November 2023 Volume 105 Issue 389

SSR in Practice

School Science Review

ASE's peer-reviewed journal for 11–19 science education

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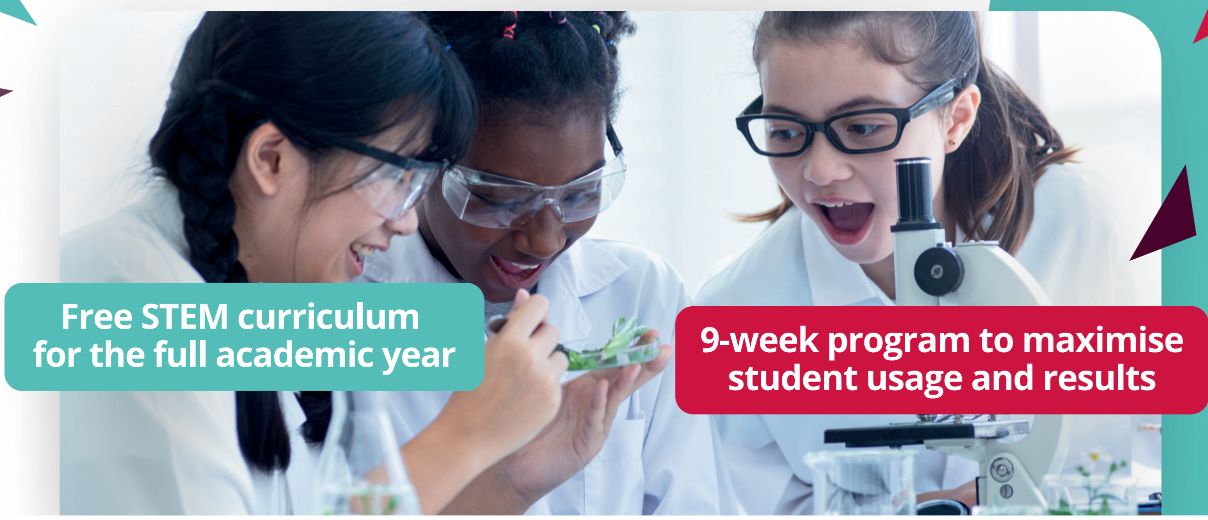

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Special thanks for this issue go to: Andy Chandler-Grevatt (Lead writing mentor); Alastair Gittner (Chair, Research Group); Maria Kettle (Student book reviews); Jane Oldham (Chair, Technician Committee and Chair-elect of the Association) and members of the ASE Health & Safety Group for their continued support with this new practitioner-focused journal. We would also like to thank Laura Townsend and Karen Dyer at ASE for their enormous help with the rebranding of the journal.

Contributing to *SSR in Practice*

If you have an idea for an article for *SSR in Practice*, please submit your proposal using the form
https://forms.gle/wcgWj1267Bi6RN7x
Writing outlines are available to support the writing of case study, practical idea and hinterland articles.
See www.ase.org.uk/submission-guidelines
SSR in Practice and *SSR in Depth* are published in November, March and June as an add-on benefit of membership of the Association for Science Education. They are also available on subscription from the ASE.

ISSN 2755-256X

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

- the requirements of UK health & safety law are observed;
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- 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 page 3 of *SSR in Depth*.

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Editorial

Fiona Williams, *SSR* Content Editor

Welcome to the November issue of *SSR*. As you will see, there has been a lot of activity behind the scenes to apply the new brand to the journal. There is a great mix of articles in this issue – I hope that there is something for everyone.

SSR's inaugural photo competition ran over the summer break. Thank you, everyone, who took part in the competition. We had some stunning entries, and you can see the winning and runner up photographs on page 35 of *SSR in Practice*. I would like to showcase the striking pictures taken by twins Charlotte and Patrick, aged 9½. Our youngest entrants have done a splendid job in capturing 'light in the natural world'. Well done!

Photo by Charlotte Hoath

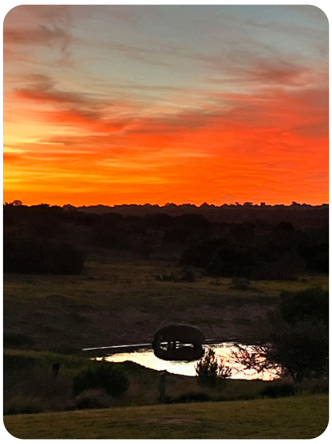

Photo by Patrick Hoath

In *SSR in Practice*, we have included a selection of book reviews written by students on books with a chemistry theme that they have chosen themselves. These reviews have been written by students who are studying science at post-16 and would like to study a scientific discipline at university. It can be difficult to keep abreast of the various popular science books that might be of interest to our students. We hope that you can share this centrefold with your students.

In the area of real-world science, Andy Markwick's articles provide insight into some recent developments in the extraction and recycling of E-metals using deep eutectic solutions. E-metals are those that are used in electronic-based technologies such as batteries, electric motors and smart phones. As we look to move away from fossil fuels, this is an important area, given our increased use of transportation, technology and communication. The article in *SSR in Practice* contains an overview of the extraction and recycling of E-metals and provides great context for teaching, while, in *SSR in Depth*, the use of deep eutectic solution chemistry is explained as an environmentally friendly way of extracting and recycling important E-metals.

In *SSR in Depth*, David Read and Stephen Barnes report the findings of their study into topics that chemistry teachers find difficult, one of these being electrochemistry, while, in *SSR in Practice*, Jennifer Marchant brings to life the topic of electrochemistry with some real-world examples.

Inclusion is very topical at present. Fiona Roberts shares some practical adaptations for students with SEND – a vital read for all as we strive to make our classrooms and teaching inclusive for students with a range of individual needs. In a second article on inclusion, Carole Kenrick writes about her experiences of putting into practice the IOP guidance on inclusive science teaching; it is a very relevant article for teachers of all the sciences.

Finally, on page 36 of *SSR in Practice*, Helen Harden (Commissioning Editor) writes about ways that you can contribute to *SSR*.

This is your journal. As such, we want to read about and share in your knowledge and practice. If you have never written for *SSR* before and are unsure whether your article idea is suitable then please get in touch with Helen at helenhardenase@gmail.com

Fiona Williams

For further articles you can access *SSR in Depth* online at www.ase.org.uk/SSR-in-depth/issue-389

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

Where are the physics teachers? Challenges and opportunities in retaining physics teachers

Mark Whalley discusses the challenges of physics teacher retention, and reflects on some possible solutions

It is common knowledge that recruiting and retaining teachers across all subjects is increasingly challenging, but we know that for physics it is especially so. We know that too few teachers are entering the profession, but this is compounded by the number leaving, taking away valuable expertise and affecting opportunities and outcomes for students. In physics, the situation is exacerbated but there are actions that schools can take to improve retention of their physics teachers and maybe even help in recruiting new ones.

The recruitment and retention problem

In England, recruiting trainee teachers across many subjects has proved to be a thorny issue, and one that even with a range of bursaries and scholarships, has proved to be stubbornly resistant to government initiatives, and in no subject, over the last four years, has it remained more so than in physics. Over the last decade the number entering physics initial teacher training (ITT) has remained in the region of 500 each year; Figure 1 shows how the number of physics trainees undertaking initial teacher training in England compares with the Department for Education's (DfE) recruitment target over that period. In 2021/22 the target setting process was changed to reflect the actual need for teachers and this target has grown as targets fail to be met. The gap between targets and ITT recruitment continues to grow, and the odds of it closing in any significant way soon look slim. It is also worth noting that only about 70% of those who commence ITT in physics take up positions in state schools when they qualify.

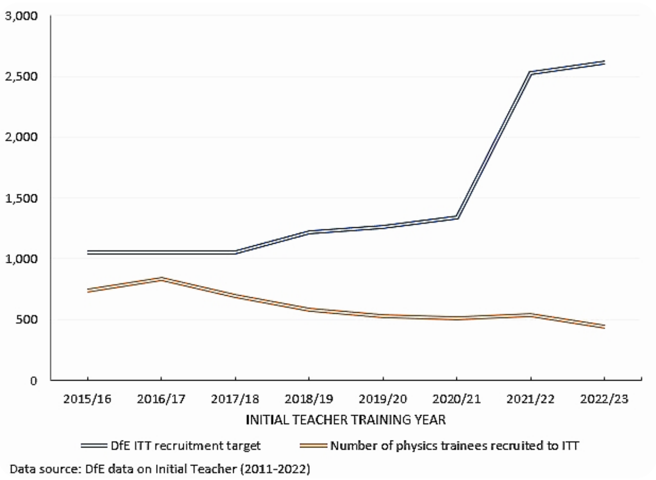

Figure 1 Physics initial teacher training targets and number of trainees from 2015/16 to 2022/23

However, this is not just about recruiting trainees. There is a clear limit to how many trainees are recruited in any year, and this is significantly influenced by the number of physics graduates; the most recent data from HESA (2020/21) for England shows that this is approximately 4000, of whom only about 7% consider teaching as a career (Prospects, 2023). The other major challenge, which is within the influence of schools, is keeping hold of the physics teachers already in the profession. Data from NFER (see *Useful links*) show an annual attrition rate across most subjects at around 9% to 10%, and we have also seen recently that the percentage of teachers leaving teaching for retirement has plummeted from 34% in 2011 to only 9% in 2022. Quite simply too many teachers are leaving the profession too early.

It is worth noting that the situation is even more challenging in certain communities. Sibieta (2020) reports that both recruitment and retention, especially of teachers in shortage subjects, is even more difficult in areas with the highest levels of social deprivation. Students from those communities will be even more adversely affected.

Why are teachers leaving?

The DfE's own research, *Working lives of teachers and leaders* (DfE, 2023), shows that 28% of secondary school teachers are considering leaving the state school sector within the next 12 months. The most commonly reported reason is high workload, but also listed is government initiatives, performance pressures related to inspection and outcomes for students, dissatisfaction with pay, and lack of support from leaders.

My own research focuses on the experiences of physics teachers, looking at both the relationship between intentions to leave and job satisfaction (in collaboration with the Institute of Physics), and also the experiences of those who have left the profession (supported by The Ogden Trust). Physics teachers can be seen as an extreme subset, a group who seem less likely to enter the profession and also possibly more likely to leave it for a range of reasons, including more lucrative careers outside of teaching. What we can learn from this research will hopefully be applicable not only across all science disciplines but also across all subjects.

External factors: things we probably can't change

The reasons why teachers are leaving can be divided into two groups, external factors that are probably beyond the control of school leaders, and those internal ones that leaders can directly influence. The two most significant external factors causing teachers to consider leaving the profession are pay and performativity. We are all aware of the recent problems around teacher pay, but this is compounded for physics teachers; Figure 2 shows the pay differential for teachers and non-teachers for various subjects, showing a positive differential of more than £6000 for physics graduates outside of teaching.

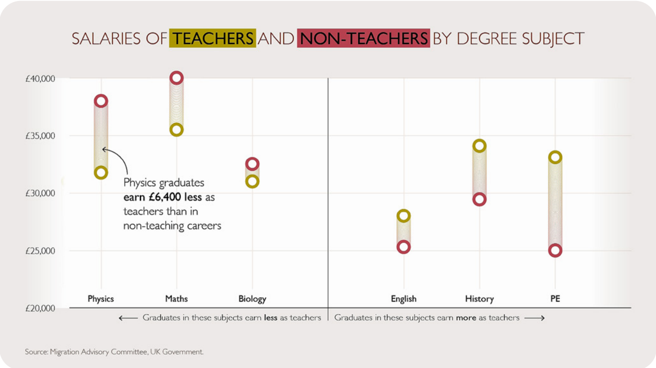

Figure 2 Salaries of teachers and non-teachers by degree subject (reproduced by kind permission of The Gatsby Foundation)

Many schools have control over their salary structures, but these are limited by the budget they receive, and it would also be a brave head teacher who adopted a subject-based pay policy.

Performance measures are inescapable, whether because of Ofsted or for student attainment and progress. Our education system has become increasingly high stakes in nature, and pressure is distributed throughout all tiers of the profession, placing an increased burden on everyone.

It is also worth considering the representation of teaching by the media. One does not have to look too hard to find the teaching profession being vilified by certain parts of the media, views which are too often reinforced across social media as well.

Internal factors: making a difference

At the heart of improving job satisfaction is high-quality leadership; good leaders do make changes happen. Workload is controllable by schools – adopting sensible planning and assessment procedures can significantly reduce workload and teacher stress. Timetabling is also within the gift of schools: consider implementing matched timetables, especially for early career teachers, where you allow teachers to teach their specialism and to have repeat classes, thus reducing planning workload. You can also encourage teachers into school with part-time or flexible working arrangements.

Ensuring that schools are welcoming and supportive places for teachers to work is vital. Whether it is the prep room or the staff room, all teachers benefit from positive relationships with colleagues; these school-based communities of practice are home to informal coaching and mentoring, and allow the sharing of best practice.

While shared planning and resources are a force for good in reducing workload, schools should be conscious of being overly directive when it comes to the act of teaching. Teacher agency, the establishment of professional identity and job satisfaction are related, and prescriptive approaches to classroom practice diminish a teacher's sense of professionalism.

Conclusions

The retention problem will not be solved overnight, but actions in school can help teachers of all subjects, including physics, feel more valued, improve job satisfaction, and reduce the chances of losing our most precious educational assets, the teachers.

Useful links

DfE data on initial teacher training (2011–2022): www.gov.uk/government/collections/statistics-teacher-training

HESA, the Higher Education Statistics Agency: www.hesa.ac.uk

NFER data recruitment and retention dashboard: www.nfer.ac.uk/key-topics-expertise/school-workforce/teacher-recruitment-and-retention-in-england-data-dashboard

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Technician – a career on life support?

Caroline Butler discusses the relevance, benefits and barriers to training and professional learning for technicians

Within educational departments, technicians are a pool of talent. Their reservoir of practical knowledge supplements that of our teaching colleagues to deliver successful and effective teaching and learning across the STEM curriculum. As subject-matter experts, technicians are often said to be the 'lifeblood' of a department. Then why is it that many of us feel undervalued, struggling to get professional learning (PL)/continual professional development (CPD) opportunities, on career 'life support'?

