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June 2022
volume 103 number 385

The ASE's professionally reviewed journal for science education 11–19

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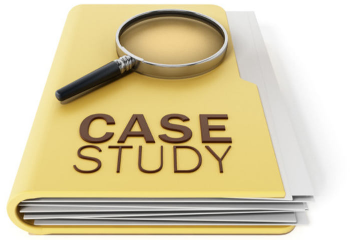

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Acknowledgements

ASE would like to thank the editorial team, authors, reviewers and online feedback group without whom this first issue of *SSR in Practice* would not have been possible:

Authors (see *Contents* list on page 1.)

Reviewers: Wendy Pearmain (Wollaston School, Northants); Christian Moore-Anderson (Oak House School, Barcelona); Simon Flynn (Camden School for Girls, London); Thandiwe Banda (The Beacon School, Banstead); Deepika Narula (Beaumont School, St Albans); David S. Moore (retired teacher, Oxford); Alaric Thompson (Ulverston Victoria High School); Dawn Leslie (formerly of Davenies School, Beaconsfield); Hal Sosabowski (University of Brighton); Simon Carson (University of York); Ben Rogers (The Paradigm Trust); Janet Williams (Mayflower High School, Billericay); Maria Bateson (The Charter School, East Dulwich); Ian Carter (Ecology Consultant, Alderney); Cerian Angharad (ASE Field Officer, Cymru/Wales); Michael Reiss (UCL Institute of Education); Dom Shibli (University of Hertfordshire); Ian Kinchin (University of Surrey); David Swinscoe (Independent Consultant); Kristy Turner (University of Manchester and Bolton School Boys' Division); Peter Borrows (ASE Health & Safety Group).

***SSR in Practice* online feedback group:** Jo Pellereau (University of Warwick CTE); Toby Evans (Purbrook Park School, Waterlooville); David Paterson (Aldenham School, Hertfordshire); Rose Edmondson (Falinge Park High School, Rochdale); Helen Dearns (Royal Society of Chemistry).

Special thanks go to Andy Chandler-Grevatt (Chair, 11–19 Committee), Alastair Gittner (Chair, Research Group), Jane Oldham (Chair, Technician Committee) and Peter Borrows (Health & Safety Group) for their continued support in establishing this new practitioner-focused journal.

Contributing to *SSR in Practice*

We will be welcoming contributions for all sections of *SSR in Practice* and will be announcing how to submit proposals in the next issue (September/October). If you are interested in reviewing articles for future issues of *SSR in Practice*, please contact ssreditor@ase.org.uk. Reviewers who are currently teaching would be particularly welcome.

SSR in Practice and *SSR in Depth* are published in September/October, February/March and May/June as a benefit of 11–19 membership of the Association for Science Education. They are also available on subscription from the ASE.

ISSN 2755-256X

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Health & Safety

For all practical procedures described in *SSR in Practice*, we have attempted to ensure that:

- the requirements of UK health & safety law are observed;
- all recognised hazards have been identified;
- appropriate precautions are suggested;
- where possible, procedures are in accordance with commonly adopted model risk assessments;
- if a special risk assessment is likely to be necessary, this is highlighted.

However, errors and omissions can be made, and employers may have adopted different standards. Therefore, before any practical activity, teachers and technicians should always check their employer's risk assessment. Any local rules issued by their employer must be obeyed, whatever is recommended in *SSR in Practice*. Unless the context dictates otherwise it is assumed that:

- practical work is conducted in a properly equipped laboratory;
- any mains-operated and other equipment is properly maintained;
- any fume cupboard operates at least to the standard of CLEAPSS Guide G9;
- care is taken with normal laboratory operations such as heating substances or handling heavy objects;
- good laboratory practice is observed when chemicals or living organisms are handled;
- eye protection is worn whenever there is any recognised risk to the eyes;
- fieldwork takes account of any guidelines issued by the employer;
- pupils are taught safe techniques for such activities as heating or smelling chemicals, and for handling microorganisms.

For further guidance, please see p. 3 of *SSR in Depth*.

Editorial

Helen Harden is ASE Chair-elect and Interim Co-editor of *SSR in Practice*

As Chair-elect of ASE and Interim Co-editor, I am delighted to welcome you to the very first issue of the new two-part format *SSR* journal. We hope the combination of *SSR in Practice*, which you are reading now, and *SSR in Depth*, available online via the QR code below, will provide shorter articles focused on classroom practice as well as longer articles about science education.

Just like a school science department, the ASE community is made up of a range of science education professionals, including science leaders, classroom teachers and technicians working with students aged 11–19, as well as those who work in early-years settings, primary schools (5–11), further education (FE) and the initial teacher education (ITE) sector. Without this community, this publication would not be possible and we acknowledge and thank them on the previous page.

By providing mentoring for new writers and an accessible proposal system we hope that, over time, *SSR in Practice* will provide an opportunity for a far greater range of science teachers and technicians to get their ideas and experiences published in a journal. Please see the next issue for further announcements.

The curriculum features more than once in this issue, including the opening leadership article, an update on the new Curriculum for Wales and a discussion on the implications for schools of major educational reforms in Scotland.

The two parts of *SSR* are planned to work in tandem, so this issue of *SSR in Depth* develops curriculum thinking further with an article by Alistair Moore and Ann Fullick about the Royal Society of Biology's *Evolving 5–19 Biology* report. Christian Moore-Anderson also writes in depth about how to measure and foster biological thinking beyond short-answer questions. Kendra McMahon has contributed articles to both parts of this issue.

So, whether you are an individual 11–19 member reading this at home, a trainee teacher accessing it via your institution library, or you are coming across this in school as part of your departmental membership, we hope you will find many articles of interest that will support you in your classroom practice.

So what regular features of *SSR in Practice* should you look out for in this issue?

- **Leadership article**. Each issue will contain an article to support science leaders. The theme of the first leadership article is leading the development of a science department curriculum over time.
- **Practitioner case studies**. The case studies will provide an opportunity for teachers to share and reflect on research-inspired practice in their department or classroom. The teachers writing these very first case studies were mentored by ASE's 11–19 Committee Chair, Andy Chandler-Grevatt.
- **Practical ideas**. The practical-focused articles will be led by ASE's Technician Committee and will include all-important technician tips. Committee Chair Jane Oldham has written the first practical article, which links to the exclusive bonus content – a video extract of Jane's presentation at ASE's 2022 online Annual Conference.
- **Real-life science and careers**. ASE members have requested articles that provide hinterland (real-life contexts) for students, as well as examples of STEM careers. This issue includes articles about sickle cell anaemia, geophysics and genome sequencing as well as a career profile.
- **Education research**. ASE's Research Group will be contributing a regular *Journal club* feature, with guiding questions to explore one of the many influential articles available to members in the online *SSR* archive. In addition, Research Group Chair Alastair Gittner has carried out the first of a series of education researcher interviews.
- **Learning from primary**. This article style will facilitate the sharing of good practice from ASE's primary community by showing how primary-focused CPD can be used effectively in a secondary context.
- **Talking point**. *Talking point* articles will be designed to encourage discussion with colleagues or the wider science education community.
- **Opinion**. This article type will enable authors to share their personal opinions on topical science education issues.

For further articles you can access *SSR in Depth* online at www.ase.org.uk/SSR-in-depth/issue-385

All the weblinks mentioned in articles in this issue are listed in one convenient document available at www.ase.org.uk/ssr-resources

Improving a departmental science curriculum – steadily, over time

Peter Fairhurst describes how to lead the improvement of a departmental science curriculum; much of the content of this article comes from the ASE's member-only *Curriculum Evolution* guidance document which provides a supportive framework for in-school curriculum development

In the summer of 2021, the ASE 11–19 Committee published a support document for science teachers called *Curriculum Evolution* (ASE, 2021). The main reason for writing *Curriculum Evolution* was to support science teachers and subject leaders in improving the quality of science learning for *their* students in *their* schools, and in a manner that embeds improvements and promotes further improvement over both the medium and the long term. It is based on the premise that '*Curriculum developments should* change *what teachers do, not add to what they do*' (ASE, 2021).

In part it can be viewed as a means of responding to Ofsted's subject review for science (Ofsted, 2021), which placed the importance of a well-thought-through, structured and supportive science curriculum at the heart of their findings of what constitutes high-quality science education. Ofsted is the Office for Standards in Education, Children's Services and Skills, in England.

Map out a long-term vision

The first step in developing a high-quality science curriculum is deciding what it needs to contain (Figure 1). As with most curriculum development tasks, this is best done collaboratively as a department and should include dialogue with colleagues in the senior leadership team.

At the core of any science curriculum should be a learning and teaching plan that is coherently mapped and sequenced to develop: students' scientific understanding and knowledge; practical skills and understanding; ability to analyse and interpret data and to problem solve; and an understanding and appreciation of the subject itself. Appendix 2 of *Curriculum Evolution* includes suggestions of how this might be achieved.

Teaching straight from an exam specification, or from a textbook that is based directly on an exam specification, rarely does this in the most effective way. A high-quality curriculum needs to build on students' prior learning, both in science and in other subjects, and build knowledge of key concepts in a meaningful way.

There also needs to be flexibility in a curriculum so that it can be made relevant to all students, including the most disadvantaged, those with special educational needs and/or disabilities (SEND) or those making faster progress than most.

Define the curriculum structure

A vital step in ensuring successful implementation and continual improvement of a curriculum is to create a clear and flexible structure that is easy for teachers, learning support staff and technicians to access. This is typically a shared and curated set of resources organised to provide topic- and lesson-level support in the context of a long-term curriculum plan. It should provide the tools and materials that enable them to do their jobs most effectively and also provide support and insights to help develop teachers' pedagogical understanding and knowledge. On one hand, new staff or those teaching outside of their specialisms should be able to readily access the ideas and expertise of their colleagues. On the other hand, the knowledge and wisdom of those leaving the school should be retained to support those who follow.

Appendix 1: What does a science curriculum need to include?

What do you think your curriculum needs to include, and which are more/less important?

	Must always be included	Should be included, if possible	Nice to include, but not essential	Should not be included
List of basic content	☐	☐	☐	☐
Detailed breakdown of content to be taught	☐	☐	☐	☐
List of learning outcomes for each topic	☐	☐	☐	☐
Exam specification	☐	☐	☐	☐
Bought-in scheme of work	☐	☐	☐	☐
Structured progression	☐	☐	☐	☐
Shared resources	☐	☐	☐	☐
Detailed lesson plans	☐	☐	☐	☐
Medium-term teaching plans	☐	☐	☐	☐
A five-year 11-16 curriculum plan	☐	☐	☐	☐
Flexibility within teaching plans	☐	☐	☐	☐
Regular recall tests	☐	☐	☐	☐
Summative assessment for each topic	☐	☐	☐	☐
Summative assessment for each term/teaching cycle	☐	☐	☐	☐
Summative assessment for each year	☐	☐	☐	☐
Formative assessments	☐	☐	☐	☐
Information on pedagogy	☐	☐	☐	☐
Information on misconceptions	☐	☐	☐	☐
Information on learning progressions	☐	☐	☐	☐
Policy on developing practical skills and understanding	☐	☐	☐	☐
Integrated resources to develop practical skills and understanding	☐	☐	☐	☐
Policy on literacy	☐	☐	☐	☐
Integrated resources to develop literacy	☐	☐	☐	☐
Policy on numeracy	☐	☐	☐	☐
Integrated resources to develop numeracy	☐	☐	☐	☐
Policy on science capital	☐	☐	☐	☐
Integrated resources to develop science capital	☐	☐	☐	☐
This list is not exhaustive and may be added to: e.g. retrieval practice within each topic.	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐

Figure 1 *Curriculum Evolution* provides a tool for identifying and prioritising science curriculum content

Plan a curriculum improvement cycle

Effective curriculum improvement over time is often both planned and regular, and changes that are made need to be embedded into the working practices and resources of the department. There needs to be consideration, for example, of how improvements made to units of learning or to teaching strategies are communicated to and picked up by new staff joining the department.

In the UK, curriculum development often takes place during the summer term, in June and July, after exam classes have left and when teachers have more hours of non-contact time. The planning and follow-up work that is necessary can be spread out through the whole year.

The following six-step curriculum improvement cycle (Figure 2) describes one way of doing this that has been very successful for some science departments.

1 First, evaluate the curriculum and identify which part of the curriculum needs improvement. This might be determined by:
- a change of exam syllabus;
- a whole-school initiative;
- the analysis of exam results;
- a curriculum audit;
- science education research.

Although this evaluation will be ongoing throughout the year, it is important to draw together and consider all the evidence at one time, probably in preparation for writing the departmental improvement plan. If several areas are found to need improvement, these may need to be prioritised and planned over several years so that changes can be robust and manageable. A simple support tool in Appendix 2 of *Curriculum Evolution* provides support and guidance for completing an effective science curriculum audit.

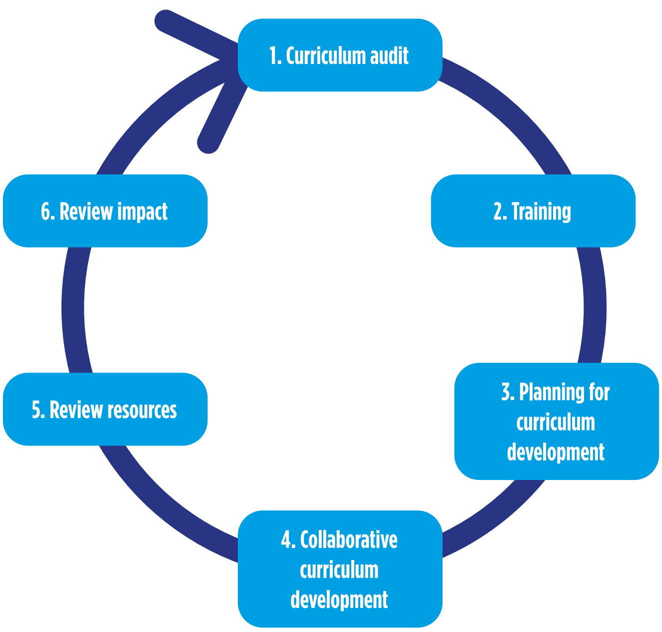

Figure 2 Model of an annual curriculum improvement cycle

2 Identify training that will help staff achieve the curriculum goals. This might involve attendance on external courses, or planned training in departmental meetings through the year. Teachers need opportunity to develop skills and understanding necessary to implement what is expected. This might be training in the school's literacy strategy, or information about common student misunderstandings written into topic plans.

3 Towards the summer term, curriculum leaders should ensure that teachers understand their roles in the planned development work and that they have access to useful reference sources and exemplar materials.

4 Collaborative development of resources is excellent CPD for teachers and it is almost always well worth the effort to ensure teachers have the time and space to work together on this. Resources developed in this way are more likely to be used and incorporated into teachers' practice.

5 Review curriculum materials developed to control for quality. A peer-review process shares out this work and allows teachers to learn from each other.

6 Review the impact of these changes during the next school year and start the process again. Measures that might be considered are:
- student attitude surveys, which can be compared from year to year;
- changes to the amount of disruption caused by students in science lessons;
- changes to effort grades teachers report to parents;
- changes to the quality of work seen in students' notebooks;
- changes in behaviour and engagement observed in science classes;
- changes to the enthusiasm of teachers towards the curriculum they are being asked to deliver.

Further support

Much of the content of this article comes from the ASE guidance document *Curriculum Evolution*, which contains further advice and support, as well as a set of useful curriculum audit tools.

References

Ofsted (2021) *Research Review Series: Science*. Ofsted. www.gov.uk/government/publications/research-review-series-science

ASE 11–19 Committee (2021) *Curriculum Evolution*. Hatfield: Association for Science Education. www.ase.org.uk/curriculum-evolution

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Practitioner case studies

Andrew Chandler-Grevatt, Chair of the ASE 11–19 Committee, introduces three practitioner case studies

Science teachers are often implementing new ideas based on research evidence and making 'internal' professional reflections on how they work for them and their students. These case studies capture those implementations and professional reflections.

