Teaching science interdisciplinarily – the BRaSSS approach

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Abstract Recently, there have been a number of moves to encourage the development of approaches to science teaching that emphasise its links with other curriculum subjects. This article describes the rationale of one such project for 11- to 16-year-olds: the Broadening Secondary School Science (BRaSSS) project. We situate the project in the history of interdisciplinarity in science education, explain the principles that underpin the project and describe the extensive materials that have been produced and are now freely available for others to use.

The place of science in the school curriculum, certainly in the secondary phase, seems secure. Somewhat ironically, this gives rise to its own problems. In particular, unlike many other subjects, such as geography, design and technology or religious education, this has resulted in a degree of complacency among science educators, who have not had to fight to defend or creatively reinvent their subject in the curriculum to the extent that other subject educators have. 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, with the exception of mathematics which is simply utilised for the benefit of quantitative science. It is the contention of the Broadening Secondary School Science (BRaSSS) project that the engagement of school science with other subjects is to the benefit of students and, ultimately, science itself.

Almost everyone acknowledges that scientists, whether working in academia, in industry or elsewhere (e.g. in health or the environmental movement), usually work in interdisciplinary teams. While each scientist nearly always needs a core area of conceptual knowledge in which they have deep understanding, they also need, at the very least, to be aware of the boundaries of their own knowledge and of how that 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 (Reiss and Straughan, 1996).

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

In England, there is a particular problem with over-specialisation in post-compulsory secondary education (including at university level), given that most A-level students in years 12 and 13 (ages 16–18) study only three subjects. It is therefore important that subjects are not construed too narrowly. Science is a subject where this danger is perhaps particularly apparent. Given this, and the importance of subject specialisation to teacher identity, if we want to see substantial moves towards interdisciplinarity in science in large numbers of schools and colleges, the most likely way forward is to broaden science so that science teachers 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.

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, religious education or philosophy classes.

The BRaSSS project

BRaSSS has been funded by a grant to University College London Institute of Education from the Templeton World Charity Foundation (TWCF) as part of their 'Big Questions in Classrooms' initiative (www.templetonworldcharity.org/our-priorities/big-questions-classrooms). This initiative seeks to develop teachers' and students' understanding and insight about 'how knowledge works'. BRaSSS seeks to do this by providing materials to help teachers of 11- to 16-year-old students to develop a broader understanding of secondary school science.

The TWCF's Big Questions in Classrooms initiative specifically 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 place 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 and other subject disciplines are likely to gain at best only modest purchase in most schools in England.

The approach adopted in the BRaSSS project has therefore been 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 'AT17', 'The nature of science' and 'Working scientifically') in the 11–16 science curriculum. This means that the project can build on existing good practice.

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. We have concentrated 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.

The project has a substantial research component – to see what the consequences are of teaching science in a more interdisciplinary manner. One of us, Tamjid Mujtaba, is leading on this. In this article, we report on the pedagogical materials that we developed for students and for teachers.

Phase 1 (September 2018 – August 2019)

In the first phase of the project, an extensive bank of trial materials was developed for use in lessons in biology, chemistry (including earth science) and physics (including astronomy/cosmology). The materials are designed for use with 11- to 16-year-olds (originally, separate materials for each year group but feedback from this phase meant that the final materials are labelled as suitable for either years 7–9 (ages 11–14) or years 10–11 (ages14–16)) 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 were 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. However, the onset of 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 2019–2020 school year in 2020–2021. 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 was 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 worked with 16 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 did not expect any participating school to use the materials we produce in more than 12 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). 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.

Rich lesson materials

We have produced two sorts of materials: a teachers' pack and materials for students and teachers that are probably best described as rich lesson materials. All materials can be downloaded free of charge, under 'Outputs', from our project website (see *Resource links*).

The lesson materials have been written by Dr Jonathan Allday (physics), Professor Vanessa Kind (chemistry) and Professor Michael J. Reiss (biology). They 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:

- Science lessons can include content from other subjects – for example, history or philosophy.
- 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. religious education), 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, using either or both of these approaches. To exemplify what we have done, we describe below one of the shorter sets of lesson materials, 'Biomechanics'.

