-questioning
Think – Pair – Share	A technique for involving all students in a class in reflective discussion	Students are invited on their own to think about the statement 'evolution means getting better', then discuss with a neighbour, then share with the class	https://www.readingrockets.org/strategies/think-pair-share
Fishbowl discussion	A technique for managing classroom discussion with large groups by splitting the group into 'discussants' and 'listeners'	The teacher splits a class of 30 into two groups of 15. Fifteen students form an inner circle, and discuss the evidence for the Big Bang. The 15 around the edge are asked to listen then make one point about something they have learned. The groups are then swapped over so that the discussants become listeners	https://www.betterevaluation.org/en/evaluation-options/fishbowltechnique

Activity	Description	Example of use	References
P4C seminar	A structured approach to group discussion of philosophical questions	Following a unit of study of genetics, students are given a newspaper report about the use of genome analysis for seriously ill children. They are asked to brainstorm questions that they would like to discuss. A list is generated. The class then votes on which questions to tackle first. In their discussion, they are asked to support their statements with arguments	https://educationendowmentfoundation.org.uk/public/files/Projects/Evaluation_Reports/EEF_Project_Report_PhilosophyForChildren.pdf
Online discussion thread	A question or comment posed on a learning platform as a starting point for an online discussion	A link to a BBC article about the environmental benefits of reducing meat consumption is shared with a class on their learning platform. They are invited to respond to the statement 'we should become vegetarians in order to save the planet'	How to eat well - and save the planet http://www.bbc.co.uk/news/science-environment-45472966

A case study of classroom philosophical discussion

At the end of a sequence of lessons on the Big Bang cosmological model, the teacher convenes a philosophical seminar. The class is given a summary of the scientific evidence relating to the Big Bang and a list of questions for discussion. The teacher opts for a fishbowl arrangement. The class is invited to choose a stimulus question from a list provided by the teacher. The teacher asks them to remember to back up their comments with supporting arguments and reminds them that discussions work best when each participant listens first and then adds to the point just made, questions it, or offers a challenge. The discussion unfolds with occasional prompts from the teacher. After 10 minutes, the teacher stops and asks the students around the edge of the room to make one observation each about something they have learned. Then the two groups swap around, a new stimulus question is chosen, and a new philosophical discussion begins.[17]

Utilising projects to broaden and deepen scientific learning

As a means of encouraging deeper thinking and broader reflection on the connections between scientific knowledge and ideas drawn from other disciplines, project work has a valuable role to play.

[17] For resources to support the exploration of this topic, see the materials in this project on cosmology.

We will use the term 'project' to refer to the process of developing a personal response to an open question. The involvement of a question is important: a project in the sense that we mean is not simply the collection of materials that relate to a topic, but a process of inquiry or creative development that seeks to answer or respond to a central guiding question. The question serves to give unity and direction to the activities that make up the project. So, for example, a project such as 'make a poster about racing cars' may or may not lead to fruitful scientific investigation. By contrast, a project beginning from the guiding question 'Is science the key to success in Formula 1?' may well be more productive.

At their heart, projects involve personal engagement with the learning process; choice enters, either by way of the choice of topic, or through decision-making about the form the response takes, if the guiding question itself is prescribed. Alongside the elements of freedom of choice, another crucial ingredient is time: a project is not simply a task that is carried out, but a process, typically involving activities such as research, reflection, refinement of ideas, and the development of a response to the guiding question.

A model that will assist us in thinking about good choice of project titles is the FACE question model:

Fertile	The question leads naturally into learning about relevant topics of study.
Accessible	The level of demand of the topics to be explored is appropriate.
Controversial	There is scope for argument and counter-argument, or the consideration and evaluation of alternative possibilities.
Engaging	The project interests the student.

A skate park design project

Suppose that a teacher intends to use project work to explore the science related to the design of skate parks. He asks the class to spend two weeks designing their own skate park. Is this a good way to introduce project work? Let us evaluate the project title against the FACE criteria.