These professionally reviewed case studies, written by practising teachers, are small scale, context-dependent and not generalisable. However, they do offer a starting point for readers to address a similar issue in their own practice. Below are some guiding questions for readers.

Professional reflections

- What have you learnt from reading the case study?
- Is this an issue you have in your own context?
- Is the change suggested adaptable to your context?

Critical reflections

- What are the strengths and limitations of this case study?
- How was the evidence base used?
- What else would you want to find out before following up this case study?

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Case study 1

Amber Heath explains how her science department moved from marking books to in-class feedback

The issue

As a subject leader, two recent pressing issues have been plugging gaps in student learning and mitigating against workload demands on my team. The obligation to diagnose gaps and address misconceptions, together with the need to unburden staff from the weight of curriculum 'catch-up', presented an opportunity to refocus our approach to marking.

We have departmental autonomy for feedback but school policy stipulates that marking should be regular with more enhanced feedback every six weeks, including SMART targets or questions for students to respond to in green pen. Our department's previous model included a range of approaches over a period of weeks, including questioning, self-marked quizzes, tests and fortnightly 'tick and flick' marking along with some deep teacher marking of selected pieces. The latter elements had little impact on learning but placed the greatest burden on teachers' time.

Using the DfE (2018) report on reducing workload recommendation that a teacher should only write in a student's book if it is going to affect progress, we refined our approach to replace detailed marking of books with whole-class feedback at specified points in the curriculum. Our approach was to design a model of whole-class feedback that applies the seven principles of good feedback practice proposed by Nicol and Macfarlane-Dick (2006). These aim to:

1. help clarify what good performance is;
2. facilitate the development of self-assessment in learning;
3. deliver high-quality information to students about their learning;
4. encourage teacher and peer dialogue around learning;
5. encourage positive motivational beliefs and self-esteem;
6. provide opportunities to close the gap between current and desired performance;
7. provide information to teachers that can be used to help shape the teaching.

Context

Our school is a maintained comprehensive secondary for students aged 11–18 and our current departmental priority is to improve students' recall and application of key concepts across all year groups. To achieve this, our focus has been on embedding retrieval practice into our schemes of work to ensure that fundamental scientific concepts were frequently recapped and assessed at relevant points in the curriculum.

Approach

We used whole-class feedback as part of our focus on retrieval practice and identified 'hinge-points' (Wiliam,

2015) in our curriculum plans to support this. We defined these as points in the learning sequence where fundamental understanding is required before moving on to more complex aspects in a topic. Wisniewski, Zierer and Hattie (2020) warn that the potential limitation of whole-class feedback is that it can reduce opportunities for differentiated instruction. So as part of our whole-class feedback we developed three feedback sheets with differing demands (knowledge, application, extension) (Figure 1).

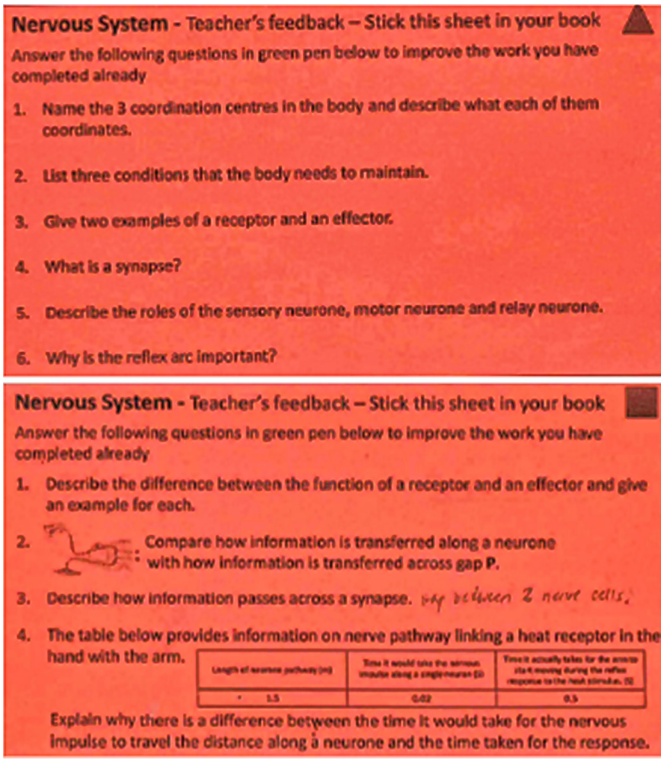
Whole-class feedback happens in a ‘reflection lesson’. This is described below, linking each part to Nicol and Macfarlane-Dick’s (2006) seven principles of good feedback.

Structure of a reflection lesson

Retrieval of basic knowledge and concepts (Figure 2): students self-assess these when the teacher reveals the answers using the ‘green pen’ school policy (principles 2 and 7).

Whole-class feedback: based on the teachers’ knowledge of the class in the current topic and the responses to the retrieval questions, the teacher addresses the gaps and misconceptions through modelling, explaining and questioning (principles 1 and 6).

Using feedback sheets: these are allocated based on the retrieval activity outcomes (Figure 2, *Dictation of teacher thought process*). Students are often put into focus groups to work together on the same feedback sheet (principle 6). As students complete these activities, some teachers circulate to do ‘live marking’. This involves verbal feedback, annotating work as it is completed (Figure 2, *Student response*, red pen) and addressing any issues that arise with a whole group or whole class (principles 3, 4, 5 and 7).


Nervous System - Teacher’s feedback – Stick this sheet in your book
Answer the following questions in green pen below to improve the work you have completed already
1. Name the 3 coordination centres in the body and describe what each of them coordinates.
2. List three conditions that the body needs to maintain.
3. Give two examples of a receptor and an effector.
4. What is a synapse?
5. Describe the roles of the sensory neurone, motor neurone and relay neurone.
6. Why is the reflex arc important?

Nervous System - Teacher’s feedback – Stick this sheet in your book
Answer the following questions in green pen below to improve the work you have completed already
1. Describe the difference between the function of a receptor and an effector and give an example for each.
2. Compare how information is transferred along a neurone with how information is transferred across gap P.
3. Describe how information passes across a synapse.
4. The table below provides information on nerve pathway linking a heat receptor in the hand with the arm.
Explain why there is a difference between the time it would take for the nervous impulse to travel the distance along a neurone and the time taken for the response.

Figure 1 Differentiated feedback sheets (application and extension)

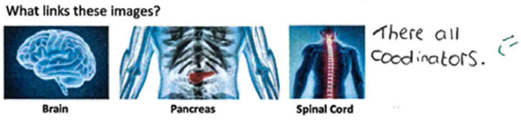
Results

A variety of marking strategies that teachers did outside lessons have been replaced with a combination of self-assessment and teacher-assessment in designated lessons. This has eliminated the time given to less useful marking practices and has moved marking to lesson time.

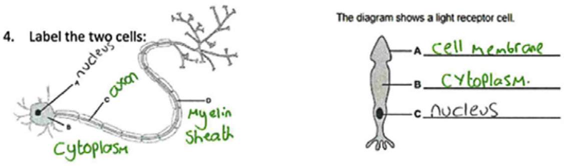
The production of the differentiated sheets does have an initial time implication, but once they are made they can be reused by all teachers and easily edited as

Initial assessment of basic concepts:

1. What is the control of conditions inside the body called?
Excretion ☐ Fertilisation ☐ Homeostasis ☑ Osmosis ☐
2. What links these images?



3. Complete the following sentence:
Automatic control systems may involve nervous responses or Chemical responses.
4. Label the two cells:



Dictation of teacher thought process:

“This student demonstrated that they were struggling to recall some of the fundamental principles of the topic so far in the initial retrieval task and struggled to give deeper explanations when questioned. After the re-teach they were given the apply feedback sheet to develop their ability to expand on their recall of essential knowledge.”

Student response to feedback task:

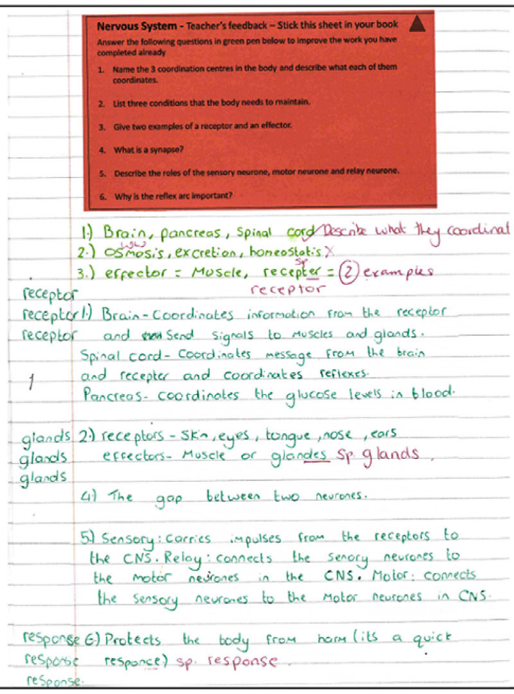


Figure 2 Aspects of a reflection lesson

required. The lesson preparation is no more than that for a normal lesson.

From a monitoring and evaluation perspective, the impact of this strategy has been greater consistency and more measurable feedback practices across the department. There is also more confidence in the structure of our reflection lesson as it is based on evidence such as Nicol and Macfarlane-Dick's (2006) seven principles of good feedback.

The structure and frequency of reflection lessons together with the differentiated feedback sheet enable students to see the gaps in their knowledge and what is required to improve. This can be seen by the example student response (Figure 2); most students respond positively to this type of lesson and make improvements.

Reflections and next steps

As a science leader, I can see that this approach has not only reduced workload, but has supported teachers in more focused assessment practices.

An unintended benefit of this model has been that it has enabled us to help students self-regulate, allowing them to know what they know and what they still need to know before moving on in their learning.

Not all teachers have yet embraced the 'live marking' aspect of the reflection lesson. The next step is to improve the use of our feedback tasks by combining them with the use of live marking in all reflection lessons. Some members of the department are working on this already (Figure 2).

References

DfE (2018) *Reducing school workload*. www.gov.uk/government/collections/reducing-school-workload

Nicol, D. and Macfarlane-Dick, D. (2006) Formative assessment and self-regulated learning: a model and seven principles of good feedback practice. *Studies in Higher Education*, **31**(2), 199–218.

Wiliam, D. (2015) Designing great hinge questions. *Educational Leadership*, **73**(1) 40–44.

Wisniewski, B., Zierer, K. and Hattie, J. (2020) The power of feedback revisited: a meta-analysis of educational feedback research. *Frontiers in Psychology*, **10**, 3087.

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Case study 2

George Filsell discusses the use of 'Exam Wrappers' to encourage metacognition and self-regulation in science

The issue

I found that my students often approach summative assessments without any sense of 'ownership'. The Education Endowment Foundation has produced a toolkit to support metacognition and self-regulation in the classroom (EEF, 2018). Muijs and Bokhove (2020) show that encouraging metacognition and self-regulation in the classroom is a low-cost, high-impact strategy that can increase progress by up to 7 months in secondary school students, with particular benefit to disadvantaged students. Based on these ideas, I have designed 'Exam Wrappers', which scaffold metacognitive thinking and foster self-regulation.

In science, we set regular summative tests on an approximate two-week cycle. I wanted to find a way to engage students with the revision and testing process to give them 'ownership' of these processes. I used the EEF report (Quigley, Mujis and Stringer, 2018) on *Metacognition and Self-Regulated Learning* and the report on this (Muijs and Bokhove, 2020) to scaffold these strategies in Exam Wrappers.

There is debate over the definitions of metacognition and self-regulation (e.g. Mannion, 2020), so for clarity in this case study, I am using the EEF (Quigley *et al.*, 2018) definitions. They say '*Self-regulation is about the extent to which learners … are aware of their strengths and weaknesses and the strategies they use to learn*' (p. 8) and define metacognition as '*the ways learners monitor and purposefully direct their learning*' (p. 9).

The EEF report (Quigley *et al.*, 2018) sets out seven recommendations. This case study focuses on how the Exam Wrappers support Recommendation 1 (Box 1).

Context

St Richard's Catholic College is a mixed-faith school in a coastal town in East Sussex. We teach a 2.5-year GCSE, starting in term 3 of year 9 (ages 13–14). We have one smaller 'nurture' group with a high proportion of students with special educational needs and disabilities (SEND) and low prior attainment per year. The other sets are mixed ability. This case study is focused on students in the 'nurture' groups of years 7 and 8 (ages 11–13).

During PSHE (personal, social and health education) lessons, key stage 3 students (ages 11–14) are taught study skills, and metacognition and self-regulation strategies are taught throughout secondary school. External providers run weekly small-group sessions for students who are disengaged with learning.

Box 1 Recommendation 1

Teachers should acquire the professional understanding and skills to develop their pupils' metacognitive knowledge:

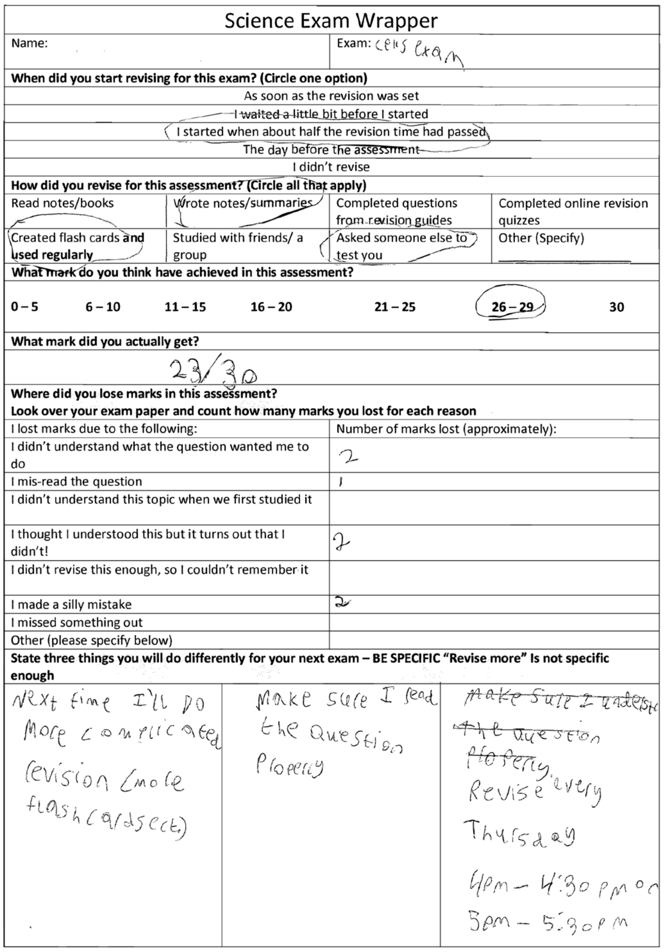
- Self-regulated learners are aware of their strengths and weaknesses, and can motivate themselves to engage in, and improve, their learning.
- Developing pupils' metacognitive knowledge of how they learn – their knowledge of themselves as a learner, of strategies, and of tasks – is an effective way of improving pupil outcomes.
- Teachers should support pupils to plan, monitor, and evaluate their learning.

(Quigley, Mujis and Stringer, 2018)

Approach

The Exam Wrappers are so called because they are used before and after a summative test is taken to scaffold metacognitive and self-regulation strategies. Immediately prior to an assessment, students answer a series of reflective questions on the revision process to aid self-regulation and metacognition after the test. I used multiple-choice options, with space to elaborate if required (Figure 1). After the assessment is marked, the pupils are presented with the next set of reflective questions to scaffold their metacognitive thinking and self-regulation.