Biomechanics lesson

Background, National Curriculum links and suggested aims

This lesson is intended for use when teaching the human skeleton to years 7–9. It has been written for use in a biology lesson.

Teacher background knowledge

No special background knowledge is required for a biology teacher. If a science teacher with a specialism in chemistry or physics teaches the lesson there are opportunities to make links with chemistry (e.g. properties of the various materials used to make casts) or physics (e.g. strength of materials, including metals and bone).

Cross-curricular links

The intention is to introduce students to approaches normally used in design and technology. There are also links to health education.

Design and technology curricula tend to emphasise that when designing, students should be taught to:

- use research to identify and understand user needs, including the needs of people from different cultures;
- solve their own design problems and understand how to reformulate problems given to them;
- develop specifications to inform the design of innovative, functional, appealing products that respond to needs in a variety of situations;
- develop and communicate design ideas using annotated sketches, detailed plans, 3-D and mathematical modelling, oral and digital presentations and computer-based tools.

Student background knowledge

Students should know that a bone is a living tissue and can break.

Resources and timing

No special resources are required. If no extension activities are included, about 50 minutes should suffice.

Activities

The context of the lesson is a broken leg.

1. Introduce students to the four bones in the human leg (femur, patella, tibia, fibula). There is no need for them to learn the Latin names but they should know where the bones are.
2. Now, focus on the largest of these – the femur, often called 'the thigh bone', the longest bone in the body.
3. Imagine someone has broken one of their femurs. Ask students what might lead to this happening? There are several possibilities:
   (a) An accident causing too large a force to be exerted on the femur, causing it to break. The accident might, for example, be because of a car or bicycle crash or in a contact sport.
   (b) The result of a disease. For example, the femur might be weakened because of cancer or some other disease, for example osteoporosis, which becomes more common in older people, especially women.
   (c) Occasionally, repetitive overuse of the leg, such as excessive long-distance running, can result in what is called a 'stress fracture' to one of the bones in the leg (though unlikely to be the femur).
4. This might be the time to teach a bit of first aid (part of health education). If someone has a broken leg – whether the femur or any other of the bones:
   (a) Get someone to 'phone 999 and ask for an ambulance.
   (b) Help the person to keep the broken leg as still as possible until help arrives.
   (c) If available, apply an ice pack wrapped in a towel (or similar) to help reduce swelling.
   (d) If possible, keep the leg slightly elevated with pillows or a cushion or similar – again, to reduce swelling.

(e) Don't allow the person to eat or drink anything unless a doctor or paramedic says they can. This is because they may need an operation.

5 Reinforce this first aid by getting the students to do a quick role-play about what to do when someone seems to have broken their leg. (There are roles for the person with the broken leg, one or two first aiders, worried bystanders – possibly offering unhelpful advice, arrival of paramedics.)

6 Introduce students to how the break might be treated. The short video (2 min 20 s) at www.youtube.com/watch?v=1S1nrCwm1qc is one possibility; there are others available on the internet. This video shows how the bones may need to be put back in alignment (called 'reduction') and then how a metal rod may be used in treatment. After initial surgery, it is common for some sort of cast (plaster or fibreglass) to be used.

7 Get students to think why a metal rod may be used. (They can use the internet for research or think among themselves.) The key points are that:
   (a) Bone is a living tissue and so breaks can be healed, but bones can rejoin in the wrong places if not helped by medical technology.
   (b) Metal is strong and allows the fractured bone ends naturally to join together and heal rather than grating against each other.
   (c) The metal will not react with anything in the body – it won't be recognised as a 'foreign body' and attacked by the immune system, which normally functions to repel foreign biological matter.
   (d) It can be left in place permanently, though sometimes metal implants are removed.

8 Get students to think what properties a good material for a cast would have. (Again, they can use the internet for research or think among themselves.) The key points are that:
   (a) A cast needs to be fitted easily to precisely the shape of the person's leg.
   (b) A cast should be strong but not too heavy. (Plaster and fibreglass have lower specific gravities than do some alternatives.)
   (c) The cast needs to be easy to remove, typically by (carefully) using a saw – do not try this at school.