Current landscape

The modern role of a technician requires a diverse range of skills. We often support multiple subject areas – chemistry, physics and biology – and require a working knowledge in each of these to Advanced Higher/A-level. We suggest or design experiments, equipment and apparatus, manage hazardous substances and, given that we are often in lone-post situations, must be self-starters, highly organised with an ability to work in situations where our colleagues have a range of diverse experiences. Essentially, we are polymaths. These skills need to be continuously honed, and that's the function of effective PL/CPD.

Research

In Scotland, this lack of commitment was highlighted in annual STEM surveys by Education Scotland (2021; 2022). Looking at PL/CPD across education sectors, it identified school-based technical support staff as reporting the lowest number of STEM PL/CPD hours. The surveys highlighted how, in addition to funding barriers, factors such as a lack of support from employers and the changing role/workload since the COVID-19 pandemic are impacting the ability of technicians to access PL/CPD. Similar trends were identified in England by the Gatsby report (2017), which recorded that only 56% of schools and colleges responded stating that their technicians had regular opportunities for professional development. The Royal Society of Chemistry *Science Teaching Survey* (RSC, 2022) reported similar findings, with only 34% of teachers and technicians in Wales having received adequate PL/CPD, and only 16% in Northern Ireland! With this background, it is easy to see why technicians can be disenchanted with their roles. School technicians are becoming an endangered profession. NFER (Worth, 2020) reported that, since 2011/12, the average number of FTE science technicians per school has fallen by 16% in England. SSERC (Scottish Schools Education Research Centre) reported in *TES* in 2018 a drop of 37% from 2005 to 2018 (Seith, 2018).

In addition, anecdotal evidence suggests that recruitment and retention are now becoming issues, with over 100 vacancies advertised in *TES* over the summer period, many of them being re-advertisements.

Many of us will not be surprised by this, feeling that our profession does not get the recognition, support or pay that it deserves. Technician hours are often seen as an easy target, when organisations have to deal with ever-smaller budgets, with hours being lost not just through direct job losses but also through depreciation, with contracts changing from full time to term time only. Our roles also face job creep, with some of us tasked with IT, first aid, exam invigilation, reprographics and lunch and break-time duty, to name but a few.

Our roles are being diluted, often at the expense of science, with less time for behind-the-scenes work such as practical development, testing and maintenance. It also means there is often no succession planning, no transfer of knowledge from one generation to the next. Given the fact that often technicians find themselves in lone roles, is it any wonder that recruitment and retention are issues?

In practice

It is a key, but not often acknowledged fact, that technicians lessen teacher workload. The Ofsted (2023) report highlights this support role and the surveys by RSC (2022) and NFER (Worth, 2020) reported similar findings, with the latter calling for research into better understanding of this relationship. The question of what is *Good Practical Science* was examined in the Gatsby report (2017), which found a strong consensus '*that hands-on practical work is an essential part of learning science*'. It went on to say that not only do technicians play an essential role in delivering practical science, but that their skills need constant honing through PL/CPD.

> *Science technicians played a key role in supporting teachers to deliver high-quality practical work across schools. This support was particularly valued by teachers new to teaching science and*

those teaching outside their area of specialism. In schools where technicians were valued staff, supported with appropriate training and CPD, practical work was more likely to be high quality, well-resourced and meaningful. (Ofsted, 2023)

Key scientific bodies too have highlighted the importance of technicians, including SSERC, CLEAPSS, the Association for Science Education (ASE), the Royal Society of Chemistry, the Institute of Physics and the Royal Society of Biology. Between them they provide many excellent PL/CPD opportunities. Professional registration, RSciTech, and the Technical Champions quality mark (see *References*) are options available to individuals and organisations willing to support technicians further.

While suitable courses exist, cost and geographical location can be barriers to participation. However, online training courses are available, some free of charge, and organisations such as the ASE run courses for both new and experienced technicians. While residential courses tend to be more expensive, some offer subsidies reducing the overall cost.

Professional review and development (PRD)/annual appraisal is an important process that should be offered to all staff. When PRD is done well, it is a key means to identify where individual, and team, strengths and weaknesses lie. The identification and addressing of these skill gaps is critical to the PL/CPD process.

Where career progression into senior/leadership roles is available, opportunities to attend relevant training should be given to maximise the potential of the overall service provided. The ASE has a leadership programme for technicians online and SSERC are investing in this area. CLEAPSS offers health and safety management and audit training courses and STEM Learning offers a number of options nationwide.

Much of what makes a high-performance individual is the accumulation of knowledge and experience. This aspect is vital for advising, training and demonstrating practical techniques to teaching colleagues. Since the COVID-19 pandemic, there is anecdotal evidence that this part of the job role has expanded, with technicians 'bridging the gap' with regard to practical skills that students and our NQT teaching colleagues missed out on during this period. While a great example of peer-to-peer learning, it also highlights the role of technicians as a repository of practical knowledge.

The leadership challenge

Technicians are vital parts of your educational team who want to help deliver excellence. It is important then to see what the technician team does, to understand the diverse nature of their roles and how technicians can help your institution engage, inspire and direct our young people into future STEM careers. Practical work is key to motivating young people in science, we can and should be doing more, and technicians are part of this solution.

Conclusion

We all have to acknowledge that the current fiscal environment is challenging, but investment in the technician service UK-wide is absolutely necessary and at a tipping point. Without better career structures/pathways, PL/CPD, improved pay and most importantly adequate technician provision and recognition we cannot hope to recruit and retain a professional and motivated workforce. We risk losing essential skills and knowledge as experienced staff leave the service. I would strongly argue that the status quo is no longer delivering job satisfaction for technicians.

Ultimately, we deliver high-quality hands-on practical experiences that engage our young people; without technician investment teaching and learning will suffer.

After all the reports and research, if not now, then when?

Acknowledgement

Thanks to Jane Oldham for help with preparing this article.

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Powerful learning: delivering the curriculum through open-ended investigative projects

Maria Rossini outlines how BSA CREST Award projects can be integrated into the curriculum

Effective practical science is a vital part of a high-quality science education, and all students should have opportunities to do open-ended and extended investigative projects at some stage in their educational journeys (Gatsby, 2017: 38). However, there is large variation in the quality and quantity of practical science work taking place in schools across the country (Ofsted, 2023). In secondary schools, this has been attributed to a range of factors, including a heavy focus on science content resulting in fewer opportunities for students to practise and consolidate their learning, fewer school science technicians to support practical work and lower numbers of teachers with specialist (especially physics) backgrounds.

In 2020, the British Science Association (BSA) commissioned a pilot study that concluded there is high value in incorporating open-ended investigative science projects into the curriculum and that more must be done to ensure all young people leave school with a secure foundation in science and feel that science is 'for them'. Following that, the BSA developed and disseminated a guidance toolkit to help more teachers deliver the curriculum using its CREST Awards scheme, which is detailed below. The project has now been evaluated, with significant positive findings.

Embedding open-ended investigative practical work into the science curriculum at key stage 5 (ages 16–18) in England

The pilot involved 10 secondary schools in England, including comprehensive secondary schools, a university technical college and a sixth-form college.

In-person training was held with the lead staff from the pilot schools, and those that were unable to attend were given online training through a webinar. The lead staff were then offered support across the academic year, including a meeting once a term, as well as support over the phone.

The timing of the pilot coincided with the height of the COVID-19 pandemic; however, many of the projects were able to continue using home learning during the national lockdown.

A full summary of the pilot, including the methodology used and the results for the schools can be found in the March 2022 *SSR* (Clegg and Collins, 2022).

A pilot study: Building project work into the curriculum

The BSA's CREST Awards programme inspires young people to think and behave like scientists and engineers through extended, student-led, open-ended investigative projects. The evidence-based programme provides practical activities and resources that enable students to develop key skills and embed knowledge in a way that brings together scientific concepts and topics that are relevant to their lives.

In the 2019/20 academic year, 10 secondary schools took part in the BSA's 'CREST: Building project work into the curriculum' pilot study, funded by the Gatsby Charitable Foundation. The pilot aimed to encourage more schools to embed open-ended student projects within the formal science curriculum.

As detailed in a previous *SSR* article by teachers Amanda Clegg and Karen Collins, the pilot project involved a research review, mapping resources from the CREST Awards scheme to the science curriculum and mentoring teaching leads in the 10 schools (Clegg and Collins, 2022). The schools were based across England and supported a variety of students from different communities, socioeconomic backgrounds and ethnicities. For example, the proportion of students eligible for pupil premium across the pilot schools ranged from 8% (Hertfordshire) to 55% (Lincolnshire).

Guiding teachers in open-ended investigations

Based on learnings from the pilot project, the BSA published its *Investigative practical science in the curriculum: making it happen* guidance for teachers in April 2021 (British Science Association, 2021) and commenced a year-long communications campaign to disseminate the findings of the pilot. The guidance provides a step-by-step plan and top tips for how to embed open-ended extended investigative work into the curriculum, and explains why it is beneficial for students and teachers alike. Teachers are encouraged to consider which area of the curriculum would be used as a focus for the CREST Award selected and what core knowledge, practical skills and techniques students may need to know in advance. Student research is an important step in the process. Ideally students should generate the project idea and question and conduct preliminary research as independently as possible, as a feeling of ownership over the project is key for investment.

The guidance also explores eight reasons that teachers and students who participated in the pilot project identified for embedding practical science work in the curriculum, including:

- To improve student motivation: '*The chance to do extended research helped me learn more and be more interested in science.*' (Year 9 student)
- To extend investigations beyond an individual lesson: '*You don't get many opportunities to do blue sky science; to show students what science is really like, that it is not a quick answer from a half-hour practical.*' (Head of biology)
- To value practical work as a learning experience in itself: '*I chose the experimental method myself and I think this made me more invested in the project.*' (Year 13 student)
- To reduce the number of hours outside the curriculum for teachers and technicians: '*We have not deviated from our curriculum plan particularly; we have delivered it differently and the students have enjoyed it and learned more.*' (Science lead)

Evaluating the guidance and reporting the results

An evaluation of the guidance was carried out in June 2022 (British Scienec Association, 2022). A survey was conducted with 93 respondents, and qualitative interviews were conducted with 13 school staff who participated in the pilot phase.

The evaluation found that:

- All respondents rated the guidance as 'good' (38%) or 'very good' (62%).
- CREST can and is being run successfully in curriculum time.
- The number of CREST projects in the curriculum has risen due to increased teacher, pupil and senior leadership buy-in.
- CREST improves the inclusiveness of the curriculum, as it is accessible for all children, and provides equity of access for investigative work.

Since the guidance about using CREST in curriculum time was produced, teachers' use of CREST Awards as part of the curriculum has increased by 41% (from 44% of all CREST Awards in 2018/19 to 62% in 2020/21). During this period, there has also been a significant rise in the proportion of Gold and Silver level CREST Awards being completed in curriculum time across the UK. Gold CREST Awards are the most extensive open-ended projects CREST offers, requiring 70 hours' work. The proportion of Gold CREST Awards being completed in curriculum

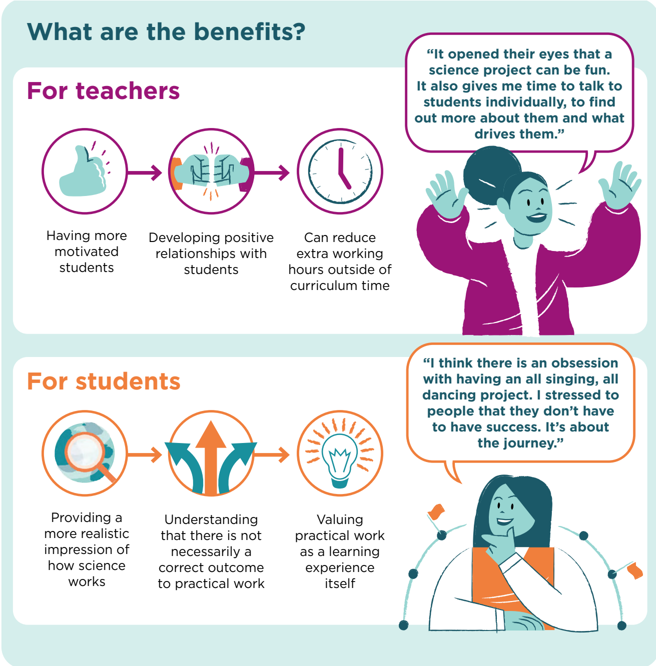

Figure 1 The benefits of embedding open-ended student projects within the formal science curriculum; source: British Science Association (2022)

time increased by 157% in the four project years (from 7% before the guidance was published, to 18% afterward). Meanwhile, the proportion of Silver CREST Awards completed in curriculum time, which require 30 hours' work, increased by 182% (from 11% to 31%) in the same timeframe.

Numerous benefits for teachers and students were identified in the evaluation of the project (Figure 1). Students reported that they were more motivated, which benefited them and their teachers, as, according to surveys and interviews, lessons were much more enjoyable and productive. Teachers who took part in the pilot also reported that they were able to build more positive relationships with students. Running open-ended, extended investigative work in the curriculum, once it had been bedded in, was also found to reduce some teachers' planning time overall, as it reduced planning and time requirements for out-of-school clubs.

There is a lot to be gained from including open-ended investigative science projects in the curriculum. However, the evaluation also found barriers for embedding this practice, including a lack of curriculum time, senior leadership buy-in and staff confidence. The BSA is continuing to work with schools and partners across the sector to address such barriers. UK schools in challenging circumstances can also access support and opportunities to apply for funding to support CREST activities through the BSA's Engage network (see *Useful links*).

References

British Science Association (2021) *Investigative practical science in the curriculum: making it happen*. https://secondarylibrary.crestawards.org/investigative-practical-science-in-the-curriculum/65418842

British Science Association (2022) *CREST: Building project work into the curriculum*. https://crestawards.org/s/CREST-Building-project-work-into-the-curriculum.pdf

Clegg, A. and Collins, K. (2022) Embedding open-ended investigative practical work into the science curriculum at key stage 5 (ages 16–18) in England. *School Science Review*, **103**(384), 64–71.

Gatsby (2017) *Good Practical Science*. London: The Gatsby Charitable Foundation.