I encourage students to reflect on the way they prepared for the assessment and attempt to diagnose where they lost marks. This is scaffolded by providing options for students to choose from (Figure 1) and explicitly teaching what each strategy looks like in the context of their assessment.


Science Exam Wrapper

Name: | Exam: cells exam

When did you start revising for this exam? (Circle one option)

As soon as the revision was set
I waited a little bit before I started
I started when about half the revision time had passed
The day before the assessment
I didn't revise

How did you revise for this assessment? (Circle all that apply)

Read notes/books	Wrote notes/summaries	Completed questions from revision guides	Completed online revision quizzes
Created flash cards and used regularly	Studied with friends/ a group	Asked someone else to test you	Other (Specify)

What mark do you think have achieved in this assessment?

0 – 5 | 6 – 10 | 11 – 15 | 16 – 20 | 21 – 25 | 26 – 29 | 30

What mark did you actually get?

23/30

Where did you lose marks in this assessment?
Look over your exam paper and count how many marks you lost for each reason

I lost marks due to the following:	Number of marks lost (approximately):
I didn't understand what the question wanted me to do	2
I mis-read the question	1
I didn't understand this topic when we first studied it	
I thought I understood this but it turns out that I didn't!	2
I didn't revise this enough, so I couldn't remember it	
I made a silly mistake	2
I missed something out	
Other (please specify below)	

State three things you will do differently for your next exam – BE SPECIFIC "Revise more" Is not specific enough

Next time I'll do more complicated revision (more flashcards ect)	Make sure I read the question properly	~~Make sure I understand the question properly~~ Revise every Thursday 4pm – 4:30pm or 5pm – 5:30pm

Figure 1 Example of a completed Exam Wrapper

The final question is an open-ended reflection on revision. Here, I encourage them to be as specific as possible about their next steps, for example: '*I will revise for 20 minutes, three times a week*'. These statements are used when the next revision cycle begins.

Findings

I have trialled Exam Wrappers with two key stage 3 nurture classes this academic year. Here, I present some of my findings based on those classes and using Figure 1 as a completed example.

Students' identification and use of metacognitive strategies seem to have improved, probably because the prompts support the metacognitive processes by asking the students to monitor and evaluate their learning in the first sections and then plan future strategies in the last section. For example, the student completing the Exam Wrapper in Figure 1 has circled how they revised for the coming exam and has written strategies to use next time.

Students now seem to be more able to write down what specific revision techniques they will use, as in the last section of Figure 1. Any general targets were challenged to encourage more specific responses. I observe that students are now more able to do this independently.

With respect to increasing confidence in their revision, there are two examples. Students' ability to reflect on the reasons for their lost marks has improved, with them now saying why they lost marks and linking this to a target for the next exam.

Reflections and next steps

I intended to use Exam Wrappers to improve the use of metacognitive and self-regulation strategies, based on the EEF Recommendation 1 (Box 1). In combination with whole-school strategies, the Exam Wrappers provide an application of these skills to a specific context – science (Muijs and Bokhove, 2020).

Students took time to get used to the Exam Wrappers; for example, when they were unsure how to complete them, I encouraged them to choose the option that was the 'best fit' for them. For the final question, I considered using multiple choice but decided against it as I wanted the students to learn how to articulate their revision strategies independently. Although they have needed support, I have seen a particular improvement in this 'plan, monitor, evaluate' approach.

An issue that remains is whether the improvement in completing the Exam Wrapper translates into students actually using the revision techniques, something I will continue to monitor. I will consider how Exam Wrappers can be applied to the remaining EEF recommendations and I am interested in learning more about self-regulation (e.g. Mannion, 2020).

In conclusion, EEF (2018) suggests that developing students' self-regulation is an effective way of improving student outcomes. The Exam Wrappers, for me, are proving a useful scaffold for learners to identify and apply different strategies for learning. The scaffold particularly supports the recommended plan, monitor, evaluate cycle. It is not possible to make generalisations about improved attainment, although I feel the changes that I have observed have given me confidence to continue to use and develop Exam Wrappers to develop students' self-regulation.

References

Education Endowment Foundation (2018) Metacognition and self-regulated learning toolkit. https://educationendowmentfoundation.org.uk/education-evidence/guidance-reports/metacognition

Mannion, J. (2020) Metacognition, self-regulation and self-regulated learning: what's the difference? *Impact*, 8,w6–69.

Muijs, D. and Bokhove, C. (2020) *Metacognition and Self-Regulation: Evidence Review*. London: Education Endowment Foundation. https://educationendowmentfoundation.org.uk/evidence-summaries/evidence-reviews/metacognition-and-self-regulation-review

Quigley, A., Mujis, D. and Stringer, E. (2018) *Metacognition and Self-Regulated Learning: Guidance Report*. London: Education Endowment Foundation. https://educationendowmentfoundation.org.uk/education-evidence/guidance-reports/metacognition

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Case study 3

Philippa Veal discusses the use of word maps to improve understanding of key terminology

The issue

Some of my students, whose literacy scores were lower than average, were struggling to communicate ideas that required the use of key vocabulary. It appeared they were trying to use these key terms, but often got them mixed up, misspelt them or were unable to recall them. Such struggles have been known for a while in science (Wellington and Osborne, 2001). More recently, the Education Endowment Foundation's report on improving literacy in secondary schools (Quigley and Coleman, 2018) has made seven recommendations. For this study, I focus on Recommendation 2 (Box 1).

Tier 2 vocabulary refers to words that are not used in everyday conversation but are often written to contextualise a piece; tier 3 words are those that are very rare or are specific to one area, such as science (Beck, McKeown and Kucan, 2008). It was these subject-specific words that I found my students struggling with most.

In science, Markwick (2020) recommends teaching students how to deconstruct and reconstruct words by identifying prefixes and suffixes of Greek or Latin origin. He found this improved students' ability to discern the meaning of key vocabulary in examination questions. This persuaded me to include time for students to deduce the etymology and history of the vocabulary used in lessons. I applied these ideas to support my year 10 (ages 14–15) students and decided to develop a scaffold to help target these tier 3 words directly.

Box 1 Recommendation 2

Provide targeted vocabulary instruction in every subject:

- Teachers in every subject should provide explicit vocabulary instruction to help students access and use academic language.
- Effective approaches, including those related to etymology and morphology, will help students remember new words and make connections between words.
- Teachers should prioritise teaching tier 2 and 3 vocabulary, which students are unlikely to encounter in everyday speech.
- Teachers and subject leaders should consider which words and phrases to teach as part of curriculum planning.

(Quigley, A. and Coleman, R., 2018)

Context

Seaford Head School is a mixed academy found along the East Sussex coast half an hour from the popular city of Brighton. Seaford Head teaches key stage 3 (ages 11–13) and key stage 4 (ages 13–16) and is annexed with Seaford Head Sixth Form (16+). We use OCR 21st Century Science exam board for GCSE in ability sets; at key stage 3 we teach mixed-ability classes.

Approach

Based on existing templates, I designed a 'word map' that would fit into A5 exercise books. This could be modified to be drawn directly into exercise books by dividing a page into quarters and writing the subtitles (Figure 1).

With support, the word map allows students to bring together their knowledge on key vocabulary using the four sections:

- textbook definition;
- word break down (etymology, synonyms/antonyms and any alternative meanings);
- a drawing;
- using the word in a sentence.

This structure is to help the learner identify any historical origins, develop deeper understanding of the word and be able to identify where these aspects are used within the definition. The drawing is to encourage students to be creative to help them memorise the definition; it does not have to be scientifically accurate. For students who are apprehensive to start the task, I provide sentence starters or model an example.

Findings

I have made three observations from using the word maps. Figure 1 shows a completed example.

Students appear more confident to use terminology both verbally and in written form; for example, my lower-attaining year 10 students often struggled using the key phrase '*sea of delocalised electrons*'. In a revision lesson, I overheard a student using this phrase while creating revision resources. When reviewing their written work, many of them were able to use the phrase in the correct context. When quizzed three months later, the same students were still able to recall the phrase and use it correctly in the new scenario.

The drawing allowed them to imagine the word. They became more imaginative in their drawings and were confident to move away from models they were shown. Students with lower literacy were interpreting the vocabulary more expansively through drawing.

At the moment, the classes have yet to sit their mock exams. However, based on the students' increased confidence and engagement with vocabulary and its use, I am hopeful that this method may improve attainment.

Reflections and next steps

The purpose of this case study is to illustrate how word maps can be used to increase student confidence with using science terminology, particularly tier 3 words. Applying the EEF recommendations (Quigley and Coleman, 2018) and considering the specific issues in science (Markwick, 2020), I was able to construct and use the word maps with my classes to implement the recommendations.

I found that a common barrier was using new terminology because I was introducing all the terminology at the beginning of the topic. This made it difficult for students to link to any prior knowledge. In future I would allocate time for key vocabulary throughout the topic.

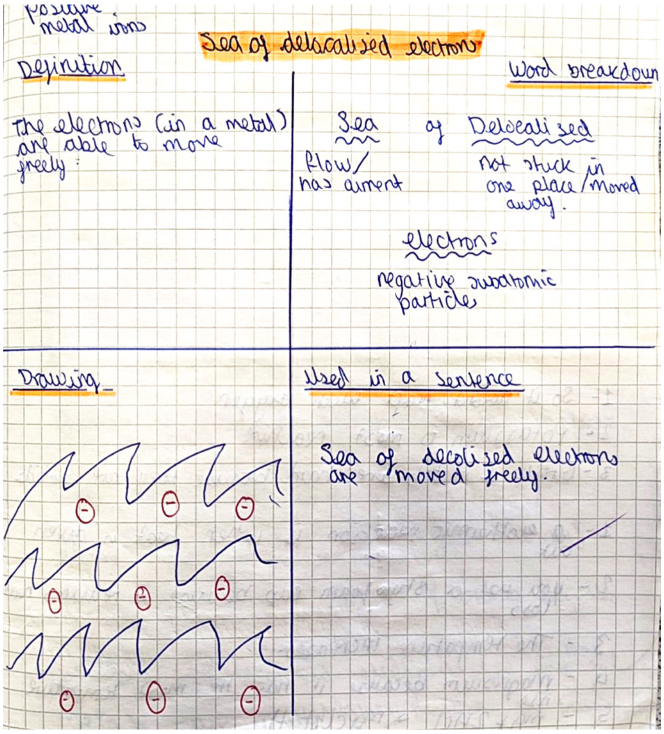

Figure 1 A student's completed word map

I was concerned that this approach may introduce misconceptions, for example, allowing students to draw freely rather than copy a diagram may cause confusion. So, I told the students that this section of the word map is not scientifically accurate and is for memory rather than knowledge.

I have shared this approach with my science colleagues as this technique has the potential to be used with a variety of groups. My next steps are to use the word map for a wider range of vocabulary that students struggle with, including some tier 2 words. I hope to provide more time and resources for the students to find the origins of these words independently, including a list of common prefixes and suffixes.

References

Beck, I. L., McKeown, M. G. and Kucan, L. (2008) *Creating Robust Vocabulary: Frequently Asked Questions and Extended Examples*. New York: Guilford Press.

Markwick, A. (2020) Deconstructing scientific vocabulary for low-literacy students: an action research study. *School Science Review*, **101**(377), 81–85.

Quigley, A. and Coleman, R. (2018) *Improving Literacy in Secondary Schools*. London: Education Endowment Foundation. https://educationendowmentfoundation.org.uk/education-evidence/guidance-reports/literacy-ks3-ks4

Wellington, J. and Osborne, J. (2001) *Language and Literacy In Science Education*. Buckingham: Open University Press.

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Rates of reaction and rhubarb

Jane Oldham shows how the decolourisation of acidified potassium manganate(VII) solution by the ethanedioic (oxalic) acid found in rhubarb may be used to support understanding of the effect of surface area on rate of reaction

Equipment list per group

Eye protection; 3 × 100 cm^3 beakers; 1 × 50 cm^3 measuring cylinder; 1 × timer; stirring rod; white tile or sheet of paper; 1 × sieve; 3 × 4 cm pieces of prepared rhubarb stalk – 1 × whole, 1 cut in two equal pieces, 1 cut in four equal pieces; 100 cm^3 acidified potassium manganate(VII) solution of about 0.0003 mol dm^{-3} [WARNING: irritating to eyes and skin]

Method

You may need to adapt the guidance here for local circumstances, ensuring you comply with your employer's model risk assessments and policies.

1. Wear eye protection throughout the practical and when clearing up.
2. Using the measuring cylinder, measure 30 cm^3 of acidified potassium manganate(VII) solution [WARNING: irritating to eyes and skin] into two of the beakers and 30 cm^3 of water into the third beaker.
3. Place the beakers on the white tile or paper (Figure 1).
4. Put the rhubarb [WARNING: contains ethanedioic acid, which is harmful if swallowed and to skin and eyes] into one of the beakers that contains potassium manganate solution and start the timer.
5. Gently swirl or stir until the solution is colourless and then stop the timer – use the two other beakers to check the colour loss and endpoint of the reaction (it can be difficult to discern when the solution is colourless so use the water to compare).
6. Dispose of the solutions in the sink/waste container, using a sieve to collect the rhubarb pieces. Rinse the beaker.
7. Repeat with the second rhubarb piece cut into two.
8. Repeat again with the third piece of rhubarb cut into four.

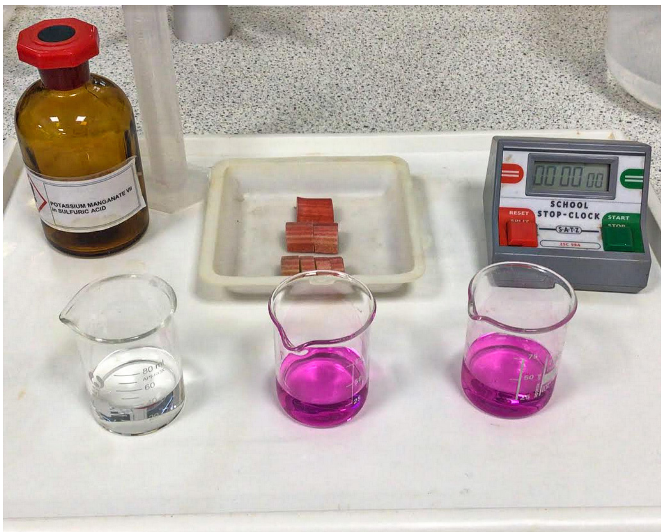

Figure 1 The experiment set-up

Sample results

Rhubarb pieces	1 × 4 cm	2 × 2 cm	4 × 1 cm
Time to decolour (s)	132.0	70.6	32.5

Technician tips

Preparing the rhubarb

The rhubarb [WARNING: contains ethanedioic acid, which is harmful if swallowed and to skin and eyes] can be fresh or frozen and defrosted. Tinned rhubarb (drained before use) can also be used depending on the size of the pieces.

- For a typical class experiment you will need approximately 8 sticks of rhubarb.
- For fresh rhubarb, make sure all traces of leaves have been removed.
- For fresh and frozen rhubarb, try to ensure that the 3 × rhubarb lengths per group are the same thickness and aim to cut into equal lengths.
- If using frozen rhubarb, it's best to either pre-cut and freeze, or cut while still partially frozen.
- The outer layer of rhubarb can be stripped if preferred, but this is not essential.
- If using tinned rhubarb (juice or syrup), sieve and dispose of the liquid. Select similar size pieces and trim so that they are as close in size as possible.

Making the acidified potassium manganate(VII) solution

- Add a few crystals or the tip of a spatula of potassium manganate(VII) into a beaker with about 800–1000 cm^3 of 1 mol dm^{-3} sulfuric acid [WARNING: irritating to eyes and skin].
- Stir until dissolved.