9 Get students to think about the design features they might want for someone who has to use a wheelchair for weeks or even a few months because of a broken femur. There is lots of literature available for you (not 11- to 12-year-old students) to read about wheelchair design – for example, www.physio-pedia.com/Wheelchair_Design. Some of the key points are:
   (a) Ease of movement (whether user-propelled, pushed by others or motorised) including when making changes of direction.
   (b) Stability (so it doesn't tip over).
   (c) Comfort for the user (seating, not too heavy if user-propelled).
   (d) Ability to cope with wear and tear (and think about walk-in showers).
   (e) Think about the ability of a wheelchair user to see and be seen.
   (f) Not too expensive – especially if not provided by the National Health Service/insurance.

Formative assessment opportunities

As a teacher, think about the assessment opportunities. Students should have learnt things from their work on casts (paragraph 8) that they can use when designing a good wheelchair (paragraph 9).

Extension activities – wheelchair design for teenagers

This would be an ideal starter for a small-scale (two- or three-week) year 8 (ages 12–13) or year 9 (ages 13–14) extended project. Alternatively, it could be run during a collapsed timetable day or two at the end of the year, using the combined resources of the science and design and technology departments.

Instructions

You have been entered by your school in a competition to design a wheelchair for use by teenagers. Prepare a presentation with your design ideas. Work in teams of no more than three. The duration of the entire project process is 6–8 hours. You should include:

- research on the needs of wheelchair users;
- research on adapting wheelchairs for teenager use (this can include primary research in the form of interviews with wheelchair users or professionals with relevant knowledge);
- analysis of existing designs (considering key design features, cost, aesthetic features);
- specification of your chosen design;
- sketches and evaluation of two or three possible designs;
- model making (either physical models or, if time and expertise permits, some CAD work using *SketchUp* or *Autodesk Fusion 360* if available);
- evaluation of final product;
- final presentation.

Resource links

Rich lesson materials are available from our project website at: www.ucl.ac.uk/ioe/departments-and-centres/departments/curriculum-pedagogy-and-assessment/broadening-secondary-school-science-2018-2022

SketchUp is available freely to schools that are signed up for *G Suite for Education*: www.sketchup.com/products/sketchup-for-schools

Autodesk Fusion 360 is available via a free three-year educational license: www.autodesk.com/products/fusion-360/students-teachers-educators

Copyright-free photographs and animations can be obtained from the internet, e.g. https://commons.wikimedia.org/wiki/File:Femur_-_animation5.gif

Gallery of examples

- https://gallery.autodesk.com/fusion360/projects/34582/wheelchair
- https://gallery.autodesk.com/fusion360/projects/wheelchair-2
- https://3dwarehouse.sketchup.com/model/3b37f4a8461555d81fabf3cbd0fc77bc/Wheelchair
- https://3dwarehouse.sketchup.com/model/3a131153-61fb-4bc5-b8f4-917ad5af4860/Wheelchair

Teachers' pack

In the 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. The philosophy note was added as a result of feedback received during the pilot, and briefly describes the relationship between philosophy and science.

History in science lessons

One of us [MJR] admits that when he taught school science, he simply used history as a way of motivating certain students. For example, while teaching genetics, some student most appreciate the inherent logic of the topic – understanding, for example, how the behaviour of chromosomes in meiosis leads to the various ratios that one sometimes observes in dihybrid crosses (9:3:3:1 and so on). Other students are particularly interested in medical genetics – the inheritance of sickle-cell disease and cystic fibrosis, for example. Others find the uses of applied genetics in fields such as agriculture and brewing to be of particular interest. But many students like the addition of a bit of history to help humanise the subject. Most of the students MJR taught had no particular interest in Roman Catholic theology but found stories about Mendel, an Augustinian friar and often described as the father of genetics, to be fascinating. Was he lucky or were his results too good to be true? Why didn't other biologists appreciate his findings?

When MJR told one of his history-of-education colleagues, Dr Catherine McCrory, how he used history in science, she didn't entirely rubbish what he did but tried to explain that there is much more to how history can be used in school science. For instance, in her chapter she writes:

> *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 which includes the day before yesterday and the day after tomorrow.*

To give one further example, McCrory writes about how the history of science can help students appreciate better how science is undertaken by scientists, something that the science educator Joan Solomon, who was on the original working party for the first Science National Curriculum in England, long argued (e.g. Solomon *et al.*, 1992).