Fertile	This is a potentially fertile topic as there is plenty of science to be explored. But if the relevant science proves complicated, it might be tempting to students to focus on other areas, such as aesthetic features, in which case the project will not be fertile as a source for scientific learning.
Accessible	Some relevant scientific ideas, such as energy transfer processes or discussion of materials, may be accessible. Other parts of science (such as calculations using equations of motion) probably won't be.

Controversial	There is scope for argument about the relative merits of different designs, though whether scientific knowledge can be used as part of these arguments is not clear.
Engaging	Potentially this is of interest to students and, even for those who aren't keen skaters, the design challenge has the merit of giving an opportunity to explore a real-world application of scientific ideas.

Refining project titles

It is commonly the case that the first idea for what to do in a project – whether the teacher's or the student's – is not the best. Project ideas often begin life as rather vague suggestions of what could be done or looked into. The process of refinement of the title – perhaps by means of doing some initial research, then discussing what could be done to sharpen up the question – is integral to almost all successful projects.

How could our skate park project be refined to improve the likelihood of productive learning of some relevant science? A more focused aim than 'Design a skate park' would be as follows:

The energy skate park challenge

Use the Phet Energy Skate Park simulator to investigate the effect of gradient on the speed achieved by skaters. Then use these data to make recommendations for the best gradients to be used in a new skate park for teenagers. Your recommendation should include research into the safety of skaters at different speeds.[18]

An attraction of this scaffolded approach to the skate park project is that the framing of the question will lead students towards exploration of the effect of physically significant changes, so that instead of looking more broadly at aesthetic features, they are more likely to engage in a fertile investigation of how scientific knowledge can be used to help understand a significant design problem. The project also has the merit of bringing into focus some of the value conflicts that go into the design process in real-world scenarios, where the thrill of achieving higher speeds needs to be balanced with the requirements of safe usage.

Managed transfer of responsibility for learning

To what extent should students be given choice during their project work? It is not an 'all or nothing' affair. It might be tempting to 'hand over control' straight away, and simply let students follow their immediate interests, but a more secure route is to manage a phased

[18] The Phet Energy Skate Park can be found here:
https://phet.colorado.edu/sims/html/energy-skate-park-basics/latest/energy-skate-park-basics_en.html.

transfer of responsibility for the learning process, with elements of choice growing as the skills and knowledge of your students develop. In the following case study, there is planned growth in the extent to which students are expected to manage their own learning.

A case study of developing project learning throughout a term

At the start of a term-long study of human physiology, students are asked to choose from one of four case studies about the ethics of sport. They are provided with some references, taught some basic techniques for carrying out research and asked to produce a summary based on three sources that they have accessed.

Midway through the term, students are asked to identify an ethical question related to the topic of physiology, find a stimulus (an article or short video) and introduce a seminar discussion of the ethical question. Seminars run for five minutes each with groups of five students participating in each.

At the end of the unit, students have five lessons plus homework time to choose a FACE question arising from the work they have done on physiology. They are to research their question, identifying at least three sources, summarising the information and preparing a five-minute class presentation in which they lay out the science related to their question and make an argument for their preferred answer, as part of which they should also consider counter-arguments.

The role of the teacher in project learning

The model we have been exploring is one in which the teacher plans carefully for students to take more responsibility for the learning process, using a sequence of project activities that afford scope for greater choice by the student as the process unfolds. The role of the teacher will therefore be more didactic at the outset, and, as time goes by, there will be scope for them to become a facilitator of the process of project learning.

When asking students to engage in project work, many teachers are concerned that students will venture into areas where the teacher's expertise is limited. This is a genuine challenge and needs careful thought. Clearly, there are elements that do need specialist oversight – not least amongst these being the management of practical work in a safe manner. A model that works well is for the science teacher to work collaboratively with teachers from other departments, so that an arrangement can be made for specialist instruction if needed. If time constraints are likely to make this impossible, this limitation needs to be considered when the project is being set up; it would be impractical, for example, to ask each member of a science class of 30 to design a physical model that will take hours of workshop time to build. But what might work is to have a few minutes conversation with a Design and Technology teacher at break time, in order to establish whether there are readily accessible resources (e.g. design challenge worksheets, or online tutorials) that could be used to support a meaningful practical challenge.