- The exact concentration of solution is not critical – you are aiming for a light purple-pink solution of about 0.0003 mol dm^{-3}.
- Store in brown glass bench bottles or equivalent.
- Label this solution 'Acidified potassium manganate(VII) solution (irritating to eyes and skin)'.

Concentration of acidified potassium manganate(VII)

The acid content of the rhubarb varies so you must trial before each use and adjust the concentration of the acidified potassium manganate(VII) to give a reasonable reaction time by adding more sulfuric acid or potassium manganate(VII) as required.

Going further

Rhubarb 'juice'/extract can be used to study the effect of concentration on rate of reaction to decolourise potassium manganate(VII).

Preparation of the rhubarb juice/extract

- Cut a rhubarb stalk into thin slices and place in a 500 cm^3 beaker.
- Cover with distilled water and boil until the stalk breaks down (about 5 mins).
- Allow to cool and then filter the mixture using muslin or a strainer, retaining the filtrate.
- Dispense 15 cm^3 of this extract to each group/pair.

Figure 2 The colour of acidified potassium manganate(VII) solution

Students then add 1 cm^3, 2 cm^3, 3 cm^3, 4 cm^3 of the filtrate to 30 cm^3 acidified potassium manganate(VII) solution in a 100 cm^3 beaker and measure the time for the solution to decolourise.

Teaching ideas

This experiment is a superb way of quantifying surface area in the rates of reaction topic. Other alternatives such as marble chips and acid give a rather vague definition of surface area, for example 'large marble chips' and 'medium marble chips'. It can be quite difficult for students to conceptualise that smaller marble chips have a larger surface area as they often visualise just the one chip rather than a fixed mass of chips. In this experiment it is possible for students to see the generation of the new surfaces for the reaction and therefore gain a concrete appreciation of the concepts involved.

There is the opportunity for strengthening students' maths skills. For example, how would they estimate the surface area of the peeled rhubarb pieces? (Rolling them on a piece of graph paper and drawing around the area worked in my class.) What units would be appropriate for these values? Can they plot a graph of measured surface area against time to decolourise?

Acknowledgement

The author would like to thank Dr Kristy Turner, School Teacher Fellow, Department of Chemistry, University of Manchester, and Bolton School Boys' Division, for contributing the teaching ideas to this article.

Useful links

https://edu.rsc.org/download?ac=15063
https://edu.rsc.org/experiments/rate-of-reaction-of-potassium-manganatevii-and-oxalic-acid/745.article
www.sserc.org.uk/subject-areas/chemistry/chemistry-resources/rhubarb-rhubarb

ASE member exclusive content

Go to https://vimeo.com/717853276/a67dce999a to view an extract of Jane's ASE Annual Conference session 'From glowsticks to rhubarb'.

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Determining the empirical formula of magnesium oxide – a microscale method

David Paterson describes a microscale method using bottle-top crucibles

Combustion of magnesium is commonly carried out in porcelain crucibles and requires regularly lifting the lid to ensure complete oxidation. This method suffers from cracked crucibles and loss of magnesium oxide as 'smoke' when the lid is lifted.

The method described here is inspired by the CLEAPSS Practical Procedure PP063 Finding the formula of magnesium oxide. The method uses bottle-top crucibles, which are more robust, and provide an air gap that allows effective flow of air to the magnesium during heating.

Data produced from the experiment allows students to experimentally determine the empirical formula of magnesium oxide and appreciate the challenges of high-quality data collection and analysis.

Method

Integrated instructions for the practical are shown in Figure 1. You may need to adapt the guidance here for local circumstances, ensuring you comply with your employer's model risk assessments and policies. Wear eye protection and ensure the laboratory is well ventilated.

1. Coil a 10 cm piece of magnesium around a pen, pencil or glass rod.
2. Weigh and note the mass (m_1) of two bottle tops and a 15 cm piece of nichrome wire.
3. Place the coiled magnesium between two bottle tops and secure the bottle tops together with nichrome wire to produce the 'package'.
4. Weigh the assembled 'package' (m_2).
5. Support the 'package' on a pipe-clay triangle and heat with a roaring blue Bunsen flame for about 10 minutes. Do not look directly at the combusting magnesium.
6. Allow the 'package' to cool for 4–5 minutes. Ensure the heated apparatus is cooled before you weigh it.
7. Reweigh the 'package' (m_3).
8. Calculate the mass of magnesium ($m_2 - m_1$).
9. Calculate the mass of oxygen in the magnesium oxide ($m_3 - m_2$).
10. Determine the empirical formula of magnesium oxide from the data in steps 7 and 8.

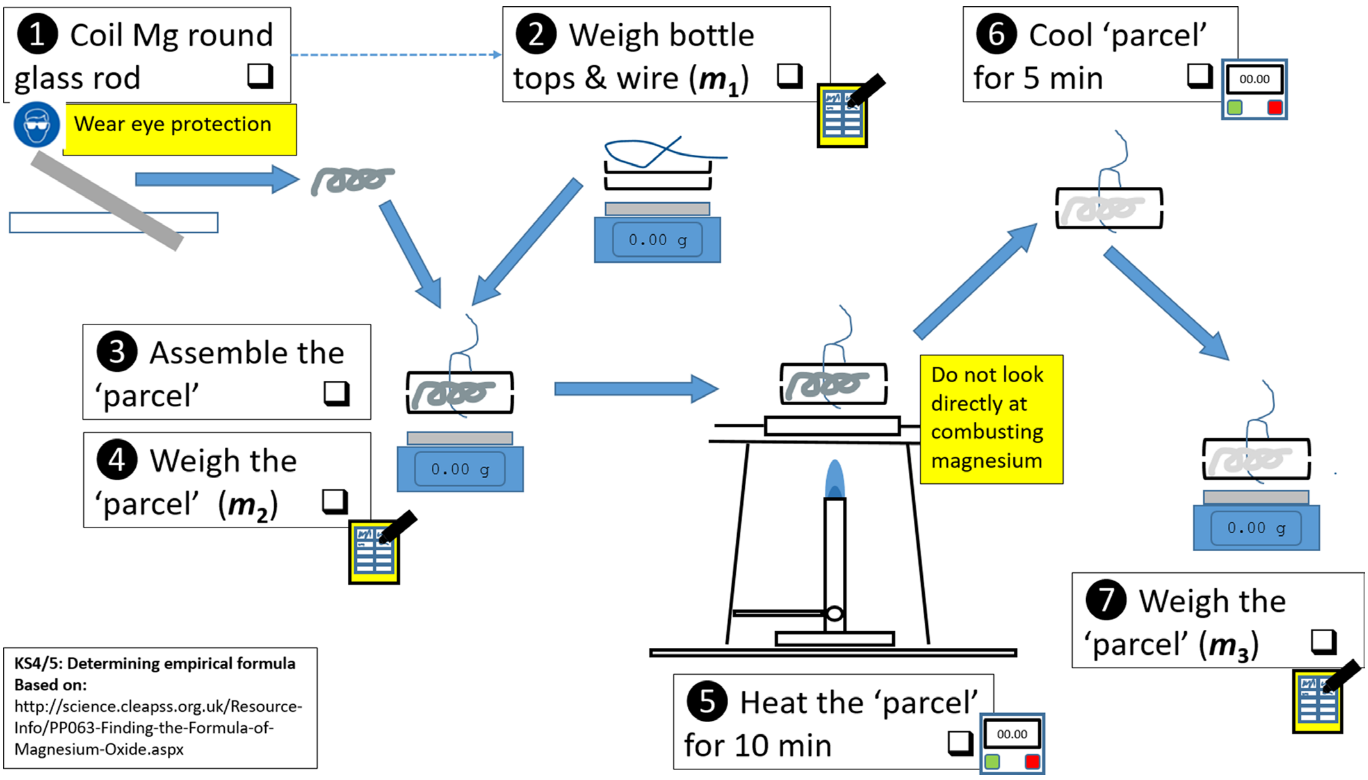


Figure 1 Integrated instructions

Teacher tips

- Students may find assembling the bottle-top crucible quite fiddly. Demonstrate to them how to wrap the nichrome wire around the bottle tops and then tighten using pliers.
- Combusting magnesium can release very bright white light. Warn students against looking directly at the magnesium when it is being heated.

Technician tips

- The pipe-clay triangle needs to support the bottle-top crucible: one of the pipes may need to be broken to make the opening smaller.
- The bottle tops must have any plastic insert removed. This is most easily achieved by burning it out by holding the bottle top with tongs in a roaring Bunsen flame in a fume cupboard.

Going further

Using the method discussed here, individual students can calculate the empirical formula of their magnesium oxide. If the magnesium was fully oxidised, they should calculate the expected empirical formula of MgO.

A good alternative that allows the class to collect and compare their data is to plot their results on a pre-drawn graph (Figure 2).

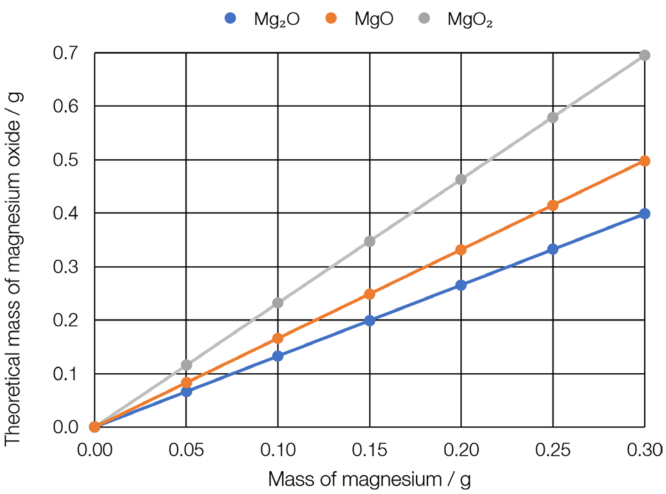


Figure 2 Graph for student results

For this alternative, give each practical group different initial masses of magnesium. This graph shows the theoretical mass of magnesium oxide formed ($m_3 - m_1$) for magnesium oxide with three different formulae, Mg_2O, MgO and MgO_2. Assuming accurate practical technique and measurement, the students will see the class data points scattered around the MgO line. This will give them an authentic demonstration of the importance of collecting large quantities of data from which valid conclusions can then be drawn. For the students saying '*but we know the formula is MgO because magnesium forms Mg^{2+} ions and oxygen forms O^{2-} ions*', remind them that the early chemists didn't know this when they were first investigating empirical formulae. Indeed, the very existence of atoms as physical objects was still a contested idea.

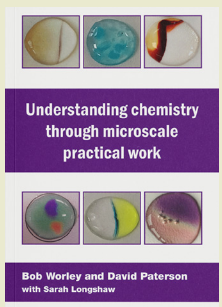
As an interesting context on the necessity for large amounts of data, highlight the difficulty of detecting new subatomic particles, and the enormous effort required. For example, to produce just one Higgs boson, the particle that confers mass on other particles, around one trillion proton–proton collisions have the be carried out (https://home.web.cern.ch/news/news/physics/new-results-indicate-new-particle-higgs-boson).

Teaching ideas

This experiment fits well into the study of quantitative chemistry, both in 14–16 and post-16 courses. Most specifications will require calculation of empirical formulae from given data. Providing students with an opportunity to collect their own data opens up discussion points on the quality of experimental data and the importance of repetition to exclude experimental error and minimise uncertainties.

This method is a form of microscale chemistry, developed to minimise hazards through use of smaller quantities of substances, use of simplified equipment to reduce the cognitive burden on students, and to allow faster data collection, allowing more time for analysis and evaluation.

An introductory text on *Understanding chemistry through microscale practical work* has been published by Bob Worley and David Paterson by ASE/ Millgate House. It is available from the Millgate House website (www.millgatehouse.co.uk) with a discount available to ASE members.



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How to build a rate of reaction experiment into a teaching sequence

Sarah Longshaw suggests how a well-known core practical can be constructively integrated into a teaching sequence

The rate of reaction between marble chips and hydrochloric acid is, for some awarding bodies in England, a core (or required) practical at GCSE level (ages 14–16), but how do you build this well-known experiment into a teaching sequence? What prior knowledge do students need and what practical experiences help to best prepare students for this experiment?

Box 1 Core practicals

GCSE students need to be able to suggest practical methods for determining the rate of a reaction and are required to learn about the factors that affect the rate of a reaction. For rate of reaction, the specific guidance for the apparatus and techniques to be covered requires the '*Making and recording of appropriate observations during chemical reactions including changes in temperature and the measurement of rates of reaction by a variety of methods such as production of gas and colour change*' (DfE, 2015: 41). The core practicals (activities that enable students to cover the use of a range of apparatus and techniques specified) are broadly similar across the awarding bodies as they are closely linked to specific chemistry content in the specification.

Prior knowledge and skills

Before starting the practical students need to be able to:

- recall the signs of a chemical reaction including formation of a gaseous product;
- use the apparatus appropriately including accurate measurement of a gas in an inverted measuring cylinder.

Students should be familiar with content from the specification that relates to this practical and should be able to:

- describe the effect of different factors on rates of reaction;
- explain rate of reaction in terms of collision theory and the effects of the different factors on the change in frequency of these collisions.

Teaching sequence

Signs of a chemical reaction and formation of a gaseous product

Although it is important that students have experience of carrying out the full core practical, it may be beneficial to start with a very simple introductory experiment to remind them of the signs of a chemical reaction and to check for any misconceptions.

Adding a small piece of magnesium ribbon [DANGER: flammable solid; take steps to prevent theft; reels of magnesium ribbon should not be left out in the laboratory; use pre-cut lengths] to a test tube of dilute hydrochloric acid (less than 0.5 mol dm^{-3}) provides a quick and easy demonstration. The magnesium metal disappears as it reacts with the acid and soluble magnesium chloride is formed. Another product, a gas (hydrogen) is given off (as seen by the bubbles).

While colour change and temperature change are commonly referred to signs of a chemical reaction, in this example it is the formation of a gaseous product that enables the measuring of rate of reaction.

The effect of different factors on rates of reaction

Students could carry out some simple practicals to stimulate their thinking and investigate qualitatively how different factors affect rate of reaction.

Fizzy vitamin C tablets can be used to investigate the effect of surface area. Breaking the tablets into pieces or crushing them helps students to understand the concept of surface area. Adding the pieces to water enables students to qualitatively observe the effect of increasing the surface area.

Fizzy vitamin C tablets can also be used to investigate the effect of changing the temperature of the water. The height of the foam (Figure 1) can be used as a simple way of comparing the difference in rate of reaction. It can also be used to encourage discussion with students about the difference between qualitative (observational judgement) and quantitative methods (measurement of the volume of gas produced).

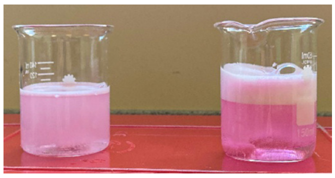

Figure 1 Comparing the height of foam produced by vitamin C tablets in cold and hot water

Practical skills

Prior to carrying out the core practical you could demonstrate the core practical reaction (of marble chips with dilute hydrochloric acid) and provide the word and chemical equations:

hydrochloric acid + calcium carbonate →
calcium chloride + carbon dioxide + water

$$2HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

Box 2 Gatsby benchmarks

Developed under the guidance of former ASE President Professor Sir John Holman, on behalf of the Gatsby foundation (a firm advocate of the importance of practical science in schools and colleges), the Gatsby benchmarks are a series of recommendations that provide a framework for good practical science in schools (Holman, 2016).

The approach described here would meet the following Gatsby benchmarks:

- **Benchmark 1**: Planned practical science. This is one of the core GCSE practicals. It allows students access to the specific apparatus and techniques required to fulfil the GCSE curriculum.
- **Benchmark 2**: Purposeful practical science. Consideration of the prior learning needed and how to sequence the activities will help to develop student understanding.
- **Benchmark 4**: Frequent and varied practical science. The integration of additional short introductory practical activities will increase the amount of practical experience to which students are exposed. This should allow students to become confident in using the equipment and enable them to focus on understanding about rates of reaction.