Ethics in science lessons

The chapter on ethics in science lessons is intended to provide four things:

- 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.
- Examination of the question of whether ethics should be taught in school science lessons.
- Suggestions as to what student progression in ethical reasoning might look like – so that teachers can see whether students are indeed making progress.
- Suggestions as to how student understanding of ethics in science might be assessed.

Perhaps the key question is whether or not ethics should be taught in school science lessons. A fuller discussion of this question is given in McCrory and Reiss (2023). In the teachers' pack it is acknowledged that 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, not to pontificate on whether they are beautiful or to press us on 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 this. 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 among 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.

Independent scientific research projects for year 8–10 students

Finally, the teachers' pack has a chapter on independent scientific research projects for year 8–10 (age 12–15) students. There is a growing literature on the benefits of students undertaking independent scientific research projects in school science (Bennett *et al.*, 2018). Here, the emphasis is specifically on how such projects can enable more interdisciplinary science teaching.

Taylor provides a number of approaches that teachers can use to help their students undertake interdisciplinary research projects, and gives a number of examples of students who have undertaken such projects. For example, Sarah became interested in the question of whether the rules surrounding performance-enhancing drugs should be changed. She carried out desk research to find six sources and summarised 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 wrote a discussion in which she decided to argue that performance-enhancing drugs should still be banned. She looked at arguments against banning, as well as arguments for, before drawing conclusions. For the evaluation of her project, she prepared a five-minute presentation covering the main elements of her research and discussion, as well as reflecting on what she had learned from the process. Her final output was a written report of 1200 words together with her presentation slides and notes.

Discussion

There has been quite a long history of attempts to broaden school science, for example, through making richer links with history, with ethics or with religious education (e.g. Solomon, 1988; Bennett and Lubben, 2006). Many of those undertaking such attempts are positive about them, though other science educations have cautioned against such attempts, with Donnelly (2002) noting that often they succeed with only a minority of teachers.

More recent work is examining in more depth the epistemic differences between different subjects (Billingsley and Fraser, 2018; Erduran *et al.*, 2019; Woolley *et al.*, 2022) and the implications this has for high-quality pedagogy. Our hope is that the BRaSSS project contributes to this ongoing work and proves of value to secondary science teachers striving to motivate their students and ensure that they learn science well.

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References

Bennett, J. and Lubben, F. (2006) Context-based chemistry: the Salters approach. *International Journal of Science Education*, **28**(9), 999–1015.

Bennett, J., Dunlop, L., Knox, K. J., Reiss, M. J. and 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**(14), 1755–1773.

Billingsley, B. and Fraser, S. (2018) Towards an understanding of epistemic insight: the nature of science in real world contexts and a multidisciplinary arena. *Research in Science Education*, **48**(6), 1107–1113.

Donnelly, J. F. (2002) Instrumentality, hermeneutics and the place of science in the school curriculum. *Science & Education*, **11**(2), 135–153.

Erduran, S., Guilfoyle, L., Park, W., Chan, J. and Fancourt, N. (2019) Argumentation and interdisciplinarity: reflections from the Oxford Argumentation in Religion and Science Project. *Disciplinary and Interdisciplinary Science Education Research*, **1**(1), 1–10.

McCrory, A. and Reiss, M. J. (2023) *The Place of Ethics in Science Education: Implications for Practice*. London: Bloomsbury.

Reiss, M. J. and Straughan, R. (1996) *Improving Nature? The Science and Ethics of Genetic Engineering*. Cambridge: Cambridge University Press.

Solomon, J. (1988) Science technology and society courses: tools for thinking about social issues. *International Journal of Science Education*, **10**(4), 379–387.

Solomon, J., Duveen, J., Scot, L. and McCarthy, S. (1992) Teaching about the nature of science through history: Action research in the classroom. *Journal of Research in Science Teaching*, **29**(4), 409–421.

Woolley, M., Bowie, R. A., Hulbert, S., Thomas, C., Riordan, J. P. and Revell, L. (2022) Science and RE teachers' perspectives on the purpose of RE on the secondary school curriculum in England. *The Curriculum Journal*. https://doi.org/10.1002/curj.191

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