Structuring projects

The management of time in the context of project work creates a challenge both for students and their teachers. A common trajectory is for a project to begin with a surge of enthusiasm, only for the process to stall when difficulties emerge a few lessons in (the so-called 'muddle in the middle').

To some extent, productive difficulty is desirable – maybe even essential – as part of the process of genuine learning in the context of open-ended challenging projects – and so the key to success is management of this part of the process. Handled well, the final phase of project work can feel like the re-emergence of the sunshine after the clouds have passed; the culmination of many student projects in some form of presentation frequently provides an uplifting sense of just how much has been learned.

The key is the maintenance of momentum: keeping students moving forward, even if only slowly. To make progress easier, it helps students enormously if the project process is broken down into a sequence of manageable stages. It also helps the teacher, who can provide guidance at each stage of the process, and monitor the progress of a whole class in a way that is harder to achieve if each student devises his or her own preferred project structure.

The most widely used template here is based on the design cycle: plan – research – develop – review. The idea is that project work begins with reflecting on the choice of title, which should take the form of a question (for investigative projects) or a practical challenge (for design / creative projects). Once a title has been selected, research sources are reviewed to identify source materials to be used in creation of the project. Next comes a development phase in which the student responds to the material they have found. In the case of investigative projects, this will involve evaluating the strength of the arguments found in sources, and, if data are involved, analysing the data and exploring their significance in relation to the chosen question. Finally, the project ends with a review, which addresses the conclusions and the methodology that was used; this section can often involve some form of presentation of the work, either as an oral presentation or through a display.

The following framework is designed to allow an independent research project to be produced over 16 lessons (with some time outside of lessons for private study). This could be done using one lesson per week over the course of a term, or a three- to four-week block of time at the end of the summer term when all science lessons are allocated to this one task.

Template for a Year 8–10 independent research project

Project phase	Duration	Activities	Resources
Plan	Three lessons	Brainstorming for questions; planning use of time; division of labour in the case of group projects; decisions about format (e.g. written report, artwork, presentation, video or podcast)	Online sources of project ideas; controversies in the news; examples of other student projects
Conduct research and write literature review	Five lessons	Gathering and analysis of information; referencing and bibliography construction; visual / technical research; refinement of project question following research; method for data collection; gathering results; consideration of reliability and validity of sources	Web search for age-appropriate information about genetics; Google EXPLORE tool; online guides for practical techniques; automatic citation generators (e.g. EasyBib)
Develop project and write discussion	Five lessons	Laying out and evaluation of alternative possible answers to question; exploration of alternative possible designs for practical projects; presentation and analysis of data; drawing conclusions	Google Docs / Word / Slides / PowerPoint / Keynote / Spark Video / iMovie
Evaluation	Three lessons	Reviewing the project process and giving presentations	Data projector and classroom time for short final presentations

Planning the project

As we have discussed, the choice of title is important and should not be rushed. Allow students time to explore topic areas that attract their interest. Remind them of the FACE model: their chosen question should link to relevant scientific knowledge; it should be accessible; it should allow scope for the exploration of alternative points of view; and lastly, but by no means least, they should choose a topic that they find interesting.

Students can also choose to present the output of their project work in a variety of formats. For simplicity, we will divide these up into either the writing of a report, or production of a creative output. The terminology is in some ways unhelpful since creativity will be involved in writing as well as the production of artworks, but the distinction should help students to focus on whether they will present their project and its findings in the form of a report or in some form of creative output, whether a film, presentation, artwork or design.

Students can be asked to produce a project plan:

Project plan

Run a classroom discussion activity, choosing one or more of the following questions as a stimulus to discussion. It is unlikely to be productive to try to engage the entire class in discussion, so break into sub-groups, and invite one member of each group to feed back to the whole class in a plenary. Alternatively, you can use the 'fishbowl' arrangement, with half of the class sitting in a larger circle, auditing the discussion of the rest of the class as they sit in an inner circle.

- Title for project (in the form of a question or practical challenge)
- Format for project presentation of the project (e.g. report, presentation, film, sketchbook)
- Areas that will be researched
- List of sources to be used

A typical written report produced by a Year 9 student would be around 1200 words in length.