Ofsted (2023) *Finding the Optimum: the Science Subject Report*. London: Ofsted. www.gov.uk/government/publications/subject-report-series-science/finding-the-optimum-the-science-subject-report--2

Useful links

CREST Awards Engage teacher network: www.crestawards.org/engage

Information about CREST and free project resources: www.crestawards.org

Maria Rossini has 15 years' experience working in education and science engagement. She trained in KS2/3 science and now leads the British Science Association's education team.

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Comparing photosynthesis and respiration rates using hydrogencarbonate indicator

Sindhu Jacob describes a method to investigate the relative rates of photosynthesis and respiration in a water plant with the help of hydrogencarbonate indicator

At the IB school where I work, the post-16 age group students conduct a biology experiment using algal beads to see how light intensity affects the rate of photosynthesis. While the results of this experiment are a visual treat, occasionally the students do not manage to obtain the results within the lesson timeframe. I trialled the experiment described here using *Elodea* sprigs and hydrogencarbonate indicator (bicarbonate indicator), and observed the result within 30 minutes.

This method tells the investigator whether the rate of photosynthesis is higher, lower or equal to the rate of respiration. In bright light, the rate of photosynthesis will be higher than the rate of respiration, leading to a net reduction of carbon dioxide (therefore a lower pH and a shift in colour of the hydrogencarbonate indicator to purple). Environments with lower light levels would cause a reduced rate of photosynthesis compared with respiration, leading to a net production of carbon dioxide (therefore a shift in colour of the hydrogencarbonate indicator to yellow). Crucially, the initial red colour of the indicator will be retained if the rate of photosynthesis is equal to the rate of respiration, leading to carbon dioxide consumption being balanced by carbon dioxide production.

The hydrogencarbonate indicator, which contains thymol blue and cresol red, is prepared as described in CLEAPSS *Recipe Card/Book 48, Indicators (carbon dioxide)*. For Scottish practitioners, the SSERC website contains guidance on the use of hydrogencarbonate indicator via the general 'Indicator' section of the Hazardous Chemicals Database.

Technician tips

Hydrogencarbonate indicator colour may vary depending on the supplier. In Figure 1, the initial colour of the indicator was cherry red.

If the indicator colour has turned deep red/purple, adding a pinch of sodium bicarbonate will give it a cherry red colour to use for the experiment.

If the purchased indicator colour is yellow, you can see its colour change from yellow to cherry red and deep red.

SAPS (saps.org.uk) has a document on useful pondweed species, including *Egeria densa*, *Egeria najas*, *Ceratophyllum demersum* (hornwort), *Myriophyllum scabratum*, *Cabomba piauhyensis/furcata* (red cabomba) and *Cabomba aquatica* (yellow cabomba).

The sources below are from the SAPS website. There are several online suppliers, but you could use:

- Urmston Aquatics: www.urmstonaquatics.com
- Blades Biological: www.blades-bio.co.uk

Method

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

1. Wear eye protection throughout the practical and also when clearing up.
2. Label the vials A, B, C and D. Vials A and D will be the controls.
3. Fill the vials with hydrogencarbonate indicator.
4. Cut the same length of two *Elodea* sprigs on the white tile using scissors and a ruler.
5. Gently immerse the *Elodea* sprigs in vials B and C.
6. Cover vials C and D with aluminium foil so light will not pass through.
7. Place the four vials under a lamp.
8. After 30 minutes, observe the change in the hydrogencarbonate indicator colour in vials B, C and D. Compare the colour with that in vial A.

[SAFETY: If a non-LED light source is used, place a large beaker of water or other glass container in front of the vials to limit the heating effect of the lamps.]

Equipment and materials per group

- hydrogencarbonate indicator (bicarbonate indicator) [SAFETY: CLEAPSS *Hazcard 32* suggests it is low hazard. However, it is advisable to be careful and avoid skin exposure. (Although *Hazcard 32* is the relevant reference for the hazards of the indicator used, it does not actually include hydrogencarbonate indicator in the list of chemicals mentioned. However, thymol blue and cresol red are covered in this *Hazcard*.)]
- 4 vials with tight lids
- *Elodea* sprigs – see *Technician tips* for pondweed supply options
- scissors
- ruler
- white tile
- aluminium foil
- pipette
- lamp – 75 W / >1200 lumen [SAFETY: LED bulbs can be used as they have the advantage that they do not have a heating effect; do not touch the bulb when the lamp is switched on or just turned off.]

Sample results

See Figure 1 for the results observed after 30 minutes. Vial B, which has an *Elodea* sprig and is exposed to light, has undergone photosynthesis more actively than respiration. The carbon dioxide is used up, and so the indicator has turned a purple colour. Vial C, which was covered with the aluminium foil, has turned yellow because photosynthesis did not occur in the absence of light, but respiration continued; this resulted in a higher net concentration of carbon dioxide in the indicator, and so the hydrogencarbonate indicator turned yellow.

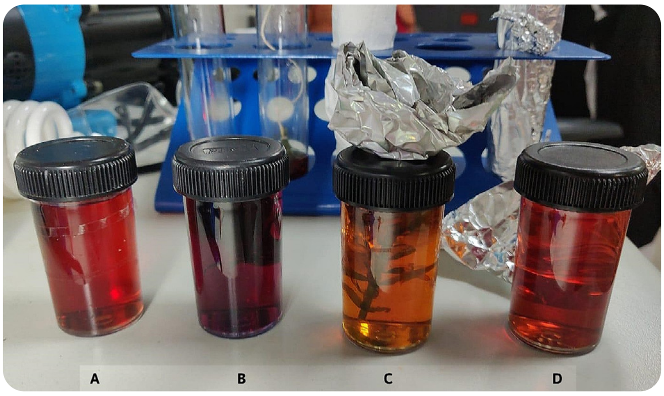

Figure 1 Results after 30 minutes; the aluminium foil has been removed from vials C and D

Going further

- pH sensors can be used to demonstrate the change in pH of the indicator in the four vials.
- Vials could be covered with different-coloured filters to see how these affect the absorption of light and hence result in different rates of photosynthesis.
- Algal balls used with hydrogencarbonate indicator is an excellent investigation for students in the 16+ age group. Students learn practical skills while performing the activity and gain insight into the procedure of immobilisation using sodium alginate.

Acknowledgements

I would like to thank Laura Paton, MYP Science teacher at Gems World Academy, Dubai, for sharing the video of LabXchange. In the video the experiment was done using bromothymol blue. I trialled the experiment with hydrogencarbonate indicator since I did not have bromothymol blue.

Useful links

LabXchange, *How to observe photosynthesis and respiration using a pH indicator*: www.youtube.com/watch?v=OwZs90hED0E

SAPS, *'Algal balls' – Photosynthesis using algae wrapped in jelly balls*: www.saps.org.uk/teaching-resources/resources/235/algal-balls-photosynthesis-using-algae-wrapped-in-jelly-balls

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Practical adaptations for students with special educational needs and disability

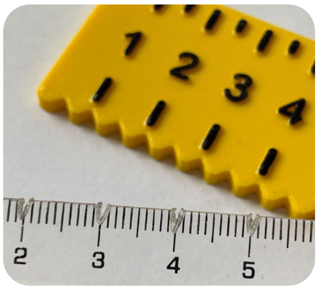
Fiona Roberts describes ways in which science practical resources and equipment can be adapted for special educational needs and disability (SEND) students

As a parent of three children with SEND, and in my role as a science technician at a large mainstream secondary school, I have developed an interest in making science practical work accessible to all. I encounter many students with diverse needs and therefore look at ways to achieve this. I have a particular interest in visual impairments. This article will highlight some ways to adapt and tailor your practicals to benefit your students, using both purchased items and simple homemade resources.

Visual impairment

There are items that can be purchased, but some can be made in house.

I saw a notched ruler in the RNIB shop and thought I could try to make one myself. I chose a clear ruler with black markings, so text is still visible underneath. The ruler was clamped in place and a scalpel was used to make notches at cm intervals. To make slightly larger notches I heated the blade in a Bunsen and then carefully touched the notches to enlarge them. Alternatively, a fine hacksaw could be used. [SAFETY: Take care with sharp blades. Some plastics produce hazardous decomposition products so use a well-ventilated room or fume cupboard.]



Fluorescent tape or paint on retort stands and tripod legs makes them more visible. This is a quick and simple method which, as well as helping VI (vision-impaired) students, acts as a reminder to all students to handle at the bottom where it is cool. The same tape or paint could be used to mark out the workspace, so it is clear where bench edges are.

Measuring cylinders can have markings that are hard to see. Using elastic bands or bright paint can make them stand out more. Using Bumpons (self-adhesive bumps) with different shapes for different-sized glassware, such as round for 100 cm^3 and square for 250 cm^3, is also an effective way to help students quickly identify the difference.

Other SEND

We introduced the use of trays to practical lessons. Students are issued with all their equipment in a tray. This has decreased the number of breakages as students do not need to carry equipment around the lab. For some classes, reagents in the trays are premeasured into bottles or small tubs ready for use. This helps less-dexterous students and has decreased wastage through contamination. Using individual HDPE bottles and dropper bottles reduces the risk of glass breakages from handling larger glass stock bottles.

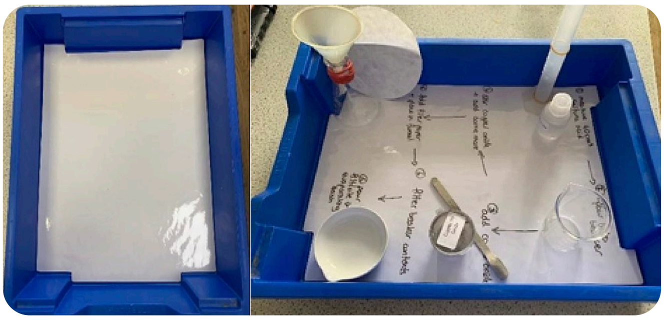
Red and green buttons are found on many equipment items; we have put Bumpons of different colours or shapes on these to help students distinguish them where colour blindness may be a factor. Consistency is key here: always use the same shape for red.

Technology

Technology, while sometimes expensive, allows students a degree of independence with practical tasks. One of our VI students has found that using the camera zoom on a tablet is a straightforward way of enlarging text during a lesson. Many schools recorded practicals during the COVID-19 pandemic for students to watch. Linking QR codes to these, or to particular sections, enables a student to scan the code to watch the relevant steps without having to always ask for repeat instructions.

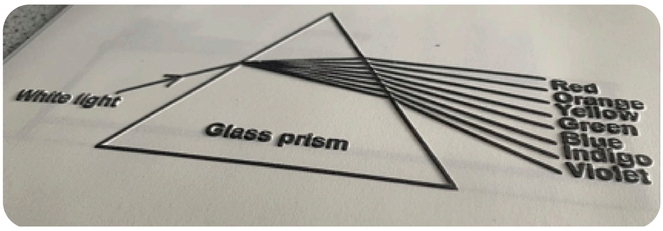
Resource ideas

Laminated practical sheets can be reused and provide a wipe-clean surface. I made inserts for Gratnells trays. These can be printed on coloured paper or kept white and then laminated to provide a wipe-clean, reusable surface. This means that it doesn't matter so much what colour the tray is. They can be tailored for practicals with equipment layouts on or with integrated instructions.



Teaching some basic BSL (British Sign Language) signs for equipment items is a fantastic way to introduce students to the language and raises awareness, even if you do not have deaf students. I have made BSL vocabulary sheets that can be used by teachers or students, which I have used in lessons at primary schools. There is a great article by Claire Ritchie (2023) suggesting how to use BSL in classes.

Exam boards provide papers in enlarged fonts and in a tactile format where diagrams are provided with raised markings. These can also be used as a teaching tool for staff.



Classroom considerations

Often labs aren't ideal workspaces for SEND students. Consider having at least one lab that is accessible. Questions to ask:

- Is there enough bench space for students to work alongside a classroom assistant?
- Is there a height-adjustable bench for students in wheelchairs?
- Are the labs noisy environments? Students with Auditory Processing Disorder may struggle to process spoken instructions with background noise.
- What is the lighting like? Consider glare on boards, particularly from lighting or bright sunlight. Ensure interactive whiteboards are clear for all learners – you may need to close the blinds in some classrooms to enhance the display.

Box 1 Raising awareness with staff

To raise awareness of VI issues, I wanted to get a set of impairment glasses. However, they are expensive, so I made our own using some old safety spectacles where either the surface was scratched or where one or more arms had come off. I made holes on both sides with a hot soldering iron and fixed some elastic around to make them easy to put on. I then rubbed their surface with very fine sandpaper to simulate reduced vision. This could be done to different degrees to vary the reduced visibility. To show different fields of vision loss I stuck black insulating tape to the lens, again in differing amounts. I would recommend using these during a CPD (Continuing Professional Development) session or with trainee teachers. Pop on the adapted glasses and then try to do a practical with and without some of the adaptations. How easy was it? What obstacles did you find? How did it make you feel as a learner?

Conclusion

By providing adapted practicals and equipment we have increased student engagement and confidence in carrying out practical work. Using a tactile exam paper for the first time helped a student become more independent and these are now being used as a learning tool for staff. Most of our practicals are now delivered in small trays for all students, which has helped with speed and classroom control, particularly in classes with a high proportion of SEND students.

Further information and references

CLEAPSS guide *G077 Science for Secondary-aged Pupils with Special Educational Needs and Disability (SEND)*: https://science.cleapss.org.uk/Resource/G077-Science-for-Secondary-aged-Pupils-with-Special-Educational-Needs-and-or-Disability-SEND.pdf

Ritchie, C. (2023) How sign language can help all learners. *Education in Chemistry*. https://edu.rsc.org/ideas/how-sign-language-can-help-all-learners/4017392.article

RNIB science equipment: https://shop.rnib.org.uk/education/curriculum-subjects/stem

Science BSL signs: www.ssc.education.ed.ac.uk/BSL

Fingerspelling Alphabet (BSL): www.british-sign.co.uk/fingerspelling-alphabet-charts

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Top tips for inclusive teaching

Carole Kenrick shares her experience of putting into practice the new guidance from the Institute of Physics on inclusive science teaching

'So, for example, let's consider an astronaut …' An audible gasp from Shanice and Leila stops me mid-explanation. They turn to look at each other and then back to the object in my hand. Their mouths are wide open, surprise and delight in their eyes.