Students could be encouraged to describe their experimental observations and link these to the reactants and products in the equation.

The marble chips (a white solid) react with the acid (colourless solution) to give off carbon dioxide (a colourless gas). The carbon dioxide is therefore observed as bubbles and can be collected either by the displacement of water (as shown in Figure 2) or in a gas syringe.

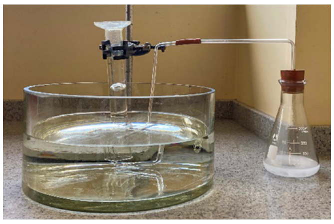

Figure 2 The experiment in progress; note that a glass trough has been used in the photograph so that the equipment can be seen more clearly

The method of collecting gas by displacement of water can be challenging for students, who may have difficulties in reading at the correct time or reading the volume on the upside-down measuring cylinder. Ideally students should have the opportunity to practise these skills before attempting the full experiment. If students are still finding this difficult you may wish to consider providing them with a set of results from which to draw the graph. This means that students can progress with this even if there have been problems with their experiment.

Graphing drawing and interpretation

Students could be asked to annotate their graph. This may help them to understand what is happening in terms of the reaction, for example where the reaction is quickest (at the start) and where it slows down and stops.

It is worth ensuring that when students plot several sets of results for the different sizes of marble chips on one graph, they can recognise that the graphs all become level at the same volume because the same maximum volume of product is formed in all cases.

Box 3 Example method for marble chips and hydrochloric acid experiment

You may need to adapt the guidance here for local circumstances, ensuring you comply with your employer's model risk assessments and policies.

1. Wear eye protection throughout the practical and when clearing up.
2. Assemble the equipment required and fill a plastic washing-up bowl, or similar, with water. Make sure that all adjustments for height have been made before any reagents are added.
3. Clamp the filled, upturned measuring cylinder in place, with space left below to insert the delivery tube.
4. Place about 1 g of large marble chips into the conical flask and measure the 0.5 mol dm^{-3} dilute hydrochloric acid into a measuring cylinder.
5. Add the dilute hydrochloric acid to the conical flask, secure the bung in place and position the delivery tube into the upturned measuring cylinder.
6. Start the stopwatch and record the volume of gas at regular intervals.
7. Repeat using medium and then small marble chips as suggested in Edexcel's core practical guidance (Edexcel, 2016).

Further practical ideas

Students will also need to understand the effect of concentration on rates of reaction so a similar experiment could be carried out in which the volume of carbon dioxide is measured at 10 second intervals for two different concentrations of hydrochloric acid (1 mol dm^{-3} and 2 mol dm^{-3}) [H&S: Although technically not classed as hazardous, eye protection should still be worn]. It is interesting to discuss with students why the lines on this graph do not end up at the same volume.

References

Department for Education (2015) *Combined Science: GCSE Subject Content*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/800339/Combined_science_GCSE_updated_May_2019.pdf

Holman, J. (2016) *Good Practical Science*. Gatsby. www.gatsby.org.uk/education/programmes/support-for-practical-science-in-schools

Edexcel (2016) *Sciences Core Practical Guide: GCSE (9–1)*. https://qualifications.pearson.com/content/dam/pdf/GCSE/Science/2016/teaching-and-learning-materials/GCSE-9-1-Sciences-core-practical-guide.pdf

Useful links

RSC *Rate of reaction of potassium manganate(VII) and oxalic acid*: https://edu.rsc.org/experiments/rate-of-reaction-of-potassium-manganatevii-and-oxalic-acid/745.article

RSC *Interpreting rate of reaction graphs*: https://edu.rsc.org/lesson-plans/interpreting-rate-of-reaction-graphs-14-16-years/95.article

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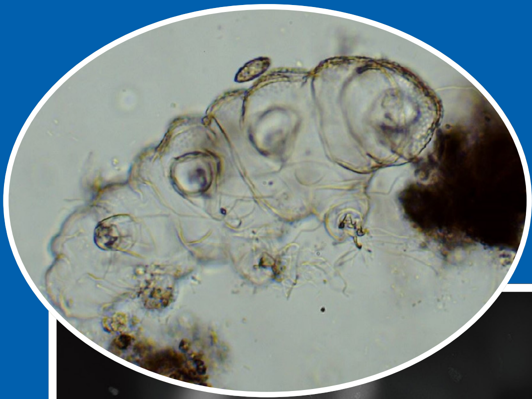
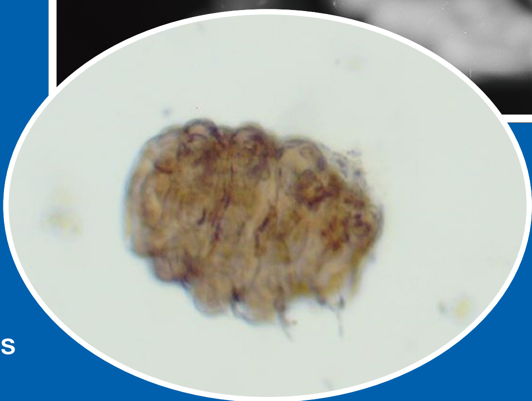
Find a ta

Tardigrades (water bears) are microscopic organisms that live in freshwater and marine environments including soils, mosses and lichens.

They have eight legs, usually with claws, two eyes made of single cells, and a ‘snout’ for a mouth to feed with.

Tardigrades can go into a ‘tun’ state when dehydrating or in low oxygen. In this state they can survive extreme conditions, including trips into space.

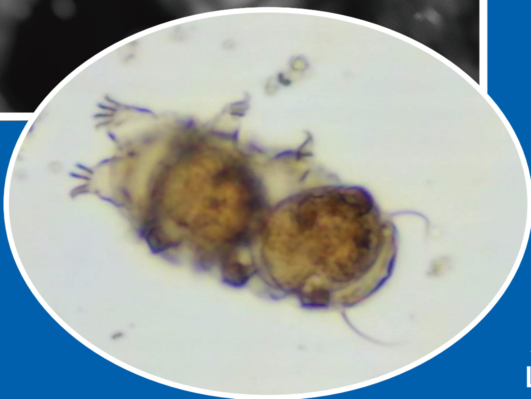




The central image is a 3D
tardigrade. The four small ima
microscope at ×100 by Andre
(clockwise from top left): shed
tardigrade, eggs inside b

Learn more about finding tardigrades and other microscopic organisms at https://mosssafari.wordpress.com
Follow on Twitter @MossSafari

rdigrade



rendered illustration of a
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skin (exuvate), an 'amoured'
body, and the tun state.

Tardigrade hunting

Find your own tardigrades in your school grounds. Soak some moss or lichen in water for 24 hours.

Squeeze out the water from the sample and look at a couple of drops under the microscope at ×40 and above.

Observe tardigrades walking, feeding, 'sleeping' and reproducing; you can sometimes see their eggs.

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Geophysics – a well-kept secret

Caroline Neuberg collaborates with geophysicists from the University of Leeds to raise awareness of geophysics as a career path among initial teacher trainees

Geophysics is a STEM career choice ranked in fifth position on the shortage occupations list by the UK Government (2022) and seems to be little known even among experienced science teachers. So, what is geophysics? What does a geophysicist do? And why should you highlight this STEM career choice to your students?

Geophysics is the application of physics to the study and understanding of the Earth. Data collected both at the Earth's surface and from space and the application of fundamental physical principles allow geophysicists to not only study the geodynamics of Earth, such as volcanism and earthquakes, but also monitor subsidence and climate change and enable exploration of everything from hydrocarbons in the crust to the structure of the Earth's deep interior.

Geophysics has long been associated with the extraction of oil and other resources from the ground, but this has changed over recent decades. The capture and sequestration of carbon dioxide to combat climate change requires the expertise of geophysicists, as does the installation of offshore wind turbines. Monitoring of volcanic activity, stress distribution in the Earth's crust and related earthquakes, glacier melts and climate change, using satellites or ground-based data, are all carried out by geophysicists. Other geophysical methods include ground-penetrating radar that is used in a wide range of applications, such as identifying disturbed ground in forensics, detecting hidden structures in archaeology and finding underground tunnels dug by meerkats!

Geophysics in the curriculum

All geophysical methods rely on principles taught in the physics curriculum, mainly at key stage 4 (ages 14–16) and above. For example, reflections and refractions of waves form the basics of seismic and ground-penetrating radar methods. The difference in arrival time between the primary and secondary wave generated by an earthquake allows for the epicentre of an earthquake to be determined, provided data from at least three seismic stations are available and the triangulation method is applied. The different absorption and reflection of the ground-penetrating radar waves, comparable to the difference of absorption of X-rays by different human tissues taught at key stage 4, generates a clear picture of the underlying structure of the ground.

The Earth's magnetic field is often mentioned in the curriculum both at key stage 3 (ages 11–14) and key stage 4, but the drift of the Earth's magnetic field and other changing aspects (such as the shift of the magnetic poles and the development of a magnetic low over Brazil) are rarely described. Students using maps during their Duke of Edinburgh's Award expedition need to correct for the declination, the ever-changing angle between the geographic and magnetic North Poles. The space industry is acutely aware of the development of the magnetic low over Brazil, as the lack of protection from the magnetosphere affects the sensitive electronics on satellites. The study of the deep Earth and its outer core where the magnetic field is generated is an essential part of geophysics.

Geophysics teacher awareness

Geophysical research teams in the UK are often associated with 'earth and environment' and not with physics departments, which may explain why this area of physics is little known to physics teachers. The geophysics programme at the University of Leeds (University of Leeds, n.d.) has started to run continuing professional development (CPD) events for science teachers to promote geophysics (Figure 1).

Figure 1 University of Leeds geophysicists demonstrate ground-penetrating radar to trainee teachers from Leeds Trinity University

A recurring statement by participants during these days is '*I wished I had heard about geophysics before, not just for my students but also for myself*'. Unlike physics, geophysics can have a strong outdoor component and offers travel opportunities, which may appeal to many students. Did we mention the average salary for a geophysicist? It is comparable to that of health managers (UK Government, 2022) or experienced nuclear engineers (Prospect, n.d.), and higher than architects on average (Unionlearn, n.d.). Geophysics careers seem to be a well-kept secret but one that needs sharing.

References

Prospect (n.d.) Nuclear engineer. www.prospects.ac.uk/job-profiles/nuclear-engineer

UK Government (2022) *Skilled worker visa: shortage occupations*. www.gov.uk/government/publications/skilled-worker-visa-shortage-occupations/skilled-worker-visa-shortage-occupations

Unionlearn (n.d.) Compare average pay by job. www.unionlearn.org.uk/compare-average-pay-job

University of Leeds (n.d.) Workshops and taster sessions. www.stem.leeds.ac.uk/earthsciences/workshops

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Sequencing life on Earth

Francesca Gale discusses how genome sequencing has transformed health care and now, as technologies become faster and cheaper, how it is revolutionising the field of biodiversity conservation

The world is said to be in the midst of a sixth mass extinction event and unless action is taken, Earth is forecast to lose 50% of its biodiversity by the end of this century. However, scientists across the world are joining forces to use genome sequencing to help protect Earth's fragile ecosystems. The Earth BioGenome Project (www.earthbiogenome.org), described as a 'moonshot' for biology, aims to sequence, catalogue and describe the genomes of all of Earth's eukaryotic (organisms comprising a cell or cells with a distinct nucleus) biodiversity. This global endeavour is pooling the efforts of large sequencing projects such as the Darwin Tree of Life project (www.darwintreeoflife.org). Led by the Wellcome Sanger Institute and ten other UK partners, this ambitious 10-year project aims to sequence all eukaryote species found in the UK and Ireland. That is about 70 000 species or, to break it down further, 41 600 animal species, 8000 plants, 18 500 fungi, and 4300 single-celled protists (Darwin Tree of Life, 2022).

Every living thing has a genome, a complete set of genetic instructions. To sequence a genome, we must extract DNA from the organism (not as easy as you think with some species) and prepare it for sequencing. The sequencing data are then assembled by algorithms into a complete genome sequence and annotated (Figure 1). This means all the genes and coding areas have been identified so you can start to work out what they do. All the data produced by the Darwin Tree of Life project is fully open access, meaning it is freely available to anyone who wishes to use it. All published genome notes can be found at www.darwintreeoflife.org/genomes/genome-notes. Some of the first fully annotated genomes produced were for Lepidoptera – butterflies and moths – and Hymenoptera – bees, wasps and ants. This was a priority as furthering understanding of Hymenoptera genomes could help in the fight to prevent the devastating global decline of wild bee species.

Applications of genome sequencing

The rapidly growing digital library of reference genome sequences can be applied in a number of different ways.

One powerful example is the field of metagenomics, where DNA from entire communities or ecosystems can be sequenced to understand what species are living there and how they are interacting. Environmental DNA (eDNA) samples, water, soil or even air, are collected and sequenced. The DNA sequence data of the samples are compared with genome data sets, enabling researchers to build a picture of that community, aiding conservation efforts by identifying biodiversity hotspots, and the presence of rare or endangered species.

DNA barcoding is another application. Like packaging on everyday items in a supermarket, all living things have a barcode. Instead of a unique sequence of numbers, these barcodes consist of a unique sequence of DNA letters. DNA barcoding sequences just a small part of a species genome and is used for rapid species identification and biomonitoring from a wide range of samples. Like the Earth BioGenome Project, there is a global effort to generate a barcode for every species. BIOSCAN (https://ibol.org/programs/bioscan) is a project contributing to this vision and a team at the Sanger Institute is working on creating barcodes for

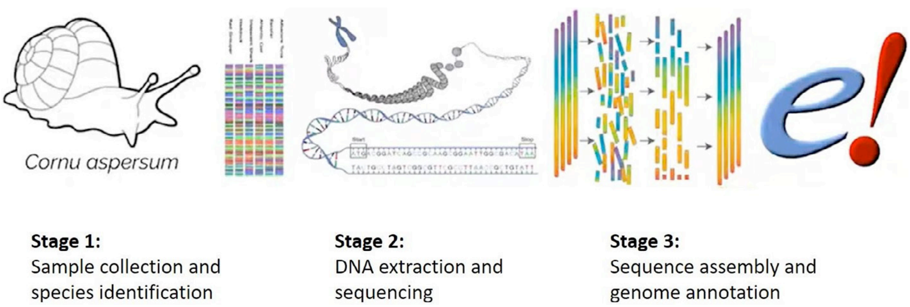

Figure 1 The processes of extracting and sequencing (from https://schools.darwintreeoflife.org/resources)

Career profile – Edel Sheerin, Advanced Research Assistant, Tree of Life programme

Edel is an Advanced Research Assistant in the Sanger Institute's Tree of Life programme. Her primary focus has been trialling and optimising DNA extraction methods for tricky taxa such as macroalgae (seaweed). Seaweed DNA can be quite 'gloopy' making it difficult to sequence. Edel recently moved to the BIOSCAN team and is responsible for setting up malaise traps to catch flying insects for sequencing, extracting DNA from samples and looking after mosquitoes in the insectory.

Skills and attributes

Working as an Advanced Research Assistant requires the following skills:

- Organisation – essential for fieldwork and lab work
- Communication – essential when working in a team and collaborating
- Problem solving – things do not always work first time (like DNA extractions from seaweed!); you need to be able to work out why that is and find a solution.

Edel's career journey so far

Edel always wanted to work in conservation. She studied biology and chemistry as part of her Leaving Cert (equivalent to A-levels) and went on to study for a zoology BSc at the National University of Ireland, Galway. Edel worked as a Project Assistant on the Mammals in a Sustainable Environment (MISE) Project using non-invasive survey techniques (collecting hair or scat samples) and DNA analysis to monitor mammal populations. Following this, she worked on a research project that used DNA barcoding to identify and assess cephalopod (octopus, squid and cuttlefish) populations in the north-east Atlantic.