Template for an independent research project

Introduction	100 words	Explanation of question and definition of terms
Literature review	500 words	Summaries of source materials with citations
Discussion	500 words	Point of view, argument and counter-argument
Evaluation	100 words	Reflections on the project work process

Writing a literature review

Once planning is underway, students should move into literature review. (In fact, the planning and writing the literature review phases usually overlap. In most projects, following initial exploration of sources, there is some refining of the project title.)

One central challenge is to help students appreciate that literature review is more than just 'finding things on the internet'. It can be helpful to explain the literature review process in terms of the following three elements:

Elements of the literature review process

Collection and selection	Finding source material and selecting what is relevant
Analysis and synthesis	Asking what source information means and linking sources
Evaluation	Asking questions about the reliability of sources

To guide students through this process, they can be provided with guidance about writing up a literature review:

Literature review

Topic headings (e.g. scientific knowledge, history of problem, ethical questions)

Summaries of sources within each topic area

Citations

Evaluation of source reliability in footnotes

Methodology for data collection (for investigative projects)

In a typical Year 9 science project lasting over 16 lessons, with five lessons for writing a literature review, it would be feasible for students to access around four to six sources.

It is helpful if students decide on some areas of research to explore in their literature review, rather than simply assembling a mass of information from websites. One easy starting point is to find a relevant Wikipedia page, and to look at the table of contents for suggested headings (one advantage of Wikipedia is that all pages have a table of contents).

Students should be taught how to use tools on a word processor for creating references and bibliographies automatically. They should also be taught about the technique of paraphrase.[19]

For students working on Microsoft Word, referencing tools can be accessed using the References – Insert Citation – Add New Source buttons.

Students also need to explore the question of source reliability. A very simple analytical tool here is the pair of questions: Who wrote it? Who published it? Students can be shown how to insert footnotes and encouraged to comment briefly on the reliability of their sources in a footnote.

Investigative projects

If a student is carrying out an investigative project, they should consider and write about their choice of methodology for data collection (e.g. design of an experiment, use of an online simulator, or creation of a questionnaire). Investigative projects should also involve writing a literature review exploring the context within which a scientific question arises.

Writing a discussion

The discussion section of a project provides space for a student to respond to the materials that they have found whilst writing their literature review. The key to the

[19] A short video which explains how to use Google Docs for referencing is available here: https://youtu.be/uVxz_s0LJFs

discussion is that it should take the form of an argument. This is the point in the project where the question should be answered, using evidence from the sources. The student needs to have a point of view that they will put forward, backing it up with data, quotations and arguments derived from their literature review.

As part of the argumentative process, there should also be consideration of counter-argument: what would an argument against their point of view look like, and how would they answer it? It is the 'dialectical' method of putting a point of view, arguing for it, putting arguments against and finally responding to these that constitutes high quality thinking about the type of open question that lies at the intersection of science with other disciplines. The model, then, for a discussion, is as follows:

The Discussion

Statement of point of view

Argument

Counter-argument

Response to counter-argument

The project model that we have been considering makes a clear distinction between the literature review and discussion phases. Students do not find this easy, and many wonder what the difference is. A very simple way of explaining it is: in reviewing research, you are finding out what other people think; in discussing, you are putting your own point of view.

The two sections are thus different, but they should be linked together in that the sources described in the literature review should provide the materials for the arguments evaluated in the discussion section.

Case study of an independent research project report

Sarah has become interested in the question of whether the rules surrounding performance-enhancing drugs should be changed. She carries out research to find six sources and summarises these in a literature review under the headings of 'history of drug use in sport', 'the effects of different drugs', 'current rules' and 'case studies'. Having written up her research, she writes a discussion in which she decides to argue that performance-enhancing drugs should still be banned. She looks at arguments against banning, as well as arguments for, before drawing conclusions. For the evaluation of her project, she prepares a five-minute presentation covering the main elements of her research and discussion, as well as reflecting on what she has learned from the process. Her final output is a written report of 1200 words together with her presentation slides and notes.