We are learning about weight and terminal velocity. After handing out cans of crisps and calculating their weight on different planets to address the common confusion between mass and weight, I showed my year 11 class (ages 15–16) a video of Felix Baumgartner's freefall from the edge of space (see *Useful links*), and then moved on to the concept of 'weightlessness'. I mentioned Mae Carol Jemison, the first African-American woman astronaut (also a dancer, actor and medical doctor) and brought out my doll, who like Jemison, and my two surprised students, is Black. My doll has an afro, and is dressed as an astronaut. I deliberately chose to use this doll in my explanation to counteract stereotypes about physicists, but I didn't anticipate such a big reaction. Shanice and Leila come up to my desk at the end of the lesson to see the doll and to hold her: *'She looks like me!'*

One of my goals as a teacher is for my students to feel they belong and have what they need to thrive in my lessons. Shanice and Leila's reaction to the astronaut doll highlights the importance of representation in the classroom. Seeing someone who looks like them engaged in scientific exploration can have a profound impact on a student's sense of belonging and their understanding of the possibilities open to them. It is essential to provide students with a range of role models and narratives that reflect the rich tapestry of identities within our society and classroom.

However, inclusive science teaching goes beyond representation. It also acknowledges and addresses the varying levels of literacy, mathematical confidence, learning needs and family connection with science that students bring to the classroom. As teachers, we must strive to provide accessible entry points into science for all students, regardless of their background, needs or prior knowledge.

The Limit Less campaign

In support of the Institute of Physics (IOP)'s Limit Less campaign (see *Useful links*) to encourage more young people from diverse backgrounds to choose physics, my colleagues and I have developed guidance on inclusive science teaching, with input and advice from fellow educators and researchers. It was informed by research and reports including the science capital teaching approach (Godec, King and Archer, 2017), the Royal Society and Education Endowment Foundation report into the link between science attainment and socioeconomic status (Nunes *et al*., 2017), and the Gatsby benchmarks of *Good Career Guidance* (Holman, 2014).

The IOP's *Top Tips for Inclusive Science Teaching* (see *Useful links*) comes in the form of a booklet and a poster, with nine tips subdivided into three themes:

- creating an inclusive classroom culture;
- making the learning relevant;
- building numeracy and literacy for science.

Creating a safe and inclusive classroom environment is key. All students should feel comfortable asking questions, sharing their ideas and making mistakes without fear of judgement or exclusion. Encouraging a collaborative and supportive learning atmosphere builds a sense of community and enables students to learn from each other's experiences and knowledge – and helps them to see themselves and each other as scientists. The booklet suggests some ideas to try in the classroom, including the use of think-pair-share, questioning what a 'good scientist' looks like (critiquing outdated stereotypes), and varying the pronouns used in examples.

Inclusive physics teaching also requires us to critically examine our curriculum and the teaching resources we use and ask whether they are relevant to our students. Are the examples, perspectives and career links we present representative of a range of cultures, different genders and both academic and vocational routes? Are we unintentionally reinforcing stereotypes or biases? It is also important to build on and value students' existing knowledge and experience of science – not only because it helps them to develop stronger understanding and remember and retrieve new information, but also because it helps them to think of themselves as scientists.

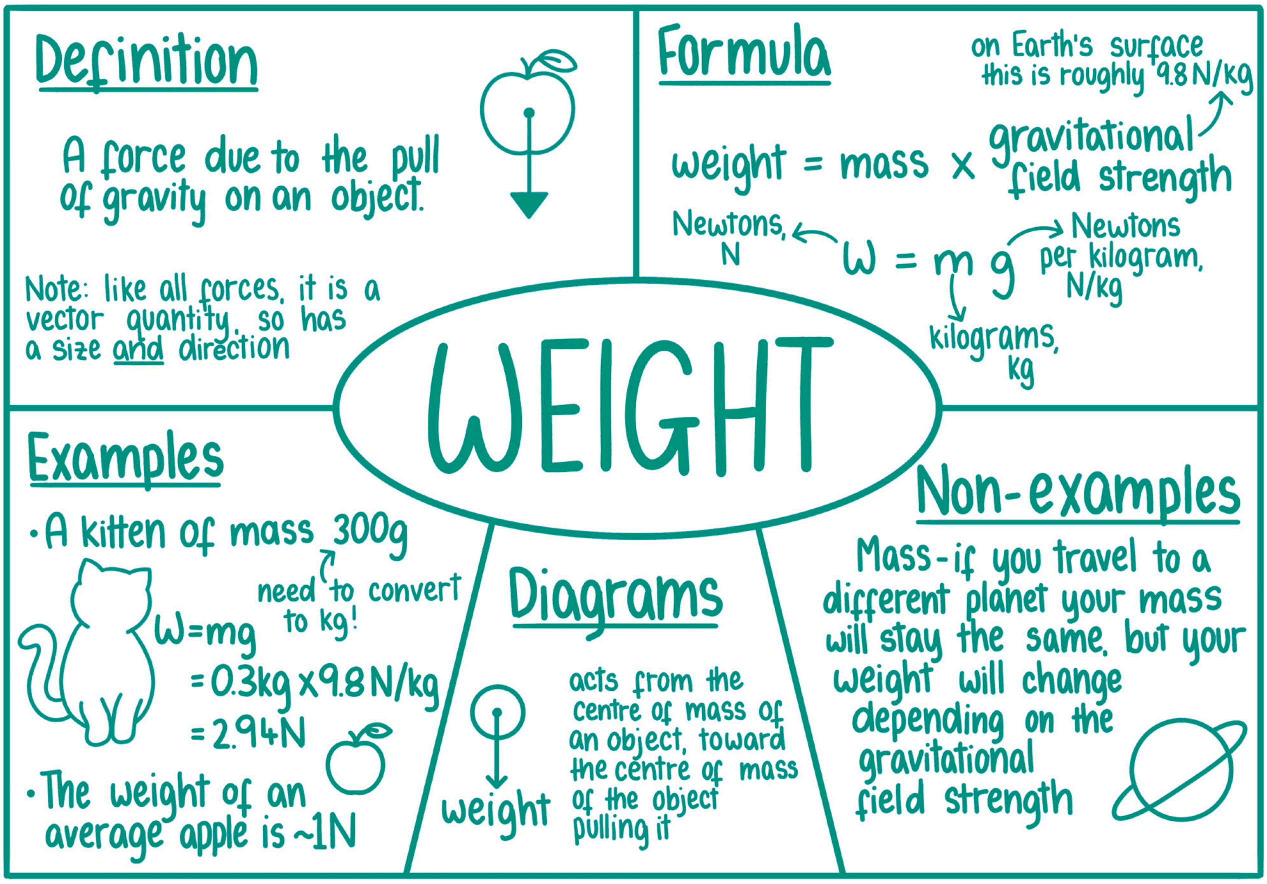

Figure 1 Using a Frayer Model to develop understanding of key conceptual words

We also know that students' understanding of and attainment in science is significantly affected by their literacy and numeracy skills. For all students to feel successful in school science, it is therefore important for science teachers to intentionally and explicitly build their scientific vocabulary, get them talking about science and make time for maths. For instance, by using Frayer Models (Figure 1) to develop understanding of key conceptual words such as weight, by using protocols for speaking and listening (the British Council's *It's Good to Talk* document (see *Useful links*) has some helpful examples) and by liaising with your maths department. Literacy is a key area that I have identified as a priority for development in my own practice, and which I am focusing on in my own classroom with these resources.

By actively implementing these strategies and recommendations, teachers can create a supportive learning environment where all students feel valued, able to access the learning and motivated to explore and excel in science.

Next steps

- Use the IOP's *Top Tips for Inclusive Teaching* as a tool to reflect on your practice and identify what you are already doing (share this with colleagues!) and ideas to try out in your classroom.
- Use the *Top Tips* as an auditing tool across your science department, multi-academy trust, federation or other cross-school partnership – this could inform departmental and whole-school inclusion plans.
- Share the IOP's Limit Less campaign with a member of your senior leadership team and get them to sign the manifesto for change.

Useful links

British Council *It's Good to Talk: Oracy Lesson Plan*: www.britishcouncil.org/sites/default/files/its_good_to_talk.pdf

Felix Baumgartner *I jumped from space* video: www.youtube.com/watch?v=Hz2F_S3Tl0Y

Limit Less campaign: https://iop.org/InclusiveResources to champion inclusive teaching and https://iop.org/WholeSchool for resources to promote whole-school equity and inclusion.

References

Godec, S., King, H. and Archer, L. (2017) *The Science Capital Teaching Approach: Engaging Students with Science, Promoting Social Justice*. London: UCL Institute of Education.

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Nunes, T., Bryant, P., Strand, S., Hillier, J., Barros, R. and Miller-Friedmann, J. (2017) *Review of SES and Science Learning in Formal Educational Settings*. University of Oxford / Education Endowment Foundation. https://educationendowmentfoundation.org.uk/education-evidence/evidence-reviews/science

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Questions for Louise Archer

Alastair Gittner, Chair of ASE's Research Group, in conversation with **Professor Louise Archer**

Louise Archer is the Karl Mannheim Chair of Sociology of Education at UCL Institute of Education and is currently the Principal Investigator of a number of large national projects.

Alastair Gittner (AG): *What were science lessons in school like for you?*

Louise Archer (LA): Mixed – I really enjoyed biology and found it fascinating. I did not have such a good experience of physics and chemistry, although I recognised their importance – perhaps due to my Dad telling me that I had to take physics or I would never be able to function in the world. I have actually found them more interesting since leaving school, particularly aspects of astrophysics.

AG: *Was there a particular science teacher who you remember inspired you?*

LA: I really liked my biology teacher – she was fun, shared her own personal experiences with us (e.g. in relation to childbirth when we were covering reproduction) and her brother was a drummer in an 80s pop band who were in the charts at the time, which gave her added cred in our eyes!

AG: *How did you get into educational research?*

LA: I have always been interested in schools and education and most of my family are or have been teachers, head teachers or lecturers, so it was perhaps inevitable! My PhD was in social psychology and focused on the educational experiences of British Muslim pupils, so I guess that is where I first formally started doing educational research.

AG: *You have been leading various projects related to science capital; if you had one message to all schools about this what would it be?*

LA: I think it would be to approach using the science capital concepts, tools and teaching approach through a social justice lens. Often we have seen people skip over this aspect and as a result they can inadvertently end up using science capital in a deficit way (e.g. the idea that young people 'lack' science knowledge, interest or experiences and, consequently, interpreting the approach as just about giving children and young people 'more science'). Tools like the Equity Compass (see *Useful links*) help explain what we mean by a social justice mindset.

AG: *I read a paper by Gina Rippon looking at gender stereotyping of children's interests and how early it can become established. Your projects, from what I read, are focused on slightly older children but could the issues be starting in foundation years and if so how do we build science capital for these children?*

LA: Yes, processes of socialisation are evident from birth and social inequalities shape people's lives from even before then. So absolutely, we need to start challenging injustices and supporting children and young people from the very beginning. Our work focuses not only on how schools and the formal education system can better support, value and build children's science capital but also the role of informal STEM learning – for instance how organisations can work with families and communities to support them to develop and use STEM-related knowledge and skills in ways that support their agency and social action. We're interested in how science can be a tool and vehicle for social change and betterment – not just a future job or qualification.

AG: *If a teacher was interested in developing the science capital of their pupils where should they go for information on your work?*

LA: I'd recommend looking at the Primary Science Capital Teaching Approach handbook and resources (see *Useful links*). Although this is a primary version, it covers the same core ideas as for secondary. There is also a Secondary Science Capital Teaching Approach handbook and resources (see *Useful links*), but the primary one is more recent and I think we articulate the ideas a bit more clearly in it.

AG: *Do you ever feel you would like to be a classroom teacher so that you could put your ideas into practice?*

LA: When I was younger, I did want to become a teacher and I have thought about it at various points over the years. But I found that I really loved research, so I didn't pursue teaching. One of the best aspects of my job is working closely with teachers and being in schools, so it is almost like the best of both worlds.

AG: *I once had a parents' evening where I spent 15 minutes trying to persuade a talented student to do A-levels in science only for his father to sit back at the end of the appointment and undermine everything I had said by saying 'Of course I was rubbish at science in school and it hasn't done me any harm'. School is only a part of children's lives – how do we help parents and wider communities see the value of science capital and that science is for all parts of society?*

LA: For me, your example underlines the importance of us all continuing to critically reflect on what messages and experiences people get from school science and how these don't just affect someone's time at school but can shape their views on science throughout their lives. Our research highlights the detrimental impact of the common stereotype that being good at science or maths is due to 'natural' talent, giftedness or aptitude (e.g. the 'maths brain', the 'science genius'), which tend to be aligned with aspects of social privilege, such as masculinity, whiteness, middle-classness. Our research shows how even students who attain highly in science can come to see themselves as 'no good' at it if they don't fit this notion of the 'naturally' gifted scientist. Your example also makes me think about the importance of approaching science engagement work from the perspective of those who feel alienated or excluded from science – taking these voices seriously and making sure that engagement is built around their identities, interests and needs – not starting from the needs or perspective of what industry or the government wants from STEM participation or engagement.

AG: *What would you have written in a letter to your younger self as they started out on their career?*

LA: I'd say '*don't worry, your career will be interesting and will take you down avenues you wouldn't have expected*'. With hindsight, there are some things that I'd like to have known or done differently, but I guess that is also part of the journey – making mistakes and learning along the way. So I probably wouldn't give myself any spoilers – well, maybe just a couple of small ones.

AG: *Is there some exciting science or learning research that we should be looking out for in coming months?*

LA: The ASPIRES3 final report is coming out at the end of November 2023, which we are excited about. This report summarises findings from the cohort we have been tracking since age 10, who are now in their early 20s. The report focuses on the factors that shaped their trajectories from age 19 to 22, looking at how and why some pursued STEM degrees and qualifications and not others. We focus particularly on pathways into/out of chemistry, maths, engineering and computer science as well as looking in more depth at university experiences and the reasons why some young people achieved social mobility. The other exciting ongoing project for us is Making Spaces 2, which involves participatory work with practitioners and youth in makerspaces in five countries, identifying how we can make practice more inclusive and equitable to help diversify STEM participation and engagement.

AG: *Tell us something about yourself that you think might surprise our readers.*

LA: I agonised a lot over this question! But I guess it would be that I once designed some men's novelty underwear that was a Christmas bestseller in a leading UK high street fashion chain. If anyone was unlucky enough to be gifted that particular festive treat 20 odd years ago, I can only apologise.