There are many different routes into genomics-related careers. For a technical role such as Edel's, this could range from gaining a BSc in a related topic such as genetics, zoology, biological sciences or biochemistry or undertaking a lab-based apprenticeship.

To watch a scientist talk about their career in genomics, visit: www.yourgenome.org/video/my-career-in-genomics-antibiotic-resistance.

every flying insect in the UK. Many flying insects are pollinators and under immense pressure due to climate change, so understanding their ecology and genomes is increasingly important.

It is still early days for projects such as the Darwin Tree of Life and BIOSCAN but the data they generate will help to revolutionise our understanding of biology and evolution and conserve and protect global biodiversity.

Links to the curriculum/teaching

Projects such as the Wellcome Sanger Institute's Tree of Life programme and BIOSCAN demonstrate how modern DNA sequencing technologies can be used to study and understand biodiversity, develop biomonitoring applications and support conservation initiatives.

This wider application of genomic sequencing provides some hinterland (background) that could be shared with students when teaching introductory ideas about DNA and the human genome at ages 14–16 and the more technical details of DNA sequencing required at ages 16–19.

Resource links

- More information on genome sequencing technologies: www.yourgenome.org
- A short video discussing the work of the Darwin Tree of Life programme and different roles within it: www.youtube.com/watch?v=szFdV9fQkls
- An activity that allows students to explore the ethical questions raised by medical genomic sequencing: www.yourgenome.org/activities/genome-generation-express

Reference

Darwin Tree of Life (2022) *Sequencing all life, explained in numbers*. www.darwintreeoflife.org/news_item/sequencing-all-life-explained-in-numbers

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Sickle cell anaemia – awareness in a snapshot

Denise Joseph, a biomedical scientist, gives a personal perspective on sickle cell anaemia

Commonly mentioned as a disorder affecting Black populations, sickle cell anaemia also occurs in others. In our multicultural society, it could affect any one of us, or our family members, depending on our genetic composition.

Biomedical scientists

Biomedical scientists are qualified registered professionals trained in a wide range of medical laboratory science investigations, which are scientific tests that assist health professionals to diagnose, monitor and manage the health of patients. It is an interesting profession with a variety of career opportunities. For more information for students about becoming a biomedical scientists, see: www.healthcareers.nhs.uk/explore-roles/healthcare-science/roles-healthcare-science/life-sciences/biomedical-science.

What is sickle cell anaemia?

Sickle cell anaemia is one of a group of inherited blood disorders that are called sickle cell disorders. These disorders occur as a result of a genetic mutation (a change in DNA) that affects the structure and function of red blood cells in the body. Red blood cells are the part of the blood that transports oxygen around the body from the lungs to the organs and tissues. The mutation is believed to have evolved as a protection against malaria (see *Weblinks* – PBS).

The Global Burden of Disease Study 2017 estimated that over 3.1 million people worldwide had been diagnosed with sickle cell anaemia. It has been estimated that in the UK 12 000 to 15 000 people have sickle cell anaemia (see *Weblinks* – NICE).

Normal red blood cells are round, flexible and efficient oxygen carriers that have an iron-containing oxygen-binding protein called haemoglobin (Hb), which transports oxygen in the blood. Most haemoglobin is a variant known as Hb A. In sickle cell anaemia, the mutation results in a different haemoglobin variant known as Hb S. This variant causes the red blood cells to be misshaped in the form of a sickle (Figures 1 and 2). These sickle-shaped red blood cells have a shorter lifespan, are inflexible and less efficient at carrying oxygen. They do not pass easily through the blood vessels and clump together to form blockages resulting in tissues and organs being starved of oxygen.

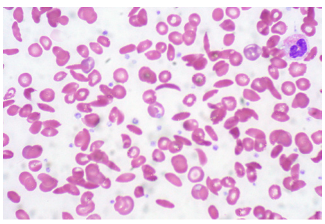

Figure 1 Example of a microscope image of a stained blood smear showing abnormal red blood cells including sickle cells (image: Ed Uthman; CC BY 2.0)

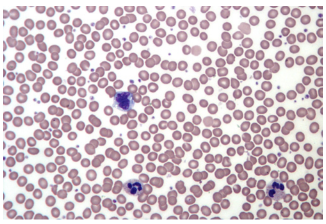

Figure 2 Comparative example of a microscope image of a stained normal blood smear with normal red blood cells (image: Keith Chambers; CC BY-SA 3.0)

How is sickle cell anaemia inherited?

Each person inherits two genes for haemoglobin, one from each parent. When two mutated genes for the condition are inherited, one from each parent, the individual will be classified as having sickle cell anaemia Hb SS, the symptomatic disorder (Figure 3). The mutated gene, S, will be passed on to future offspring.

		Parent 1	
	Haemoglobin gene (Hb)	A (normal)	S (sickle)
Parent 2	A (normal)	AA normal	AS sickle cell trait (carrier)
	S (sickle)	AS sickle cell trait (carrier)	SS sickle cell anaemia **DISORDER**

Figure 3 Inheritance of sickle cell anaemia

When the mutated gene, Hb S, is inherited from only one parent and the gene inherited from the other parent is normal, Hb A, the individual will be classified as having sickle cell trait, Hb AS, and will be a carrier of the mutated gene, which may be passed on to future offspring. Individuals with sickle cell trait usually have fewer and lesser symptoms than those with the disorder and enjoy a better quality of life. However, there have been some exceptions in special circumstances who have experienced severe negative impact on their health.

Sickle cell anaemia, Hb SS, is the most common and severe form of sickle cell anaemia.

Sickle cell anaemia and traits can also occur when other Hb variants are present with Hb S. Probably the most common are Hb SC and Hb S/beta-thalassemia, which are both sickling disorders so can exhibit some of the symptoms of sickle cell anaemia, Hb SS, but usually to a milder degree.

Symptoms of sickle cell anaemia usually appear around 6 months of age because newborns are protected by the presence of fetal haemoglobin, Hb F, but these levels usually decline as the baby gets older and the presence of Hb SS can begin to have an effect. Individuals with Hb SS may also have higher levels of Hb F than normal individuals. Oxygen binds more easily to fetal haemoglobin than adult haemoglobin (see *Weblinks* – BC Newborn Screening Program).

What are the health implications of sickle cell anaemia?

There are several health implications of the condition. These include exhaustion or fatigue, which occurs as a result of anaemia and subsequent lack of oxygen required by the body to function properly. Sickle cells do not live as long as healthy red blood cells (120 days). They die sooner (10–20 days) and anaemia occurs due to the shortage of healthy red blood cells in the blood, which leads to a shortage of iron-rich haemoglobin. Thus lower levels of iron are available to bind and carry oxygen, resulting in lower levels of oxygen being transported around the body causing the individual to feel weak and exhausted. Extreme episodes of pain are also experienced, which are caused by blockages of small blood vessels by clumped sickle cells; these episodes are called sickle cell crises. The duration, severity and frequency of such episodes vary. Individuals may also be affected by symptoms such as strokes, damage to organs such as the kidneys, joints and bones, frequent infections, delayed growth and vision problems.

What are the health implications of sickle cell trait?

It was previously thought all sickle cell carriers were healthy and clinically asymptomatic. However, recent and emerging clinical studies show that some individuals who have sickle cell trait, such as athletes and participants in extreme army training exercises (e.g. exertional running), have been affected with severe symptoms of the disorder and even death when they have engaged in extreme exertion (see *Weblinks* – Sickle Cell Trait).

What is the treatment for sickle cell anaemia?

Treatment may involve periods in hospital and can include antibiotics, strong medicines to relieve pain (such as morphine) and to reduce the frequency of painful episodes (e.g. hydroxyurea and a more recently developed treatment, crizanlizumab). Blood transfusions may be performed, which increase the oxygen levels in the blood by replacing the sickle cells with transfused healthy red blood cells and reduces the likelihood of blockages occurring. Stem cell transplant has become a curative option offered to eligible young individuals.

What are the implications for students with sickle cell anaemia?

It is obvious that this treatment would have a huge impact on the physical and mental wellbeing of students, their ability to attend, function and focus during lessons, and on their education and their quality of life in general. There should be a detailed healthcare plan in place so that educators know what to do for a student in their care (see *Weblinks* – Sickle Cell Society).

How is sickle cell anaemia tested for?

Sickle cell screening tests are performed in the hospital laboratory by biomedical scientists. The tests are offered to pregnant women, their partners and babies as appropriate. Tests can be done at any time to determine whether other individuals might be a carrier or have sickle cell anaemia. The gold standard testing techniques include a specially stained blood film, which is examined using a microscope to look for the presence of sickle cells; a full blood count test (FBC), which gives information including the number, size, maturity and shapes of red blood cells and the haemoglobin level; and measurements for white blood cells and platelets. Haemoglobin electrophoresis and HPLC (high-performance liquid chromatography) are two different methods used to identify the variants and quantities of haemoglobin in a blood sample.

Weblinks

PBS. *A mutation story*. www.pbs.org/wgbh/evolution/library/01/2/l_012_02.html

NICE. *How common is sickle cell disease?* https://cks.nice.org.uk/topics/sickle-cell-disease/background-information/prevalence

BC Newborn Screening Program. *Hemoglobinopathies: Sickle Cell Disease (HbSS, HbSC or HbS/ß-Thalassemia.* www.perinatalservicesbc.ca/documents/screening/newborn-hcp/hemoglobinopathiesscd3.pdf

Sickle Cell Trait. www.hematology.org/education/patients/anemia/sickle-cell-trait

Sickle Cell Society. *Sickle Cell and Thalassaemia: A guide to school policy*. www.sicklecellsociety.org/wp-content/uploads/2015/01/Dyson-School-policy-sickle-cell-1.pdf

Other useful links

Sickle Cell Society website includes information and support about sickle cell matters: www.sicklecellsociety.org

BBC Bitesize article includes a video-clip made by a young adult who has sickle cell anaemia, which gives a first-hand insight into the condition: www.bbc.co.uk/bitesize/articles/zybdkty

Factsheet summarising some key information about sickle cell anaemia: www.cdc.gov/ncbddd/sicklecell/documents/SCD-factsheet_What-is-SCD.pdf

Recorded session about sickle cell anaemia by Young Gifted and Stem – search Facebook for YGASTEM video 'Sickle Cell Awareness Day' video or go to YGASTEM's Instagram account, www.instagram.com/ygastem.

Denise Joseph is a biomedical scientist who is also qualified in early-years education.

Update on curriculum changes in Wales

Helen Dearns discusses how implementing the new Curriculum for Wales presents many challenges but also provides exciting opportunities; the changes will allow schools to design, plan, trial and evaluate their own curriculum tailored to the needs and interests of their own students, staff and communities

Among the challenges of the past two years, teachers in Wales have been contending with the added task of curriculum planning. This does not involve just minor tweaks here and there: a complete overhaul of how education is delivered has been introduced, allowing schools to design, plan, trial and evaluate their own curriculum tailored to the needs and interests of their own students, staff and communities.

As of September 2022, schools in Wales will be expected to roll out their new bespoke curricula. At primary level this is for all years and at secondary level it will start with year 7 (age 11) and continue into subsequent years up until 2026 when all year groups will be studying the new Curriculum for Wales.

How will it work?

The new Curriculum for Wales is built around the 'four purposes':

- ambitious, capable learners;
- enterprising, creative contributors;
- ethical, informed citizens;
- healthy, confident individuals.

Everything a school develops should have these four purposes at the heart of it. The idea is to grow and nurture students' *cynefin* (pronounced cun-eh-vin), which literally translates to habitat but its meaning goes much deeper. It is hard to do the meaning justice, but it is being used to refer to students' identity attached to the place they live and how their experiences and history influence who they are.

Progression steps replace key stages, with appropriate ages for each progression step outlined as a range to allow for more of a continuum through the years so that students can learn more at their own pace. For example, progression step 4 is roughly for ages 11–14 and so pupils in years 7–9 would study relevant ideas, concepts, skills and so on, but they may also still be developing these in subsequent years or begin them earlier, depending on the students' individual needs and capabilities. Essentially, this opens the door to genuine differentiation.

Subjects have been grouped together into Areas of Learning and Experience (AoLE), with biology, chemistry, physics, computer science and design and technology combined under the umbrella of 'Science & Technology AoLE'. The planning guidance is outlined in 27 mandatory 'What Matters' statements (six for Science & Technology AoLE) and individual schools have freedom to plan their own curriculum to allow for individual needs and interests of pupils. Mathematics, English and Welsh are also interwoven throughout with opportunities to develop skills and knowledge in these areas.

Challenges and opportunities

As previously mentioned, the past two years in teaching have been far from plain sailing and it has been hard for Welsh teachers to plan what is meant to be a world-leading, ground-breaking curriculum while battling the school closures and absences due to the COVID-19 pandemic and adapting to online teaching. To support secondary schools in this, as the changes required at secondary are arguably far greater than at primary, secondary schools have been offered a delay in curriculum roll-out, allowing them to begin the new curriculum for years 7 and 8 in September 2023. Currently, it is unknown what the new qualifications to replace GCSEs in Wales will look like as they are still under consultation.

Despite these challenges, many opportunities are presented by the new Curriculum for Wales. The chance to eliminate teaching to the exam is now on the table, as well as engaging more students in science by making it more relevant. Teaching students to understand the importance of our subject, while learning the rich scientific history of Wales that has previously been left off the curriculum, is an exciting prospect for all involved.

Further information

A brief summary of the changes planned for education in Wales: https://hwb.gov.wales/storage/94271c54-2aee-423a-b49f-4b6d7311edc6/190621-a-brief-summary-of-the-changes-planned-for-education-in-wales.pdf

Professor Donaldson's report that sparked this change: https://gov.wales/sites/default/files/publications/2018-03/succesful-futures-a-summary-of-professor-graham-donaldsons-report.pdf

In-depth Curriculum for Wales information on Hwb: https://hwb.gov.wales/curriculum-for-wales

The Journey to 2022: https://hwb.gov.wales/api/storage/cbe5e2c9-16cf-4eb7-87a1-c1a64fc598d8/the-journey-to-2022.pdf

Helen Dearns has written this article in her role as member of ASE's 11–19 Committee. She is currently the Royal Society of Chemistry Teacher Fellow (Wales). ✉ helen.dearns@gmail.com
@DearnsHelen

Practical work – making it more effective

Sarah Earle discusses an influential paper from Robin Millar and Ian Abrahams on the role of practical work in science lessons; each month, members of the ASE Research Group will suggest how other important papers from *SSR* could be used as the subject of a journal club in your school or department

Article summary

This Millar and Abrahams (2009) article discusses the effectiveness of student practical work. While noting that teachers and students feel that practical work is an important part of science lessons, the authors question whether there is clarity around the purpose of such activities. Effectiveness is considered in two ways: firstly, whether students do and see what is intended; and, secondly, whether students learn what is intended (acknowledging that this is much harder to measure). The authors identify three types of objective for practical work: (A) illustrating ideas, (B) practising procedures, and (C) developing enquiry processes. Summarising findings from a study of 25 lessons in eight secondary schools, the authors note that in the majority of lessons in the sample, the focus was on '*producing the phenomenon*', with very little discussion of scientific concepts. They propose that the focus on 'hands on' was at the expense of 'minds on', meaning that, while a practical may seem effective in that the students have done what was expected, learning was not maximised because the development of scientific understanding was not supported. They also note that the 'learning demand' of the activity should be taken into account. The authors argue that effective practical work needs to be both 'minds on' and 'hands on' and that the former needs more attention in order to develop student learning.