Investigative project work

Independent research projects do not *require* students to gather their own data. However, as we are seeking to promote engagement with scientific questions, we may want to encourage students to engage in investigative project work using the collection and analysis of primary data.

Template for an investigative project

Introduction	Explanation of the chosen research question (this could include a testable hypothesis).
Literature review	Finding out about the context for the question (this can include research into social, ethical and historical aspects of the question).
Methods and results	Following research, students decide on a method and gather results.
Data presentation and analysis	Data can come either from an experiment run by the student, an online source of publicly accessible data (such as Zooniverse[20]) or an online simulator (such as provided by the Phet interactive simulations website[21]). Analysis should involve exploration of trends and patterns in the data, with use of graphical analysis as appropriate (the freely available Google Sheets program can assist here, or the Charts function on Word can be useful). Analysis will also involve asking questions about what the data show – what conclusions can be drawn, and relating findings to information gathered from sources in the literature review.
Evaluation	Reflection on the quality of the methods used to collect data and on the quality of the data itself.

Case study of investigative projects

Sam's question is: what could be done to promote energy efficiency in my school? Sam begins his project by writing a 400-word literature review exploring why efforts are being made to improve efficiency, considering what other schools have done and addressing the science of thermal energy transfer processes[22]. He then gives a description of how he will go about gathering his own data (e.g. counting and measuring single-glazed windows in an old part of their school, looking up U values for these and for double-glazed windows and calculating energy and cost savings). He gathers his results and writes up his findings, providing tables of data and bar charts comparing the energy losses from single and double-glazed windows of different sizes. He writes a 400-word discussion of his data, linking it to ideas from his research. He includes a conclusion making recommendations about what his school should do and a 100-word introduction to the report. For his evaluation, he provides an 'executive summary' slideshow presentation to be presented to his school's governors.

[20] https://www.zooniverse.org/.
[21] https://phet.colorado.edu/.
[22] See https://youtu.be/uVxz_s0LJFs for an example of research in this area.

Case study of investigative projects cont.

Emily decides to use the Zooniverse website to find out about the large mammal community of the Lopé National Park in Gabon[23]. For her initial research, she finds out about the species described in the Wild Gabon project. She follows the online tutorial then analyses a series of images taken from the website, recording the frequency with which particular species are observed and her analysis of their activities. She submits her findings to the Zooniverse Wild Gabon project. She tabulates her data and presents them, using bar charts, in a written report. Whilst her data set is quite small, she is able to find further data from other sources and uses these to write about the impact of human activity on large mammals in the region. In her review, she draws conclusions and reflects on how research into mammal distribution can help to inform conservation efforts.

Creative projects

Students may choose to present the output of their independent research project in the form of a film, performance, artwork or presentation. In such projects, the main output will be the creative work itself, together with supporting evidence of the process of design and creation. This may be in the form of a written report summarising the creative journey, or it could be in the form of a sketchbook or slideshow.

The main elements that should be covered correspond to those in a written project, but with emphasis on the exploration of creative techniques and processes and sources of inspiration.

Creative projects are often produced using sketchbooks or slideshows, with typically one or two pages for initial planning and brainstorming, three or four pages for research, three or four pages for records of development and one page for review.

Template for a creative project

Plan	Decide on a design brief, which defines the overall practical challenge to be addressed.
Research	Explore inspirations: examples of creative work within the chosen genre. Research the processes and techniques needed for creative work. Carry out research into the subject areas addressed by the project.
Develop	Using guidance from research into genre, processes and techniques, develop the creative output. The decision-making process should be recorded (e.g. in a sketchbook, project log or slideshow), with an emphasis on explaining the reasoning process behind the decisions. What alternatives were considered, and why were certain creative options chosen?
Evaluation	Reflection on the project process. Did the student meet the initial brief? What lessons have been learned? The evaluation may take the form of a presentation or exhibition of the project output.