Useful links

Equity Compass: https://yestem.org/tools/the-equity-compass

Primary Science Capital Teaching Approach handbook and resources: www.ucl.ac.uk/ioe/departments-and-centres/departments/education-practice-and-society/stem-participation-social-justice-research/primary-science-capital-project

Secondary Science Capital Teaching Approach handbook and resources: www.ucl.ac.uk/ioe/departments-and-centres/departments/education-practice-and-society/stem-participation-social-justice-research/science-capital-teaching-approach

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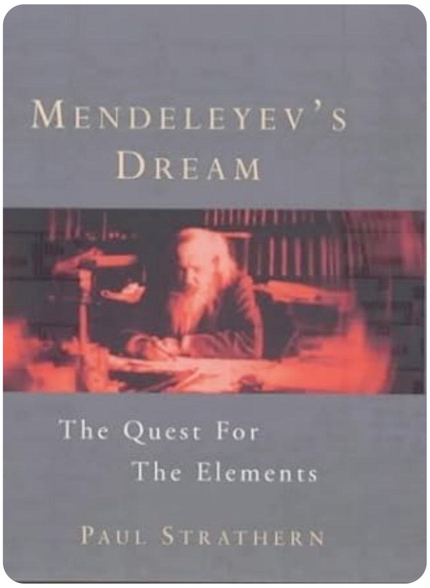
Student book reviews

Post-16 students review books they are reading now, revisit classics and see which new works light a spark



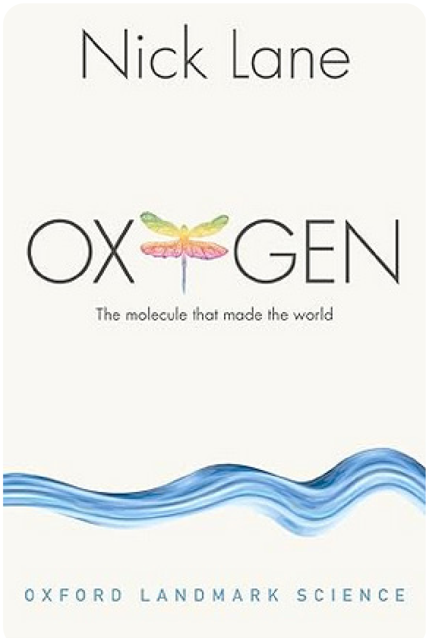
Mendeleyev's Dream: The Quest for the Elements

Paul Strathern
London: Hamish Hamilton, 2000
308 pp. £12.00
ISBN 978 0 24114065 9

Mendeleyev's Dream gives an insightful overview of the history and development of chemistry, describing its movement from philosophy to alchemy and eventually into the subject that we know today, while also provoking thought of future developments.

This isn't a gripping 'page-turner' – Strathern never intended for it to be such; it is ultimately a recounting of the history of chemistry. However, it does have its moments, as it describes the peculiar ways in which advances in chemistry have been made throughout history, exemplified by Hennig Brand's '*prolonged and extensive investigation of the properties of human urine*', leading to the discovery of a new element, phosphorus, in 1669. The concepts presented in the book are accessible, particularly for those with knowledge of chemistry, who should hopefully know more than the chemists being written about, many of whom believed in the interlinking of metaphysics and chemistry, as in the philosophers' stone, the element of aether, or the practice of alchemy, which persisted for millennia. These beliefs seem almost laughable now, but this inspires the reader to think about how much we *don't* currently know, and how our beliefs may seem far from the truth to future generations. This is well encapsulated by Strathern in '*We will all appear flat-earthers to our grandchildren*'.

Leo McGrigor
St Albans School, Hertfordshire



Oxygen: The Molecule that Made the World

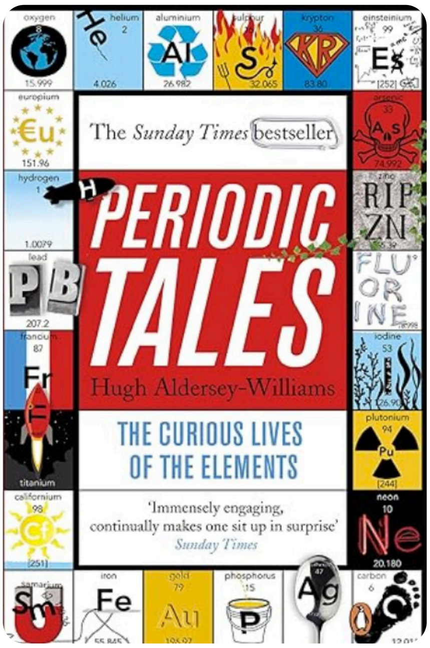
Nick Lane
Oxford: Oxford University Press, 2016
374 pp. £9.99
ISBN 978 0 19 878493 7

Nick Lane takes the reader on a captivating journey by interconnecting chemistry, biology and geology. His engaging and clear explanations make complex scientific concepts accessible, even for a sixth-form student like me with an A-level background in chemistry. Though the book occasionally ventured beyond the A-level specification, Lane's skilful storytelling kept me engrossed.

One enthralling fact that truly stood out was the revelation of the Great Oxidation Event, which occurred around 2.4 billion years ago. As oxygen began accumulating in the atmosphere due to ancient photosynthetic microorganisms it caused a monumental shift, shaping the course of evolution. This increase in oxygen triggered mass extinction for early anaerobic organisms, creating an opportunity for new, unseen aerobic life forms to emerge, which set the stage for the many diverse and oxygen-dependent ecosystems we have today.

Through these captivating stories, Lane not only taught me about the profound impact of a single molecule on life's trajectory but also emphasised the connection between chemistry and biology in shaping the world we inhabit. This book affirmed my desire to pursue a chemistry undergraduate degree and I wholeheartedly recommend it to fellow sixth-form students interested in science and eager to explore the wonders of our world.

Sachin Ravishankar
St Albans School, Hertfordshire



Periodic Tales: The Curious Lives of the Elements

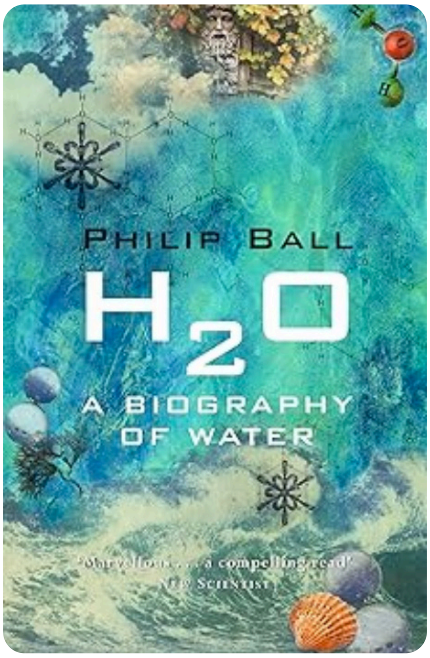
Hugh Aldersey-Williams
London: Penguin Books, 2012
445 pp. £10.99
ISBN 978 0 141 04145 2

Initially I selected the book because I am fascinated with how essential the understanding of elements is and has been for scientific development, and so I wanted to further my understanding of the elements beyond the curriculum. The book was enticing because it not only talks about chemical properties of elements but also their cultural significance and how the properties of certain elements have shaped history. I learnt how old beliefs and superstitions actually have truth to them, backed up by new scientific discoveries, and how connotations surrounding different elements have influenced societal practices through the centuries.

The book is easy to follow as it focuses mostly on historical significance rather than detailing the chemistry of the elements and their reactions. It reinforced my passion for chemistry, further encouraging me to pursue a career involving chemistry as I was intrigued by the discoveries made about elements over the years (not just by scientists) around the world. I would recommend this book not only to students studying science, but anyone wanting to widen their knowledge of past and present cultures and practices as the book details the major impact the different elements have had on our civilisation.

Simone Aramesh
St Albans School, Hertfordshire

H_2O: A Biography of Water



Philip Ball
London: Orion Publishing, 2000
400 pp. £10.99
ISBN 978 0 75381092 7

H_2O by Philip Ball describes not only the chemistry of water, as the name implies, but also water's physics and impact on life from the smallest to the largest scale. As an A-level chemistry and physics student, I was looking for a book that went into depth on the specifics of why water behaves as it does, and *H_2O* fulfils that criterion perfectly.

It goes into detail about the intermolecular interactions between water molecules under different conditions, perfect for sixth-form students looking to deepen their understanding. Yet it remains accessible to those with only a rudimentary knowledge of science: I was perfectly capable of enjoying the sections on biology with my GCSE-level knowledge. I was fascinated particularly by the sections describing liquid water at temperatures as low as –37 °C, and the struggle to lower the temperature of water further without freezing.

Despite the ubiquity of water on Earth, it still holds many mysteries. I now plan on giving a presentation on this topic to my school Chemistry Society, and I suspect you will find yourself similarly inspired by at least one part of this 'biography' of water.

Fraser Hutton-Squire
The Judd School, Tonbridge, Kent

Acknowledgement

Thanks to Deepika Narula, Research and Outreach Coordinator and teacher of chemistry at St Albans School, for supporting the student reviewers at her school.

If you are interested in your students becoming student reviewers look out for information in the next issue.

How to power a space station – hinterland electrochemistry

Jennifer Marchant shares some ‘green chemistry’ hinterland ideas for teaching electrochemistry

Electrolysis and fuel cells – the zero-carbon combination

How many students claim electrochemistry to be their favourite topic? GCSE (KS4, ages 14–16) and A-level (KS5, ages 16–18) chemistry courses all require students to be familiar with several electrochemical processes – electrolysis and fuel cells at GCSE, and electrochemical cells also at A-level. For an increasingly climate-science-aware generation of students, the opportunity to learn how these processes link together to produce green power could support students to better understand the differences and similarities between them while also improving science capital.

Building links

Electrolysis is usually the first process taught in my curriculum, often using the context of extracting metals to study the electrolysis of molten ionic compounds, followed by electrolysis of aqueous solutions. I have found that students often struggle with identifying which ions are present in aqueous solutions, and adding in these green technology contexts at the start of the topic can help. The electrolysis of water is a key part of the green energy pathway, and so students can focus on some key ideas to support their learning, but which are not always taught explicitly, such as:

- water is broken down into H^+ ions and OH^- ions, supporting the understanding of the electrolysis of aqueous ionic solutions;
- electrolysis uses electricity to allow a non-spontaneous redox reaction to occur (it's not just ‘splitting chemicals’), hence water is electrolysed into the constituent elements of hydrogen and oxygen, a chemical change that is not normally feasible!

The next electrochemical process covered is often fuel cell technology, where the spontaneous reaction between hydrogen and oxygen is harnessed in an indirect manner to generate a current rather than produce an explosion.

By using contexts where these reactions are viewed side by side, it is made clear that the processes are opposites, in a similar manner to respiration being the reverse reaction of photosynthesis, as shown in Figure 1. Both contexts show how electrolysis can be used to produce the hydrogen needed for fuel cells,

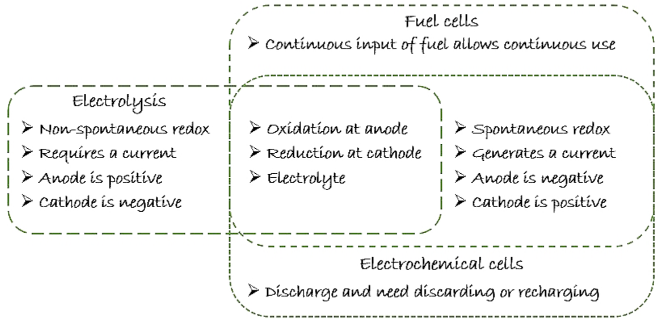


Figure 1 A chart showing similarities and differences between the electrochemical processes

while using excess renewable energy and emitting only water to maintain a zero-carbon process.

Context 1: Electrochemistry on Earth – how to power a train with zero carbon emissions

A modern twist on transport issues can be used at both GCSE and A-level, as an introduction to the topic to introduce how the processes are linked. It means talking about the ‘why’ and ‘what’ before delving deeper into the ‘how’ of the processes and all of the half equations that sometimes cloud the bigger picture.

Rail travel remains a key method of transport for commuters and freight alike, and to achieve this with net-zero CO_2 emissions by 2050 in the UK, the diesel trains need to go! Solutions that can be made green include:

- increasing electrification of lines so more trains run on electricity, using renewable sources;
- battery-powered trains, with batteries being recharged much as with electric vehicles, using renewable sources;
- hydrogen-powered trains, using fuel cells, where the only waste product is water, using hydrogen from the electrolysis of water, powered by excess electricity generated from renewable sources.

Hydrogen-powered trains, such as the ‘HydroFLEX’ prototype that was launched in 2019 by the Birmingham Centre for Railway Research and Education (BCRRE) in partnership with Porterbrook, are being developed to support this zero-carbon transport goal. The train has fuel cells, hydrogen storage and backup lithium-ion batteries on board (Calvert *et al.*, 2021). The advantages of this design are:

- hydrogen is a highly portable fuel, and can be transported with the train to areas where electrification is not possible or cost-effective;
- using electricity from renewable sources directly for charging requires those sources to be providing sufficient power. Solar and wind power production both fluctuate greatly. At times of excess, the electricity can be used to electrolyse water and the hydrogen can be stored to be used in a fuel cell at any point, a convenient alternative to using the electricity to recharge batteries.

Source: University of Birmingham

Context 2: Electrochemistry in space – how to power a space station

The space station context can be used at the start of studying electrochemical cells. A-level students can further explore uses of battery technology and make links to the previous electrochemistry topics before focusing on the physical set-up of cells and the associated calculations. $E^{\ominus}_{cell}$ values can also be used to show that electrolysis is for non-spontaneous reactions, and to explain which reactions do occur when multiple ions are present depending on their relative oxidising or reducing ability.

A big challenge for the green energy generation is developing greener space travel. A constant supply of oil-based fuels has never been an option for the International Space Station (ISS) or future planned space missions, so electrochemical technologies are already widely used for power.

The ISS has eight large 'wings' containing over 250 000 solar cells, but as the ISS orbits the Earth approximately every 92 minutes, 46 of which are completed in darkness, using solar power alone is only part of the solution. An additional power source is required.