Full article

Millar, R. and Abrahams, I. (2009) Practical work: making it more effective. *School Science Review*, **91**(334), 59–64. Available to ASE members at: www.ase.org.uk/resources/school-science-review/issue-334/practical-work-making-it-more-effective and to all at: www.gettingpractical.org.uk/documents/RobinSSR.pdf.

Questions to support reflection and discussion

These questions can support you and your colleagues to engage with issues arising from reading this article:

- Do you find the distinction between completing the intended practical and developing the learning a useful way to consider the effectiveness of practical work?
- What do you think of the way that Millar and Abrahams have categorised the purposes of practical work as: (A) illustrating ideas, (B) practising procedures, and (C) developing enquiry processes?
- What would you say if it was suggested that practical work may serve different purposes with different age groups or in the different disciplines of science?
- How do you think practical work could be made more effective in your setting?
- Do you feel that the debate about practical work has moved on since this article was published? In what ways is it the same/different?
- How do you think discussions around managing cognitive load could add to this debate?

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From the archive: 'Promoting the understanding of mathematics in physics at secondary level'

An article by **Alaric Thompson**, Head of Physics at Ulverston Victoria High School, published in the March 2016 issue of *School Science Review* (volume 97, number 360, pp. 43–48)

Do you find that your students compartmentalise their learning? Do they struggle to transfer maths skills from maths lessons to their physics learning or even from one physics topic to another?

This article explores some of the common mathematical difficulties that 11- to 16-year-old students experience with respect to their learning of physics. It shares strategies for approaching the language of mathematics, the meaning behind formulae, the importance of 'is equal to' and the rearrangement of simple equations.

This article can be found at www.ase.org.uk/resources/school-science-review/issue-360

Questions for Sibel Erduran

Alastair Gittner, Chair of ASE's Research Group, in conversation with Professor Sibel Erduran

What were science lessons in school like for you?

I went to a secondary school with an English curriculum in northern Cyprus in the 1980s. We had some brilliant teachers and I took 10 O-level subjects that included physics, chemistry and biology. I enjoyed all my science lessons, and had a particular affinity with chemistry. One downside was that we barely had any exposure to practical work: I can only remember a handful of practical sessions.

Was there a particular science teacher who inspired you?

I remember the differences in the teaching styles of my science teachers. My physics and chemistry teachers were the most engaging because they asked a lot of questions and encouraged the whole class to participate in discussions. In contrast, biology lessons felt more like facts we had to learn and the teacher would write down the information on the blackboard, yes blackboard, for us to copy down.

When did you realise that you were good at science?

When science was split into physics, chemistry and biology, I started to be increasingly fascinated by chemistry, and I was good at it. I must have been 13 years old at the time. I was good at biology and physics as well but the world of molecules and how they can produce new substances really amazed me. I also liked learning about the chemical symbols, equations and reaction mechanisms. Precipitation reactions were my favourite! Learning this new language of chemistry had a lot to do with my liking of chemistry. At university, when I was doing my bachelor's and master's degrees in chemistry, I came to experience science first hand working in research laboratories with teams of researchers. This made me realise that often what is presented as science in schools gives students a limited sense of how science actually works. Scientists constantly debate data and disagree about what counts as a reliable conclusion. This doesn't mean they never agree but rather that there is a process whereby scientists establish the knowledge that they agree on.

I also learned that one scientist does not do all the research but that there is rather a research programme where many people contribute to solving small pieces of a bigger puzzle. We can ensure that students have exposure to such experiences, where they work together to solve problems. I believe modelling of science cultures would also empower them to realise that they can contribute to a collective effort to understand the world.

How did you get into educational research?

I think I always had the mindset of an educational researcher, having grown up in a household where learning was highly valued. My father and grandfather were both teachers, and I was always surrounded by teachers of all subjects. My father has been very inspirational for me. He started as a primary school teacher and then moved onto secondary education. He was very curious about anything and everything, and he was open to learning about new teaching strategies.

Can you give us a brief introduction to your current research?

The COVID-19 pandemic has brought to the foreground the importance of understanding science in context and the different sciences in unison. In the daily news briefings, we saw how science is situated within the national political and economic landscape. We were presented with information that relied on biology (virus), chemistry (diffusion of particles) and mathematics (graphs). We have also had to understand themes such

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as risk, probability and mental health. It has become quite clear that we cannot afford to teach school subjects in silos with no connections made between them. My current research focuses on understanding how school science experiences can be authentic for students so that they can understand how science works in a cross-subject fashion and also in relation to society. Currently, we have a project on future-oriented science teaching and learning where we are collaborating with teachers and museum educators to produce strategies and resources to support complex problem-solving about issues such as the pandemic and climate change.

Can you recommend somewhere for teachers to go to read about your research?

We have recently published some articles in *School Science Review*, which would be a great place to start (Erduran, 2020; Erduran and Wooding, 2021). I would also suggest looking at some of our project websites such as the Project Calibrate website (https://projectcalibrate.web.ox.ac.uk) that includes research-informed teaching and CPD resources.

Is it ready to inform the practice of teachers now?

I try to conduct my research to develop understanding about something but also move forward to produce tangible resources to translate this understanding into practice. So, for example, Project Calibrate not only produced research publications but also video-based teaching resources, CPD materials by teacher trainers as well as sample GCSE examination questions. All these resources have been informed by our research and developed in collaboration with teachers, teacher trainers and examiners, and they are freely available on our website.

What tips could you give teachers if they were thinking about implementing research evidence?

I would say that not all research may have direct relevance at this point in time, and that's fine. Sometimes, research gives us insights and helps us recognise issues without direct impact right now. Research takes time to mature and sometimes it takes a while for researchers to move on to a different phase to produce concrete materials useful for practice. I would focus on how the strategies may be relevant for your own teaching. Most importantly, I would suggest that teachers bring in their own professional experiences and expertise to the adaptation of research. It is teachers' own professional knowledge that will bring alive the research in the classroom.

What else would you like to look at in the future?

The issue of making science education authentic is, I believe, my life's work! We need to understand how we can balance educational objectives with realistic science experiences. Schools are not scientific institutions, and education has other purposes than to only provide scientific research experiences to students. Part of what we include in the science curriculum could immerse students in scenarios that help them understand how scientists think and work.

What are the challenges facing educational research particularly in science teaching and learning?

We need to let go of two main obsessions in science education: our obsession with scientific knowledge and our obsession with summative assessment. We need more investment in educational research to be able to generate understanding of novel curriculum and assessment approaches, coupled with funding to engage teachers and school leaders as partners in such missions.

Can you tell us something that might surprise our readers?

My father was an avid BBC World Service fan. We had the radio station on in the house practically all day every single day. My childhood was influenced by its brilliant coverage, and I remember to this day some of the stories from decades ago, when I can barely remember what happened at the onset of the pandemic two years ago, I always think of this experience to remember how impressionable children can be and how good resources can impact their lives for years.

References

Erduran, S. (2020) Reframing science education in light of the COVID-19 pandemic. *School Science Review*, **102**(378), 38–43.

Erduran, S. and Wooding, S. J. (2021) A Project Calibrate approach to summative assessment of practical science. *School Science Review*, **102**(381), 71–77.

ASE member exclusive content

Both of these articles are available online to eligible ASE members at www.ase.org.uk/resources/school-science-review.

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Doing retrieval practice better

Kendra McMahon explains how rehearsing knowledge through retrieval practice helps to consolidate it; as we consolidate knowledge, we can also help students to build up more complex schemas of science knowledge by comparing and contrasting, categorising and connecting, creating and questioning within and beyond the topic context

What is retrieval practice?

Retrieval practice (sometimes called the 'testing effect') is bringing information to mind from memory. For example, at the start of a science lesson a teacher might say: '*Let's recap from last week – in what different ways can seeds be dispersed?*' The effort involved in the retrieval process helps to consolidate it as a long-term memory. Cognitive neuroscientist Efrat Furst (2019) explains that in order to bring the information to mind we invest deliberate effort, reactivating a sequence of neural networks and reconstructing the pathway to the stored information (Figure 1).

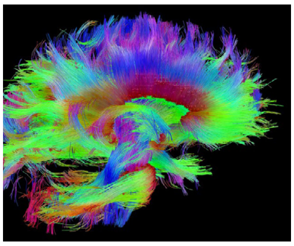

Figure 1 White matter pathways in the brain; image courtesy of the USC Mark and Mary Stevens Neuroimaging and Informatics Institute (www.ini.usc.edu) for the Human Connectome Project

The limitations of retrieval practice

At the moment, retrieval practice in many schools is usually in the form of low-stakes tests. These are good for supporting automaticity – quick and secure recall – but have limited potential for building more complex, interconnected knowledge, or 'schemas'. We can build on our current use of retrieval practice with a wider repertoire of strategies that challenge students to extend ideas as well as recall knowledge. This aim is consistent with Ofsted (2021), who advocate for an ambitious curriculum that '*not only identifies the most important concepts for pupils to learn*' but also teaches them '*how these concepts are related*'.

How can we do retrieval practice better?

We need to avoid thinking of memory as a limited region of the brain, a box in which we put facts. Neuroscientist Arthur Shimamura (2018) explains that knowledge is distributed widely across the cerebral cortex as a network of interconnected information. He sees forming memory as a process of 'generation' in which conceptual learning requires, firstly, the activation of pertinent information in working memory, then the 'binding' of that information and, thirdly, memory consolidation by '*reactivating and relating new information into existing knowledge networks stored in the cerebral cortex*' (Shimamura, 2018:22). Similarly, Furst (2019) argues that the value of retrieval '*stems from building new pathways of associations, closing gaps in knowledge and adjusting existing knowledge to current context*'.

Shimamura (2018: 27) recommends that we use techniques that simultaneously reactivate and elaborate

Primary example (ages 9–11)

Compare a real-life flower to a diagram.

Students could use the similarities that they find to help them to name the parts of the real-life flower (Figure 2).

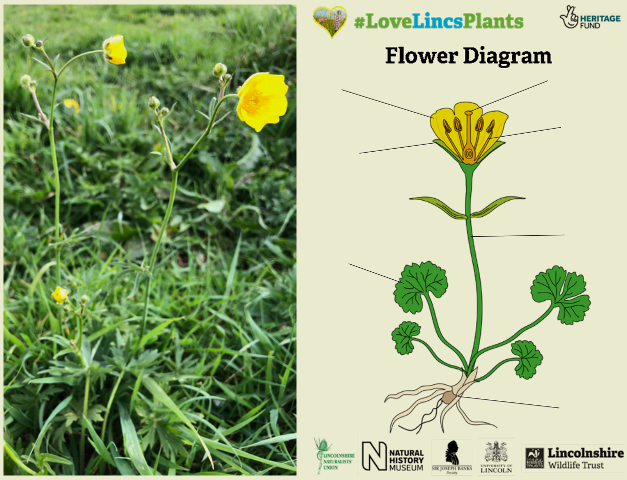

Figure 2 Photograph of real-life flower and a diagram for labelling; photo by Kendra McMahon and diagram from the free school resources at *LoveLincsPlants* (www.lincstrust.org.uk/what-we-do/love-lincs-plants/schools)

This task could be made more challenging by asking students to **compare** and **contrast** two flowers with very different-looking parts (Figure 3). Students could describe the similarities and differences using the correct scientific vocabulary for the parts of a flower.

Figure 3 Two contrasting flowers, camellia and narcissus; photos by Kendra McMahon

Secondary examples (ages 11–16)

Pollination

Students could be encouraged to retrieve primary learning about the parts of a flower and **connect** this to secondary learning about pollination by being asked to **compare** and **contrast** an insect-pollinated and a wind-pollinated plant. Students could comment on the location of the anthers, the position and type of stigma, the presence of nectaries and the type of pollen.

Cells

Compare and **contrast** a diagram and microscopic image of a plant cell (Figure 4).

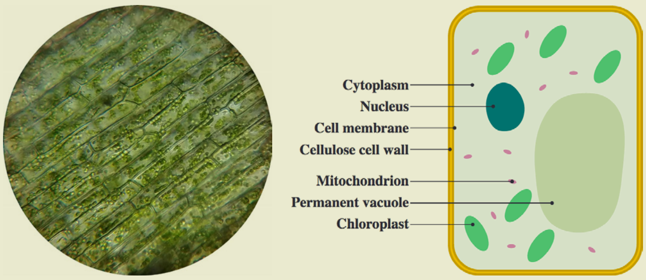

Figure 4 Microscope image of waterweed and a labelled plant cell (by domdomegg, https://commons.wikimedia.org/w/index.php?curid=46468379)

Students could use the similarities that they find to help label the parts of a cell on the microscope image. A key difference that students may observe is that not all the parts of the cell will be clearly visible in the microscope image. This type of activity could be used in different contexts at ages 11–14 and beyond, including during practical work using microscopy.

Another retrieval task with added challenge could be to ask students to use scientific vocabulary to **compare** and **contrast** a diagram of a specialised cell (for example, a ciliated cell or a root hair cell) with a basic cell diagram.

Digestive, respiratory and circulatory systems

A low-stakes retrieval quiz may ask students to recall parts of the digestive and respiratory systems or to write down the word equation for respiration. A more challenging type of retrieval question could encourage students to start connecting their knowledge from different topics. For example:

Name the process that requires substances that enter the body through the two systems in Figure 5.

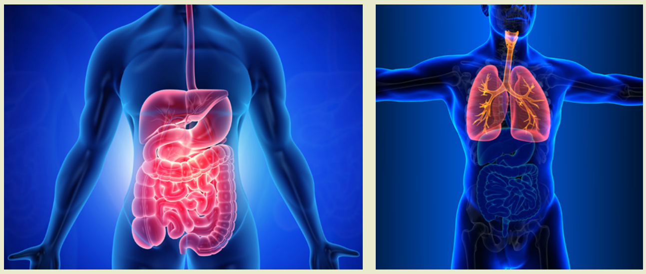

Figure 5 Photographs for body system questions (Shutterstock)

Describe how oxygen and glucose enter the bloodstream.

An even more challenging retrieval task could be to ask students to **compare** and **contrast** how oxygen and glucose enter the bloodstream.

This would require students not only to retrieve specific knowledge of parts of the respiratory and digestive system (alveoli and villi) but also to recognise similarities such as large surface area and thin membranes.

In Shimamura's model, and using the 5Cs and a question approach, it is the students who should generate the questions and do the thinking so this requires a more open-ended retrieval task. For example, the pictures in Figure 5 could be used to stimulate a discussion by asking students to '*Compare and contrast the digestive and respiratory systems*'. A teacher could provide some support to students if needed by suggesting some specific key words to include in their questions and discussion.

memories. Some techniques he lists are: connecting ideas, perhaps by visual mapping; the 3Cs – Categorise, Compare and Contrast; talking; creating stories; metaphors and analogies; explaining to others; and asking 'how' and 'why' questions.

What does this mean in practice? 5Cs and a Q!

In science education, we have long advocated activating student prior knowledge. Using 5Cs and a Q – Categorise, Compare, Contrast, Connect, Create and Question – builds on this constructivist approach, expanding retrieval practice with a wider repertoire of strategies that challenge students to extend their ideas as well as recall knowledge.

For example, developing a rich picture of knowledge of the life cycle of flowering plants would include comparing and contrasting different flowers and flower parts, categorising plants according to seed dispersal, and creating stories about the interdependence of living things (e.g. many flowering plants depend on animals for pollination and seed dispersal). This, in turn, connects to sustaining biodiverse environments that support pollinators, and ultimately the supply of food to humans.

Doing retrieval practice better by embedding a concept in additional networks, makes the concept more accessible and more useful.

Acknowledgements

Many thanks to Rose Edmondson, teacher of science at Falinge Park High School, Rochdale, and Francis Harden, student, University of Southampton, for their input and advice on the secondary examples.