[23] https://www.zooniverse.org/projects/pangorilla/wild-gabon/about/research

Case study of creative projects

Hannah and Archie decide to produce a three-minute documentary about the rules for transgender athletes. Archie works on the script, whilst Hannah researches techniques and processes for creating documentaries. Archie uses online sources to gather information about current rules and case studies that have been in the news. They interview their biology teacher, and some of their fellow students. Hannah uses an online tutorial to learn about using Adobe Spark.[24] Archie makes notes on news clips and interviews with transgender athletes found on YouTube. Records of research are kept in a scrapbook. Hannah and Archie make a storyboard, then assemble clips to make their documentary and record a narration. After editing the film, they present it to their class and invite questions.

Amy, Bea and Charlie have been entered by their school in a competition to design a wheelchair for use by teenagers. They decide to prepare a Google Slides presentation with their design ideas. Amy works on research concerning the needs of wheelchair users, looking at adapting wheelchairs for teenager use. Bea carries out primary research in the form of two interviews with wheelchair users. Charlie signs up for a free trial of the Sketchup and looks at online tutorials for guidance about how to use it.[25] They discuss analysis of existing designs, considering cost, functionality and aesthetic features, then draw up a specification for their design. Amy and Charlie work to create a digital model on Sketchup whilst Bea prepares drawings for a presentation. They produce a Slides presentation with information about their research, design ideas, the process of creating their final design and evaluation of the final product. [26]

Assessing projects

Given the diversity of output types, it is not helpful or appropriate to assess projects with a tightly defined mark scheme. However, a broad set of assessment indicators can be used within an assessment framework that draws on the teacher's professional judgement.

Assessment of projects can be done using annotations on the project output itself, together with a final grade. The following model for assessment is designed to work using 'best-fit' judgement: the teacher uses the criteria as indicators to reach a final decision about a grade. Note that it is not essential that each of the criteria is met in order for a project to be assigned a particular grade. Note too that a teacher may decide not to grade but simply to provide written or verbal feedback on what worked well and what could be developed further.

[24] See https://spark.adobe.com/.

[25] See https://www.sketchup.com/ and https://youtu.be/UsHRGDvN4sM, for example.

[26] For an example of a wheelchair model produced on Sketchup, see https://youtu.be/bKrIXg4YjOo. For a range of other design ideas, run a search for wheelchairs at https://3dwarehouse.sketchup.com/?hl=en.

Grade	Performance indicators
A	The student shows a high degree of commitment to their project work. There is evidence that the project title has been thoughtfully chosen and refined during the project process. The student shows a good ability to manage the project process, taking responsibility for decision-making. A good range of sources is used for research and sources are summarised (not simply quoted) in the project. There is use of a system of citations for sources. If the project is in the form of a written report, it is well-produced, with evidence of consideration of both argument and counter-argument. There is a review of the project, which includes thoughtful reflection on the process. If the project involves use of primary data, a good range of data is carefully collected and thoughtfully analysed, with appropriate use of graphs or calculations. If the project presentation is in the form of a creative output, there is evidence of a thoughtful process of research and design leading up to an output that is carefully developed and refined.
B	The student shows a reasonable degree of commitment to their project work. There is some evidence that the project title has been chosen and some evidence that it has been refined during the project process. The student shows a reasonable ability to manage the project process, taking some responsibility for decision-making. A reasonable range of sources is used for research and there is some summarisation of sources (not simply quotation) in the project. There is some citation of sources. If the project is in the form of a written report, it is reasonably produced, with some evidence of argument and counter-argument. There is a review of the project, which includes some reflection on the process. If the project involves use of primary data, there is some collection and analysis, with some use of graphs or calculations. If the project presentation is in the form of a creative output, there is some evidence of a process of research and design leading up to an output that is developed and refined to some extent.
C	The student shows a limited degree of commitment to their project work. There is limited evidence of thought about the project title. The student shows a limited ability to manage the project process, being dependent on guidance when it comes to decision-making. A limited range of sources is used for research and there is limited summarisation of sources in the project. There is a limited attempt at citation of sources. If the project is in the form of a written report, there is limited consideration of format and limited evidence of argument and counter-argument. There is a review of the project, which includes some basic comments about the process. If the project involves use of primary data, there is only limited collection of data and basic analysis, with minimal use of graphs or calculations. If the project presentation is in the form of a creative output, there is limited evidence of a basic process of research and design leading up to an output with very limited evidence of the output being refined.