The original additional power sources were nickel–hydrogen (Ni–H_2) batteries, and between 2017 and 2021 these were replaced by lithium-ion rechargeable batteries. These batteries can take twice the charge of the old Ni–H_2 batteries and are also smaller, so less space is needed on the ISS for their storage, and they have longer lifespans.

All the batteries eventually end up as toxic waste, so using fuel cells instead on the ISS brings an environmental benefit, with the added advantage that the product of pure water can be used by the crew on board. Wastewater from human activities and reclaimed water from dehumidifying the air are already electrolysed to produce the oxygen required on the craft by the oxygen-generating system (OGS), which makes 2.5–9 kg of O_2 per day (Jakupca, 2022). Currently, the hydrogen produced is reacted with carbon dioxide to produce water using the Sabatier system, with the methane that is also produced being vented. Using this hydrogen in fuel cells would improve efficiency and make the whole process circular. The PEMFC (Polymer Electrolyte Membrane Fuel Cell) is just one of the types of fuel cell being developed to have longer lifespans than those in use on Earth and could provide a more sustainable power supply for the ISS and longer space voyages (Bents *et al.*, 2003; NASA, 2012).

In summary

By using these contexts, students can review:

- the electrolysis of water and electrolysis of aqueous solutions;
- the reactions at the anode and cathode in electrolysis and in fuel cells;
- the difference between the anode and cathode in electrolysis and in fuel cells/batteries;
- electrolysis as the opposing process to fuel cells/batteries (recharging batteries as electrolysis).

Using the context of space can capture the imagination, and the development of cleaner green technologies is of increasing interest to students. This increases their 'science capital' by enhancing knowledge, not just by putting chemistry into context, but by making it relevant to this generation.

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OXFORD

Extraction and recycling of important E-metals

Andy Markwick, Elena Bulmer and **Phoebe Smith-Barnes** explain how the processes of reclamation and extraction of important E-metals are rapidly changing

E-metals are metals that are used in electronic-based technologies, for example in the manufacture of computer components, batteries, electric motors and smart phones. They are often rarer in abundance or costly to extract or recycle. Examples include nickel, gold, silver, copper and the rare earth elements.

The world is awakening to an immediate need to dramatically reduce the use of fossil fuels, particularly for energy production (90%), which results in CO_2 emissions, and to an increase in the use of E-metals for world transportation and communication. However, it is important to recognise that 10% of fossil fuels also have a wide range of other important uses, for example in the manufacture of medicines and building materials (Wollensack, Budzinski and Backmann, 2022). Countries are investing in alternative energy supplies, such as nuclear, wind, wave, hydroelectric and solar, and, as Macdonald (2023) argues, there is great potential in hydrogen fuel cells. A very significant challenge, however, is finding ways to store the energy produced, for example in batteries. Figure 1 shows the high reliance of renewable energy on the production of metals.

One transportation solution that is gaining momentum is the production of electrified cars, vans and lorries. However, with a move towards electrified transportation comes a much-increased demand for raw materials such as metals like Li, Ni, Au, Ag, Sn, Cu, Cd, Mn, Mg and rare earth elements (lanthanides: lanthanum, La, to lutetium, Lu). Figure 2 shows a projection of demand for minerals (metals) by 2050. As a percentage of use in 2017, some of the rarer or more difficult-to-extract minerals (e.g. cobalt and lithium) will need to increase by over 450%.

The standard methods for metal extraction from ores (minerals – often oxides and carbonates) require energy-intensive processes such as smelting (melting of ore) and /or leaching (dissolving out or dissolution) at high temperatures (pyrometallurgy).

For many years, science curricula across a range of countries have introduced students to these extremely important extraction processes, often from an historical perspective. These pyrometallurgy processes have a significant associated CO_2 footprint

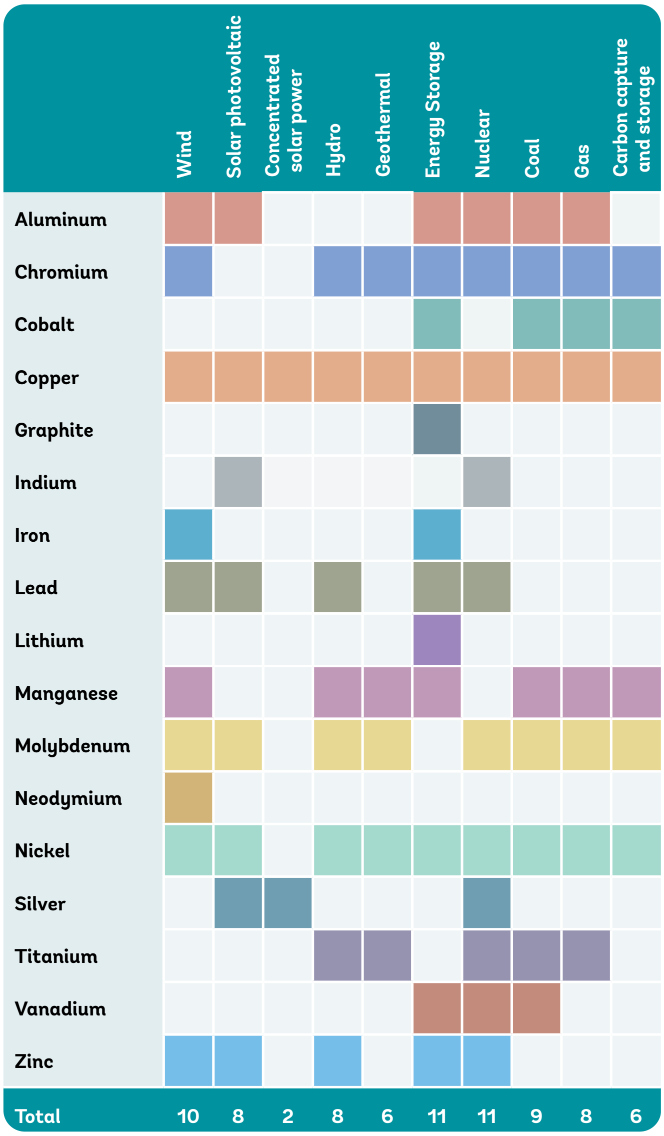

Figure 1 The metals (mineral sources) required for transitioning towards different low-carbon technologies
https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

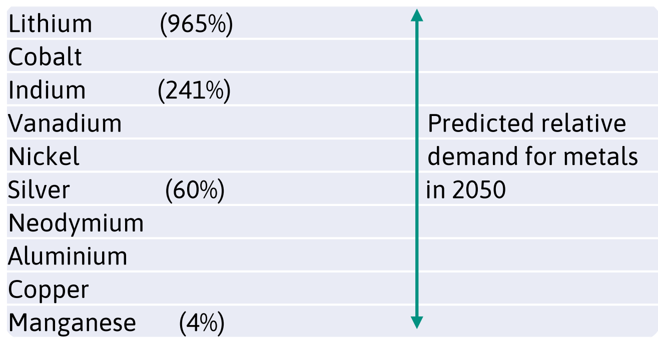

Figure 2 A prediction of the relative demand for metals for 2050 compared to 2017

and often release toxic gases into the environment, such as chlorine, nitrogen oxides, sulfur dioxide, hydrogen sulfide and arsenic. Hydrometallurgy via cyanidation, concentrated acid, alkali or H_2O_2 is widely used in the extraction of metals such as gold, lithium, aluminium and silver and as a consequence too often produces soluble cyanides and heavy metal contaminants that enter watercourses, leading to very significant environmental damage (Thompson *et al.*, 2020). Although such practices provide livelihoods for many, too often they impact negatively on the lives of people who are in poverty.

As a consequence, the processes of reclamation and extraction of important E-metals are rapidly changing, and a quick curriculum response is required to provide students with up-to-date information about future technologies, such as deep eutectic solvents (DES), developed at the University of Leicester (Abbott *et al.*, 2015, Jenkin *et al.*, 2016). These new technologies are critical for global transformation towards carbon-neutral economies and so investment in adapting our current outdated science curriculum for our students seems a sensible way forward. The UK's current GCSE (ages 14–16) and A-level (ages 16–18) curriculums provide a sound conceptual foundation for understanding DES technologies, for example intermolecular bonding, redox, dissolution processes and thermodynamics. It is extremely likely that any future career pathways relating to E-metals and their applications will require students to have a good knowledge of these developing technologies. It is important to recognise that the exploitation of people, particularly children, in the increasing need to extract E-metals will inevitably become worse (McKie, 2021). These conflicting arguments can be utilised extremely well in science to enhance students' argumentation skills.

This increased need for metals for cleaner energy, transportation and communication (e.g. lithium-ion batteries, computer, and smartphone components, etc.) not only requires greater extraction rates from metallic ores (Jenkin *et al.*, 2016) but also the ability to recover metals (E-waste) that have been or would normally end up in landfill sites and heavy metal pollution of the environment. Without an effective strategy to recover and recycle these materials, it has been estimated that, by 2030, 747 000 000 tons of E-waste will be added to landfill sites (Ahirwar and Tripathi, 2021).

E-waste contains a rich source of metals such as gold, palladium, nickel, copper and silver, and primary resources of these metals are becoming rare. It is therefore imperative that alternative metal-extraction processes are discovered that address the problems and have the following characteristics:

- Non-toxic (biodegradable and environmentally in-active).
- Low-cost (chemicals and energy consumption).
- Synthesised easily – simple production stages, effective use of resources/time, low temperature.
- Process is circular – chemicals used in the process can be reclaimed and reused at low cost.
- Leachates are low viscosity and so can easily mix and flow, making dissolution and extraction faster (in this context, leachates are solutions formed from dissolving E-metals in the DES liquid).
- Leachates are anhydrous to reduce the impact of hydration/hydroxide formation reactions to the metal surface (this impedes further reaction).

Solvents such as the deep eutectic solvents have been shown to have these characteristics (Jenkin *et al.*, 2016). They can dissolve pure metals from E-waste (e.g. computer components, batteries, etc.) and ores such as chalcopyrite (copper iron sulfide) and limonite (nickel-rich iron oxide). In general, the process requires a mixture of two chemicals that when mixed form a solution that has a much lower melting point than either of the original components. This is called a eutectic composition. The solution that is made acts as an extremely good solvent for the metal ions, either from precursor pure metals or metal ores. To enable extraction, an oxidising agent (acting a little like a catalyst) is added to oxidise the metal, forming a cation, which can more easily be dissolved in the DES. Recovery of the metal is then achieved either by electrolysis (deposition of metal at a cathode) or by displacement reactions with a less-reactive metal. Research is now underway to find the best ways to recover the metals from the DES.

These processes being developed at Leicester University and in other universities across the world have great potential for increasing the availability and obtainability of critical metals for the growing technology markets. However, even with breakthroughs such as these, the continued and, indeed, increased use of resources is unsustainable, and some have argued that we must redefine global neoliberal-based economics into a forward-thinking circular economy, that thoughtfully considers how, from extraction of materials to their end of life, we plan in the potential to recycle waste, that is, '*we see waste as a resource, so it makes the products we use today into the resources we use tomorrow with materials that flow in continuous cycles while regenerating our natural systems*' (McLean, 2022: 7).

For a more detailed explanation of the processes involved in the DES chemistry and process see the linked article in *SSR in Depth* (Markwick, Bulmer and Smith-Barnes, 2023).

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Useful links

To explore some of the global issues we are facing, and the new technologies being created:

Association for Science (ASE): www.ase.org.uk/resources/school-science-review/issue-354/climate-change-evidence-and-causes

Institute of Physics: www.iop.org/search?keyword=Climate%20change

National Association for Environmental Education https://naee.org.uk

The Geological Society: www.geolsoc.org.uk

The Royal Society: https://royalsociety.org/topics-policy/projects/climate-change-evidence-causes/basics-of-climate-change

OECD: www.oecd.org/greengrowth

Royal Society of Chemistry: https://edu.rsc.org/searchresults?parametrics=&qkeyword=climate+change

UNESCO: www.unesco.org/en/climate-change/education

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What is there to learn from time-travelling trees?

Samantha Dobbie, Kris Hart and **Jeremy Pritchard**
describe how a research institute is using one of the world's largest climate-change experiments to inspire the next generation of plant scientists and foresters

Forests, plants and ecosystems are deeply rooted within the science curriculum. By taking a closer look, it's possible to explore everything from the chemistry of carbon and water molecules to the biology of disease spread and the physics of energy changes and transfers. Plants are integral to making Earth hospitable and are likely to play a vital role in adapting to the climate crisis. Despite this, a paucity of teaching resources means plants are often under-represented in school classrooms. We hope to address this gap by actively engaging pupils in real-world plant-science research.

Research aim

In a large-scale experiment in a Staffordshire woodland, scientists at the Birmingham Institute of Forest Research (BIFoR) are releasing carbon dioxide (CO_2) around trees to simulate the atmosphere that may exist in the future, in 2050 to be precise. This helps us to see how woodlands may respond in the not-too-distant future. Do the trees grow faster and lock away more carbon? Will the ecosystem adapt because of changes in the soil and insect life? Or will impacts on the cycling of carbon and water cause wider problems?

Research techniques

An engineering feat, the Free Air Carbon Enrichment (FACE) experiment, was constructed in an existing woodland with the help of specialist helicopters in 2016. It is based in 19 hectares of mature, unmanaged woodland with 200-year-old oak (*Quercus robur*), hazel (*Corylus avellana*) and sycamore (*Acer pseudoplatanus*) trees. The experiment is divided into nine plots, six of which have masts that are 25 m high and form a 30 m wide circle, with one central mast jutting up into the landscape (Figure 1).

The CO_2 arrives on trucks daily and is stored as a very cold liquid in 120 tonne storage tanks. From here, CO_2 gas is piped to control sheds where its release is regulated by computer and a series of precision valves. In three 'treatment' plots, air that has been enriched with additional CO_2 is injected into the plots using pipes hanging down from the masts. Once released from the emitter pipes it is dispersed by the wind. In a similar way as a thermostat is used to control heating, sensors constantly measure and adjust the CO_2 levels to 150 ppm higher than the rest of the woodland. In three 'control' plots, air (with ambient levels of CO_2 at approximately 400–450 ppm) is released to the trees using similar emitter pipes. The remaining three plots have no infrastructure and are often referred to as 'ghost' plots, but in fact they provide an extra level of experimental control for the impact of the extensive infrastructure on the woods.