References

Furst, E. (2019) *Meaning first* (blog). https://sites.google.com/view/efratfurst/meaning-first

Ofsted (2021) *Research Review series: Science*. London: Ofsted. www.gov.uk/government/publications/research-review-series-science

Shimamura, A. (2018) *MARGE: A whole-brain learning approach for students and teachers*. https://shimamurapubs.files.wordpress.com/2018/09/marge_shimamura.pdf

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Extended projects – unlocking student potential

Jen Osler explores the benefits of the Extended Project Qualification (EPQ) and how it supports student-led scientific investigation and transition to life beyond sixth form

How do you help your students to stand out, with the freedom to explore beyond the curriculum and understand more of the world around them, while at the same time gaining essential skills for transition to the next stage of life? The Extended Project Qualification (EPQ) is a fantastic qualification to achieve just that, and is a great way to provide science students with the framework to extend their learning beyond sixth-form courses. The EPQ lights the fire of curiosity, exploration and initiative in a qualification that is highly regarded and recognised by higher education.

What's in an EPQ?

The EPQ is a research-based qualification of A-level standard worth half an A-level in UCAS points. Over 40 000 students in England and Wales take the EPQ every year. Its unique design allows students to develop and lead their own research project on a topic of their choice. Students engage in a core programme of project management, research methodology and academic skills development, managed by the school-based EPQ specialist, and this enables them to take the lead in their learning.

Throughout the EPQ programme the student is supported by a teacher who acts as a supervisor. This supervisory relationship mimics the one students will experience at university. Supervisors meet with their students regularly to provide guidance as their project progresses. The supervisor could be a science teacher or from another discipline; they don't need to be expert in the student's EPQ – it is better if they are not so that the student can take the lead in their own learning. This unique approach means students get a head start in developing essential study and research skills for university, and transition to the next stage of education and careers. It puts students in the driving seat of their learning, allowing them the freedom to choose their own research topic. It can be hugely motivational and inspiring for learners who are thinking about subjects for university courses, future careers, and how they can make a difference by better understanding the world around them.

Assessment of the EPQ is coursework and skills based. Students are rewarded for managing, researching, realising and reflecting on their project. This is an important feature of the qualification and means that students develop the skills required for future success in education and the work place.

Examples of EPQ project titles

Design

- To what extent will 3D printers influence the future development of prosthetic limbs?

Medicine

- To what extent does prenatal music exposure directly influence the development of a fetus?
- To what extent has patient care been compromised by ethical issues surrounding regenerative medicine?

Engineering

- Construction and testing of a small-scale hybrid rocket motor.

Science-based EPQs

The EPQ provides a fantastic platform for students to explore science beyond the curriculum, to stretch towards the next stage of their academic journey and exploit the freedom the EPQ provides to ask 'what if?' in their own way. The EPQ does not prescribe methodologies, but allows students to design their own research. This gives them the flexibility to explore the wide range of approaches to scientific investigation, not just *the* scientific method that is often considered the only way for scientists to work. The EPQ also allows for multidisciplinary research, combining science with different subjects. For example, students might have combined design technology with medicine to investigate the use of 3D printing in the development of prosthetic limbs. We have seen students use the EPQ to help refine choices of medical degrees, and to investigate ethics and science. For students who want to explore aspects of science not taught in their A-levels, or for non-science students interested in applications of science, the EPQ is the perfect platform to make discoveries. In addition, the report-writing aspect of EPQ supports science students' extended writing skills, crucial for any undergraduate course.

There's something about the EPQ

In a highly competitive university market, EPQ skills can give students the edge. Many universities make alternative offers to applicants with an EPQ, viewing it as an important programme of preparation for successful transition to higher education.

Acknowledgements

Thanks to Dr Julie Greenhough, EPQ Centre Coordinator at St Benedict's School in West London, for additional feedback and suggestions.

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Growing the technical STEM talent pipeline

Cerian Ayres raises a number of talking points for teachers working in further education or in schools to encourage discussion on how best to work in partnership to grow the technical STEM talent pipeline

There has never been a more important time to be involved in technical STEM education and training. Science education in particular is a great enabler, 'opening doors' to a diverse range of opportunities including progression to further or higher technical study and employment.

Further education (FE) is currently in the spotlight and receiving long-deserved recognition for the central role it is playing in building a greener, brighter future, prioritising social mobility through the levelling-up agenda and working to address longstanding inequalities. Technical skills lie at the heart of job opportunities in the UK's recovery plan.

The UK has some of the greatest regional variations in productivity of developed nations, which not only holds back the nation's economy but leads to lower earning potentials in some areas. Education and skills outcomes also vary significantly between regions and are strongly related to regional productivity.

To deliver high-quality technical education and training requires teachers who have the technical expertise, knowledge, skills, behaviours and relevant industry experience to bring learning to life, inspiring their learners to progress and realise their ambitions. Teachers are the single biggest influence on a learner's enjoyment, engagement and progress in a subject.

In January 2022 the Department for Education launched its Teach in FE campaign. The aim was to encourage more industry, armed services technical experts and graduates into FE teaching, often into 'hard to fill' roles. The further education and training sector cannot achieve this vision in isolation. Development of a technical STEM talent pipeline requires working in partnership across education sectors and in collaboration with industry and wider stakeholders.

Before considering how the FE sector can best work in partnership with schools and other stakeholders to develop this pipeline, it is important to understand some of the barriers that learners may be facing when working to progress to higher levels of technical STEM study and employment in science industry sectors.

Recruitment, development and retention of science learners is a challenge on multiple fronts including:

- low science capital in UK homes;
- learner perception that science is 'hard' or 'not for me';
- challenges of recruiting and retaining science teachers (in a competitive market for scientists);
- issues of diversity and inclusion in science including a lack of positive role models for under-represented groups and individuals;
- leakage at every stage of the STEM talent pipeline (Figure 1).

There are plenty of myths and stereotypes that act as barriers to access and inclusion in STEM:

- All scientists are (white) men in (white) coats working alone.
- Science is difficult.
- You must be exceptional at science to pursue a career in it.

Evidence suggests that these perceptions are learnt through school and socialisation. In 2018, a UK charity, Education and Employers, released a report called *Drawing the Future*, of a survey in which primary school children from the UK and internationally were asked to draw themselves in their future job. Children drew a whole range of jobs, such as sportsperson, vet, scientist, movie star and teacher. STEM careers featured prominently, with 'vet' (second) and 'doctor' (sixth) dominant in children's choices, scientist seventh and engineer eleventh. However, a gender gap begins to open at age 7 and the number of girls drawing themselves as scientists and engineers drops away steeply. These patterns do not change significantly between ages 7 and 17: perceptions, expectations and stereotypes embedded in primary

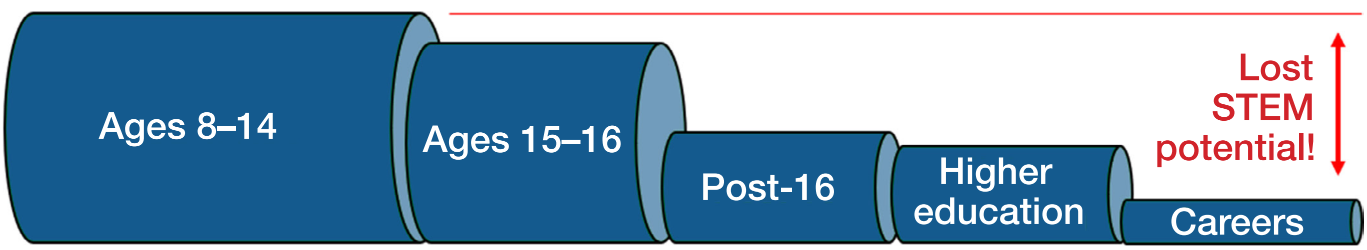

Figure 1 There is leakage at every stage of the STEM talent pipeline

school children persist right through to the entry point for post-16.

Development of the technical STEM pipeline therefore needs to start early by developing links between FE providers and local primary and secondary schools. The FE sector can provide meaningful encounters with employers, STEM Ambassadors and key stakeholder partners, bringing real-world contexts for learning that will motivate learners. This could provide the inspiration to ignite a 'spark' that could encourage some of them to progress to higher levels of technical study and employment.

When learners are considering progressing from GSCE into post-16 education, the FE and school sectors should ensure that they are sharing the breadth of STEM careers and celebrating the STEM content in a wide range of courses. Both sectors should aim to demonstrate to learners, and their parents and influencers, that STEM knowledge and skills will open up career opportunities in their subject area.

Talking points – FE

- What positive action are you taking as FE professionals, with your partners, to ensure that you are contributing to the growth of the technical STEM talent pipeline?
- What does your promotional activity and outreach do to avoid embedding unhelpful myths and stereotypes?
- How are you addressing and advancing inclusion and diversity in STEM?
- How do your outreach activities and teaching and learning materials expand learners' career horizons and encourage them to access higher levels of science technical learning and employment in the STEM industry sector?
- Do you consider the Gatsby Benchmarks for Good Career Guidance?
- Do you have a whole-organisation approach to embedding high-quality, impartial STEM careers education information advice and guidance?

Talking points – schools

- Have you developed effective partnerships with colleagues at your local FE college and with wider sector providers?
- How could you work with FE providers, employers and stakeholders to ensure that there is high-quality, impartial careers education information, advice and guidance available to all learners?
- What CPD would be useful to allow you to better understand the possible progression pathways to further and higher technical study and employment?

- Are you working with employers, stakeholders and FE providers to provide support for STEM outreach opportunities?
- How could you resume or start conversations with FE colleagues that would enable your learners to explore next step technical STEM learning?

Useful links and references

Teach in FE (Department for Education): www.teach-in-further-education.campaign.gov.uk

Drawing the Future (Education and Employers): www.educationandemployers.org/research/drawing-the-future

Gatsby Benchmarks for Good Career Guidance: www.gatsby.org.uk/education/focus-areas/good-career-guidance

Education and Training Foundation. *So what is the FE sector?*: www.et-foundation.co.uk/wp-content/uploads/2020/08/200729-ETF-FE-Sector-Guide-RGB-v10.pdf

Resources from the Association for Science Education (ASE) for primary, secondary and for science technicians: www.ase.org.uk

Good Practical Science – a framework for good science in schools from Gatsby Foundation and Sir John Holman: www.gatsby.org.uk/education/programmes/support-for-practical-science-in-schools

Gatsby Foundation. *Engaging parents in careers guidance: Innovations in practice*: https://resources.careersandenterprise.co.uk/resources/engaging-parents-careers-guidance-innovations-practice

Medical Mavericks – offers free high-quality careers education resources and tools for teachers, learners of all ages and parents: www.medicalmavericks.co.uk

Royal Academy of Engineering *This is Engineering* site – supports learners to relate their interests in everything, from films to fashion to medical engineering, to STEM careers: www.thisisengineering.org.uk

WorldSkillsUK Educator Resources – tools and resources designed to support educators to inspire and develop learners and apprentices: www.worldskillsuk.org/educator-resources

Bring a STEM Ambassador into your college (video): www.youtube.com/watch?v=43mfKt0VKOI

Good Practical T Level Science (video) – ASE member Alison Ackroyd explores ways she has found to naturally embed careers education information advice and guidance: www.youtube.com/watch?v=O35ziN2hoi8

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Major reforms to Scottish education – opportunities and concerns

Susan Burr (ASE Scotland Chair), **Stuart Farmer** (IOP Scotland) and **Colin McGill** (Edinburgh Napier University) share their opinions on the issues arising from these major reforms

In June 2021 the Scottish Government accepted the 12 recommendations of the Organisation for Economic Co-operation and Development's *Scotland's Curriculum for Excellence: Into the Future* report (Scottish Government, 2021; OECD, 2021). The Scottish Government then appointed Professor Kenneth Muir to undertake a consultation and produce a report. This report, *Putting Learners at the Centre: Towards a Future Vision for Scottish Education* (Muir, 2022), recommended major reforms, including the establishment of a new qualifications and assessment body and a new national agency for Scottish education. There will also be changes to the school inspectorate. (For further details see the May 2022 issue of *Education in Science*.)

What are the opportunities?

These reports give an opportunity for a shift in Scottish education to place teachers and learners in a more central role of policymaking.

Teachers have also been promised a reduction in contact time from 22.5 hours to 21 hours per 35-hour week. This is much needed as Scottish teachers have one of the greatest class teaching commitments of any country (TES, 2019; OECD, 2019). The increased non-contact time could be very impactful if it allows teachers collaborative planning time that could also act as subject-specific professional learning.

In recent decades, the importance of good-quality subject-specific professional learning has not been recognised or prioritised (IOP, 2020; Thomas, 2021). Many courses currently focus on leadership, which is important but does not address the basic challenges facing classroom teachers. The reforms bring an opportunity to focus on the daily teaching and learning in all classrooms across Scotland. This is also a real opportunity to improve teacher retention.

A review of the curriculum and its assessment gives the opportunity to better specify the role of knowledge and to develop it more coherently across the curriculum. It also gives the opportunity to reduce the assessment burden in the senior phase (ages 15–18).

Teachers and other stakeholders will have an opportunity to contribute to all aspects of the curriculum. Their voice is important since they have to deliver this curriculum and need to feel empowered to do so. The importance of both student and teacher voice has been recognised as a powerful driver in the improvement of teaching and learning.

What are the concerns?

There are major concerns about the restructuring of Education Scotland and that the replacement of the Scottish Qualifications Authority (SQA) will be little more than a rebranding exercise and will not provide the significant change that is needed. Structural changes will dominate over the more substantive changes needed for the curriculum, its assessment, and improvement to the support provided to teachers. Past experience has bred a level of cynicism regarding real change among many teachers. They need to feel that they are being listened to and their views and expertise are being used to improve the system.

The disconnect between the Broad General Education phase (BGE, the 3–15 curriculum), and the Senior Phase (the 15–18 curriculum), and the nature of assessment in the Senior Phase are probably the biggest issues identified in the OECD (2021) Review of *Curriculum for Excellence*. All transitions from early years to senior phase need to be looked at carefully to ensure that there is continuity and progression, which has been lacking for many years. There is a danger that the solution to these concerns will only change the Senior Phase, although many of the problems that become apparent in the Senior Phase have their roots in BGE, so it is important that the whole curriculum is reviewed and improved to give a better, more coherent experience for learners.

There is tension between wanting to get the problems fixed now and having a proper debate about the nature of the changes needed. Ken Muir (2022) has recommended there be a full and proper review, and Education Scotland and the SQA will not be fully replaced before 2024. It is important that we use the next two years to decide on the direction in which we wish to head, and that teachers do have a genuine opportunity to make their voices heard, and to continue to do so through whatever new organisations and procedures are put in place.

References

IOP (2020) *Subjects Matter*. www.iop.org/sites/default/files/2020-12/Subjects-Matter-IOP-December-2020.pdf

Muir, K. (2022) *Putting Learners at the Centre: Towards a Future Vision for Scottish Education*. Edinburgh: Scottish Government. www.gov.scot/publications/putting-learners-centre-towards-future-vision-scottish-education

OECD (2019) *Education at a Glance 2019, OECD Indicators*. https://read.oecd-ilibrary.org/education/education-at-a-glance-2019_f8d7880d-en

OECD (2021) *Scottish Curriculum for Excellence: Into the Future*. www.oecd.org/education/scotland-s-curriculum-for-excellence-bf624417-en.htm

Scottish Government (2021) *Curriculum for Excellence: Scottish Government Response to OECD Review*. www.gov.scot/publications/oecd-review-of-curriculum-for-excellence-scottish-government-response

TES (2019) *Teaching time way above average in Scotland – report*. www.tes.com/magazine/news/general/teaching-time-way-above-average-scotland-report

Thomas, L. (2021) *Subjects Matter for Scotland: An Evidence Paper*. www.researchgate.net/publication/356459829_Subjects_Matter_for_Scotland_An_Evidence_Paper

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