So, what we have effectively done is create a pocket of the future atmosphere that encompasses groups, or patches, of big trees in a UK woodland. Now in its seventh year of carbon enrichment, these trees

Figure 1 The BIFoR FACE experimental set-up

BIFoR in a Box

BIFoR in a Box is a citizen science project that empowers school pupils to install their own dendrometer, or 'tree growth' band (Figure 2). From its launch at the start of the 2023–24 growing season, over 100 schools are now actively taking part in tracking the growth of their trees over time. Teachers can use the dendrometer bands to model field work and challenge pupils to carry out their own investigations into the carbon and water cycles. Is the rate of growth higher in species X or location Y? How much carbon is being sequestered by trees on school sites? These are just some examples of the questions that school pupils have been exploring.

Compared to a school trip, monitoring tree growth on their school grounds requires teachers to carry out a minimal risk assessment and encourages students to think differently about their school environments. Each month, pupils turn their playing field into a forest laboratory. Using a set of callipers to take a reading of the change in circumference of their tree (Figure 2), they join a growing community of citizen scientists across the UK and beyond.

But it is not just limited to schools. We are encouraging anybody to take part by assembling their own kit and using the instructions provided online (see *Useful links*). By doing this, we hope to encourage as many people as we can to get involved in measurements that link directly to those taken by researchers and technical staff at BIFoR FACE.

Data collected by citizen scientists can be submitted to the online dashboard. This is regularly updated and free for anybody to download. As the monitoring season for this year comes to an end, we are looking forward to finding out how much the BIFoR in a Box trees have grown, and estimating how much carbon they have captured. A single silver birch (*Betula pendula*) tree, for example, was found to increase by 2.39 cm, capturing enough carbon to offset a drive of 43 miles from the University of Birmingham to Telford! We're looking forward to finding out how far around the world our citizen scientists' trees can take us.

Figure 2 A dendrometer band installed for the BIFoR in a Box project; tree growth measurements are taken using a digital caliper

have been transported into the future. Scientists can explore what might happen in a CO_2 enriched world. This global, collaborative effort is replicated at a site in Australia, and in the Amazon rainforest. Researchers from a range of different disciplines and institutes are working alongside a dedicated team of technicians to follow the journey of carbon as it moves through subtropical, tropical and temperate woodland ecosystems.

For one of our PhD students at BIFoR FACE, this has meant 12-hour days working high up in the treetops. They took direct leaf measurements to find out how much carbon is being absorbed into the trees through photosynthesis, a process known as 'fixing'. Once fixed, metal bands used to monitor tree growth over time (called dendrometer bands) allow us to measure how much of the sugars from photosynthesis are transferred into woody biomass in the tree.

But it's not just carbon that we are interested in. Trees act as excellent vehicles to better understand the carbon cycle and the water cycle, as well as the links between them. All plants take up carbon through small pores in the leaves called stomata. As they open, water diffuses out and evaporates from the surface. The evaporation pulls water up from the roots, through specialised xylem tissue, in a process called transpiration, before releasing it into the atmosphere. This water flow is important as it transports minerals to where they are needed and helps keep leaf cells turgid. It also cools the leaf as the water evaporates, a bit like sweating cools you down on a hot day!

However, such water loss can also make plants vulnerable to drought stress. Will our time-travelling trees overcome this? Trees with enriched carbon levels might slow water loss by closing stomata and becoming more drought tolerant. If more stomata close and the temperature of leaves increases, what will happen to the rate of photosynthesis? These are just a few of the questions our wider research team are trying to answer.

Unlike water, sugars from photosynthesis travel through the tree in phloem tissue. We can follow the journey of these carbohydrates as they pass through roots and into the soil. Root boxes give us windows into what's going on beneath our feet, and special cameras help us uncover the secrets of the mycorrhizae fungi that form close partnerships with nearly all plants. Leaf litter traps help us build a picture of the amount of carbon that is deposited into the soil. Gases emitted by soil microbes and roots, combined with the decomposition of leaves and woody matter, release CO_2 back into the atmosphere, completing the cycle of carbon. Altogether, we are getting a picture of how the forest might look in 2050.

BiFor FACE masts; photo credit Estrella Luna Diez

Findings so far

And what have we discovered so far? Firstly, the experiment works (Hart *et al*., 2020)! We have also found that the mature oak trees in BIFoR FACE increase their rate of photosynthesis by up to a third in response to the elevated CO_2 levels. This is good news as it suggests that trees might continue to act as valuable CO_2 sinks (Gardner *et al*., 2022).

But where is the extra carbon going? Is it going into the tree trunk, or the root system or the soil? Initial observations suggest that the circumference of trees in enriched plots is greater than those in control plots. The extra carbon has altered the leaves of the young oak seedlings and they are more susceptible to fungal infection than when grown under ambient CO_2 (Sanchez-Lucas *et al*., 2023). Other results from our soil scientists show a 45% increase in fine root production under enriched CO_2 compared with normal (control) conditions. These results are particularly exciting as they highlight the importance of the flow of extra carbon below ground, an often-overlooked reservoir for carbon in forests (Ziegler *et al*., 2023).

Conclusion

To embed our time-travelling trees into the school curriculum, we have developed a range of innovative teaching tools based on best practice. We have an expanding bank of KS3 (ages 11–14), KS4 (ages 14–16) and KS5 (ages 16–19) lesson plans, slides and handouts on a range of STEM topics. These have been co-created with researchers as adaptable resources to be downloaded and delivered by teachers. We hope that by translating the research outputs of one of the world's largest climate-change experiments in this way, we can help engage the next generation of plant scientists and foresters, and support the future of our woodland ecosystems, time travelling or not!

Useful links

For more information about BIFoR:

www.birmingham.ac.uk/research/bifor/face/index.aspx

BIFoR educational resources, including BIFoR in a Box:

https://canvas.bham.ac.uk/courses/52405/pages/welcome

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Key research findings so far:

Gardner, A., Ellsworth, D. S., Crous, K. Y., Pritchard, J. and MacKenzie, A. R. (2022) Is photosynthetic enhancement sustained through three years of elevated CO2 exposure in 175-year-old *Quercus robur? Tree Physiology*, **42**(1), 130–144.

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Sanchez-Lucas, R., Mayoral, C., Raw, M., Mousouraki, M. A. and Luna, E. (2023) Elevated CO_2 alters photosynthesis, growth and susceptibility to powdery mildew of oak seedlings. *Biochemical Journal*, **480**(17), 14429–1443.

Ziegler, C., Kulawska, A., Kourmouli, A., Hamilton, L., Shi, Z., MacKenzie, A. R., Dyson, R. J. and Johnston, I. G. (2023) Quantification and uncertainty of root growth stimulation by elevated CO2 in a mature temperate deciduous forest. *Science of the Total Environment*, **854**, 158661.

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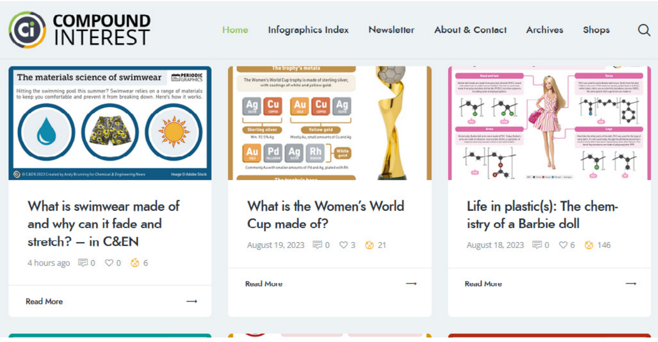
Science websearch

Jon Tarrant shares and reviews various science websites that may be of interest to SSR readers. See *SSR in Depth* pages 40–42 for more website ideas.

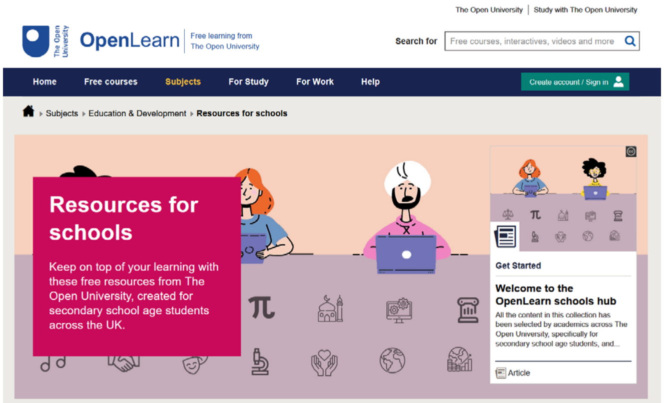


Compound Interest

www.compoundchem.com

One of the best collections of visual science resources in general is Andy Brunning's award-winning *Compound Interest* website, here making a second *Websearch* appearance following its debut three years ago. A particular strength of *Compound Interest* is the way in which content is aligned with current topics. Over the summer there were new infographics linked to the Women's World Cup (looking at metals) and Barbie (looking at plastics) – both joining May's infographic on the chemistry of coronation crowns. All of these resources, together with infographics devoted to specific families of chemicals and important contributors in the history of chemistry, are still available and can be located either by scrolling or using the website's search function. Andy Brunning's infographics also appear on the *Chemical & Engineering News* website, where his contributions are thumbnailed at https://cen.acs.org/collections/periodicgraphics.html. Nevertheless, *Compound Interest* remains the main index and links to items that are hosted on *C&EN* but the latter website grants casual visitors free access to only one article per month, although this increases to six articles after free registration. Everything that is hosted on *Compound Interest* is available free of charge.

- Websites are checked as close to printing as possible – however, website addresses do change.
- Inclusion of a website does not imply that ASE endorses the content of the site.
- Sites are suggested on the basis of 'take a look, you might find something interesting and useful' – we have not read every page nor checked every link.
- Sites that have been listed previously may be reviewed again to focus on new content that has been added.
- Some sites may involve subscriptions or payment for downloads. We have flagged this where appropriate.



Open University Resources

www.open.edu/openlearn/schools-hub

From time to time there are BBC television programmes that end with an invitation to visit the BBC website and follow a link to the Open University for more information about the topic that has been covered. As well as a variety of free courses, the Open University website also provides a diverse collection of resources for schools, which can be browsed in their entirety (349 items) or by topic; at the time of writing there are 53 items categorised as *Biology*, 18 for *Chemistry*, 25 for *Physics* and 14 for *Astronomy*. There is a certain amount of overlap, however, so across the four science subjects there are 84 separate resources, ranging from static articles and videos via interactives and quizzes to complete courses offering between two and 24 hours of guided learning. *OpenLearn* courses are designed to be completed online but can also be downloaded in various formats, including *Word* and *PDF*, for offline study. Many of the courses are biology-based, including an eight-hour course on *Meiosis and Mitosis* and an entire suite of 12 courses on the theme of mammals, providing 110 hours of study in total. As might be expected of a university, a lot of the content is best suited to older students (aged 14+) but items such as the *Mythbusting Moons* video should be accessible for ages 11 upwards.

We are always keen to learn about any websites you have found or produced that may be of interest to other SSR readers. Please send details of any websites you have found or produced to the Science websearch editor, Jon Tarrant, at jontarrant@cantab.net. We would also be interested in hearing about how you have used websites that have appeared in Science websearch in your educational setting.

Using probing questions to support the teaching and learning of moles

Amiera Davies describes how using probing questions can promote deeper thinking and improve students' understanding

The issue

Ask any chemistry teacher to name the most challenging topic for their key stage 4 classes and I'd wager the response would be 'moles'. This is reflected in the plethora of resources available to support teachers (see *Useful links*).

In my first year of teaching moles, I used shared resources. When using them, it was difficult to model my train of thought and calculations. The lessons did contain lots of tasks and activities and students were working independently but there was a sea of confusion and little opportunity for class discussion. In my second year, I modelled the calculations using the visualiser, incorporating mini whiteboards (MWBs) and cold calling. As a class we had practised the individual steps involved to solve a problem, and the students were now engaged in independent practice, successfully completing each step, when I was asked the following question:

> *Do we use the coefficients [from the balanced symbol equation] to calculate molar mass?*

This showed me that students did not have a deeper understanding of moles. Having recently attended training on probing questions, I investigated whether this strategy could help. Probing questions are open-ended and promote deep thinking because students need to do more than recall: they need to explain and elaborate, often using prior knowledge (Sahin and Kulm, 2008). They can be used to diagnose the issue by facilitating class discussion, providing a tool to determine what students are thinking (Pimentel and McNeill, 2013).

Context

This study was completed at an inner London 11–18 academy. The school currently has 1305 students and we follow OCR Gateway GCSE Chemistry. Teachers engage in regular evidence-based professional development throughout the year, both school wide and intradepartmental. We have a longer school day (08.30–16.30), and students have regular weekly homework from every subject. The class that is the focus of this study was year 10 (ages 14–15) set 1 of 9.

Approach

Probing questions were used to facilitate class discussion and to direct the students and teacher to understand misconceptions when teaching moles. Box 1 lists the steps involved.

During my circulating, it was clear that most students identified one mistake but only around half identified the second, which was connected to the stoichiometry of the chemical equation. Box 2 gives an extract of the class discussion that was recorded during the lesson. Use of MWBs is important because it reduces the stakes. Think-write-pair-share activities allow students to become comfortable with making mistakes and to practise correcting each other's work, openly and respectfully. Box 3 shows examples of probing questions.

To assess progress, a simple moles calculation exit slip (Figure 1) was used at the end of the lesson; this was repeated two weeks later to assess retention.

Box 1 Probing question steps

- Students were supplied with a moles question that had been answered incorrectly.
- Students then worked in pairs to find the mistakes.
- I circulated, listening to student conversations.
- Students then completed the question themselves, independently.
- This was followed with a think-write-pair-share task to compare their answers.
- Students then completed a fresh moles problem on mini whiteboards.
- This solution was then discussed in a think-write-pair-share.
- Students shared their work as part of class discussion.

Moles exit sheet

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

1 What is the definition of molar mass?

2 What is the purpose of the coefficients in the above chemical equation?

3 Why do we need them?

4 What mass of oxygen is required to react with 132 g of propane?

5 What mass of CO_2 is produced?

Figure 1 Example exit slip for $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

Box 2 Transcript of class discussion

Teacher: *Why do we balance a chemical equation?*

Student: *So we can have the same number of elements on the left as we do on the right.*

[pause left for students to hear and process, hands slowly begin to raise]

So we have the same number of atoms?

[more time passes]

... types of atoms.

We now had the correct terminology and key words. Students were then given a task to balance a chemical equation, which was completed with a high success rate.

Teacher: *Why don't we use the coefficient to calculate the molar mass of a compound?*

[pause]

Teacher: *What is molar mass?*

Student: *The coefficient changes the way the element is made up, so ... by adding it, it doesn't really ... it doesn't really make sense of what it's supposed to be... $2H_2O$ is different from just H_2O.*

[pause]

Teacher: *What's the difference between H_2O and $2H_2O$?*

Student 2: *There's twice as many moles.*

Teacher: *Yes, the difference is in the quantity of the molecule you have, not the type of molecule; a mole is a measure of the quantity. What is the molar mass?*

Student 3: *Is it the protons and neutrons?*

Teacher: *No, don't go sub-level.*

Teacher (to the class): *What is the molar mass?*

Student 3: *Um, the mass of a compound, um, when, um, it's only one mole.*

Teacher: *Yes, it is the mass of one mole of a compound.*

Teacher: *So, why don't we use the coefficient when calculating molar mass?*

[more hands go up]

Student: *It's not the same as one mole; if we use the coefficient, it's not the same as one mole.*

Findings

Using probing questions forced students to think and explain what molar mass was, what the coefficients in a balanced equation were used for and, therefore, why coefficients from a balanced symbol equation are not used to calculate molar mass. At the end of the approach, all students had completed the moles exit slip correctly. Two weeks later, a different moles question in the same format was completed, with only five students making a mistake in the calculation. Originally, 16 students presented the coefficient misconception. This shows that misconceptions may have been reduced using this strategy.

Box 3 Example probing questions

How did you get that/it?

What is another example of ...?

How do you know?

Why do you agree with ...?

Why?'

Reflections and next steps

This is a small case study that only reports my findings from a high-attaining group of students (set 1). Since this study, I have been trialling this approach with lower-attaining students. This case study has helped me to reflect on how I have developed my use of resources and plan my questioning.

Probing questions are different from higher-order questions because they are instructional rather than involving analysis or application (Sahin and Kulm, 2008). Sahin and Kulm found that teachers recognised the importance of probing questions, although few purposefully incorporated them into lessons. I thought probing questions would need to be planned and so involved more preparation. It can be as simple as asking: 'Why?' Following on from this class, I have rolled out this strategy with all my year 10 classes, and as a department we are looking to redesign these lessons to purposefully create class discussion through probing questions.

Acknowledgement

With thanks to Andrew Chandler-Grevatt, Senior Lecturer at the University of Brighton, for his support as writing mentor for this article.

Useful links

RSC Education: https://edu.rsc.org/searchresults?parametrics=&qkeyword=moles

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The challenges of word equations

Elizabeth Mountstevens describes the challenges of word equations and suggests ways to support students.

The challenges students face with balancing symbol equations are frequently discussed. Word equations receive comparatively less attention and are often assumed to be easier for students. However, they require the same conceptual understanding of reactions and the same knowledge of reaction types. What approaches can be used to support students with word equations?

What makes word equations challenging?

When students are learning about different types of reaction, they are often asked to complete the missing term in a word equation, for example:

sulfuric acid + sodium hydroxide → ________ + water

To complete this task successfully, students need the following knowledge:

- Equations represent chemical reactions.
- Chemical reactions form new substances.
- Sulfuric acid is an acid and sodium hydroxide is an alkali.
- When acids and alkalis react they produce a salt and water.
- There are lots of different examples of salts.
- Sodium hydroxide gives sodium _______ salts and sulfuric acid gives _______ sulfate salts.

There are three main barriers faced by students to completing word equations:

1. Misconceptions about substances and reactions.
2. High demand on working memory.
3. Lack of familiarity with chemical names.

1 Misconceptions about substances and reactions

Misconceptions about chemical reactions can arise from the use of the words ‘reaction’ and ‘substance’ in everyday speech. If I react to a noise, the noise is causing the reaction but it does not cause a change. This can lead students to believe that one reactant causes the reaction in the other (Taber, 2012). Students also focus on observable features of the reaction such as colour change rather than the underlying rearrangement of atoms. Chemistry teachers define chemical reactions as something that forms a new substance. When chemists refer to a substance, they mean a single element or compound, whereas in everyday speech we use the word more generally to describe a material from which something is made.

Best Evidence Science Teaching (UYSEG, 2023) provides several useful resources to investigate and respond to students’ misconceptions. One example from the chemical change section is shown in Figure 1. Only answer D suggests that two substances have reacted to form a new substance.

Colour change

Compound A and compound B are added to a small glass jar. Both compounds are white.

A lid is placed on the jar. The jar is shaken.
A yellow colour appears.

Think about the following statements. Then tick the box to show how confident you are that each statement is right or wrong.

		I am **sure** this is right	I think this is right	I think this is wrong	I am **sure** this is wrong
A	A yellow substance has been released from the white powder.				
B	The white powder has changed colour.				
C	One of the white substances has changed into a yellow substance.				
D	A new yellow substance has been formed.				

BEST™ Best Evidence Science Teaching

Developed by the University of York Science Education Group and the Salters’ Institute.
This question or activity may have been edited. Download the original from **www.BestEvidenceScienceTeaching.org**

Figure 1 BEST resource to investigate students’ misconceptions about chemical change produced by UYSEG, 2023

To reduce misconceptions about substances and chemical reactions we can:

- explain what chemists mean by the word substance using a Frayer Model (Box 1);
- use particle diagrams alongside word equations to show the rearrangement of atoms;
- use the BEST resources (UYSEG, 2023) to identify and correct misconceptions.

2 High demand on working memory

Working memory is the site of our conscious thinking. It only has a limited capacity so tasks that involve holding many things in mind will overwhelm working memory. Completing the missing term in a word equation requires a lot of knowledge and places a high demand on working memory. To reduce this burden, each component of the task needs to be practised so it can be done fluently before combining the elements together (Shibli and West, 2018). We can support students by designing a sequence of tasks that provides students with this practice.

Box 1 Frayer Models

A Frayer Model is a graphic organiser that can be used to help students to deepen their understanding of new vocabulary (Talbot, 2019). The traditional model contains a definition, characteristics, examples and non-examples. They are often adapted to include information on morphology and could be used to encourage deep thinking about groups of chemical substances. These Frayer Models, designed by the author, are for 'substance' and 'metal hydroxide'.

Substance	Definition: A substance is a single element or compound.	Use in a sentence: A pure sample contains only one substance.
Examples: Elements e.g. iron, oxygen and graphite Compounds e.g. salt (sodium chloride), sugar and carbon dioxide	Non-examples: Sea water Orange juice	Parts of the word: Sub – under Stance - thing

Metal hydroxide	Elements: Metal e.g. sodium calcium iron hydrogen oxygen	Examples: Sodium hydroxide, NaOH, in oven cleaner Magnesium hydroxide, Mg(OH)2, in limewater Iron hydroxide Fe(OH)2) in rust
Properties: Alkalis Greater than pH 7	Made by: Sea water Orange juice	Reacts with: Sub – under Stance – thing

For example, for the reactions of acids:

1. Keep the acid the same and name the salts for different alkalis.
2. Keep the alkali the same and name the salts for different acids.
3. Name the salts for different combinations of acids and alkalis.
4. Fill in the name of the salt in a word equation.
5. Complete word equations for different acids and alkalis.
6. Fill in the missing term in an equation.

To support students with the demands on working memory:

- Give students the opportunity for lots of practice with individual reactions.
- Use retrieval practice to revisit each type of reaction.
- Model how to identify the type of reaction from the information given.

3 Lack of familiarity with chemical names

One of the advantages of symbol equations is the ability to see the elements in the reactants and check for their presence in the products. With word equations that information is hidden from students who do not know the elements in a substance. One way to support students is to include symbol equations alongside the word equations (Taber, 2012). This will increase the demands on working memory initially but could be mitigated by focusing attention on each part of the equation in turn and linking the symbols to the periodic table. A better understanding of the components of different chemical substances should actually reduce the demand on working memory of writing word equations in the long term.

Unfamiliar chemical names are likely to be a particular problem for students with lower literacy levels. Teaching chemical names in the way we would introduce new vocabulary provides a potential solution.

To support students to become more familiar with chemical names:

- Show balanced symbol equations alongside word equations.
- Introduce the different chemical names through a Frayer Model (Box 1).
- Revisit chemical names through retrieval practice.

Reflections on implementation

In the last year we have started to update our approach by incorporating some of these recommendations. When chemical reactions are introduced in year 7 (ages 11–12) we use a variety of representations (Figure 2) and the BEST resources. The number of students who achieved the highest 'Excellent' level on the end-of-topic test increased by 10%, although this figure could be affected by several different factors.

In year 8 (ages 12–13), when we look at ***a variety*** of different reactions, we have introduced more practice. While this did help students, their feedback is that they would like to work through the sections at their own pace. At the end of the topic students found it hard to complete equations

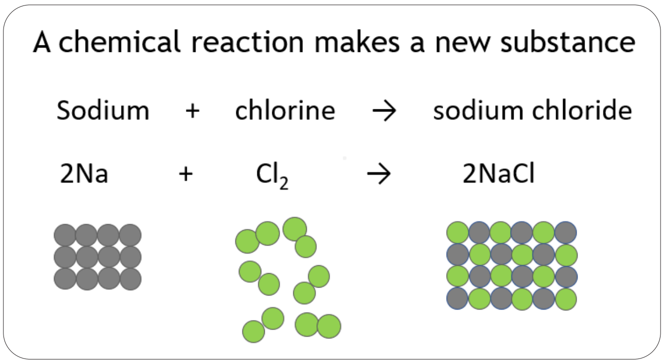

Figure 2 Slide created by the author to introduce chemical reactions using a variety of different representations

when the different types of reaction were mixed together because they were not confident identifying the type of reaction. Next year I aim to use a consistent approach when introducing new reactions: presenting the word and symbol equations simultaneously, using a Frayer Model (Box 1), providing them with the opportunity for guided practice to support them to become more familiar with the different types of reaction.

Useful links

Best Evidence Science Teaching resources:
https://www.stem.org.uk/secondary/resources/collections/science/best-evidence-science-teaching
Chemical misconceptions: Prevention, diagnosis and cure:
https://edu.rsc.org/resources/chemical-misconceptions/1967.article

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SSR Summer Science Shots

Ed Walsh announces the results of *SSR*'s science photography competition

Light in the natural world

Many thanks to all the entrants to this year's photographic competition. Every single entry was worthy of serious consideration and everyone who participated should be proud of their work. A first prize and a runner-up prize have been awarded, and one other entry has been highly commended.

In the West Wing of the White House is a series of 20" × 30" frames called jumbos. Official press photographers cycle images through them to gauge reactions and to discover which images make people stop and look. I looked for photos in this competition that would tell a story and be at home in a science journal, but would also arrest attention; and I found them.

Ed Walsh is a science education consultant who has studied photography with the Open University.

First Prize – Richard Needham

The use of light and darkness in this photograph is excellent, and the restricted colour palette adds to the impact. The composition is classic, going from two-thirds down on the left-hand side to two-thirds up on the right. This photograph shows a confidence in the key features: the ripples in the foreground are in sharper focus, and the bird looking across the water and towards the light makes the viewer do so too.

Runner up – Elizabeth Mountstevens

There is so much that is right about this photograph. The light and shade on the land transform it from a duller texture; the mist and sunlight in the back draw the eye. The masterful feature though is the use of leading lines. The eye is drawn to the mountains by the light, then led down again towards the textures in the foreground.

Highly commended – Deepika Narula

The colours in this are gorgeous and the light upon the water works so well but then there's this intriguing aspect of the silhouetted animal life. The composition is strong: the arrangement of the animals forms a near parallel to the water's edge and draws the eye from low left to mid right.

Going deeper

As you are reading this issue of *SSR in Practice*, don't forget that you also have online access to *SSR in Depth*.

November *SSR in Depth* contents:

5 **ASE Presidential Address: Science education at a time of existential risk**
Michael Reiss

11 **Identifying topics in which chemistry teachers lack confidence**
David Read and Stephen M. Barnes

19 **Using deep eutectic solvents for extraction and recycling of E-metals**
Andy Markwick, Elena Bulmer and Phoebe Smith-Barnes

25 **Unpacking procedural and conceptual difficulties in solving genetics crosses**
Sheyne Moodelly, Michael J. Reiss and Anwar Rumjaun

32 **Scientific language: how important should it be to teachers of science?**
James D. Williams

38 **Book reviews**
Mike Follows, Stephen Hearn and Sarah Wood

40 **Science websearch**
Jon Tarrant

Get involved

Are you a teacher or technician who has improved a practical to support student learning, or to help students gain better results?

Have you created a demonstration or a class practical that helps to explain a phenomenon in a new way?

Our summer reader survey revealed that the practical idea articles were the most popular type of article in *SSR in Practice*. They are not however the most commonly submitted so we need you to get involved!

Share your idea with us via our submission form https://forms.gle/GySWab7MCjSBnmBM7.

Please do not think that your idea is not original enough, or not good enough. Submit it and let us decide. Full writing guidance for *Practical ideas* articles is provided (see https://www.ase.org.uk/submission-guidelines).

We also welcome *Science notes* for *SSR in Depth*. These articles have a longer word limit of 2000 words and are appropriate for more complex practical methods, or for those requiring more advanced understanding (e.g. post-16 student level).

Could you review a couple of articles a year?

As the number of articles being written increases, we also need more reviewers.

We would be delighted to hear from teachers, technicians and those working at universities. If you could support *SSR* in this way, please complete the form at: https://forms.gle/4Nzd6wmqeK7QU5kRA. On this form you can let us know whether you would be interested in reviewing articles for *SSR in Practice*, *SSR in Depth*, or both.

Helen Harden
Commissioning Editor

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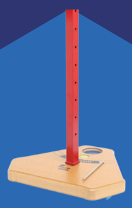

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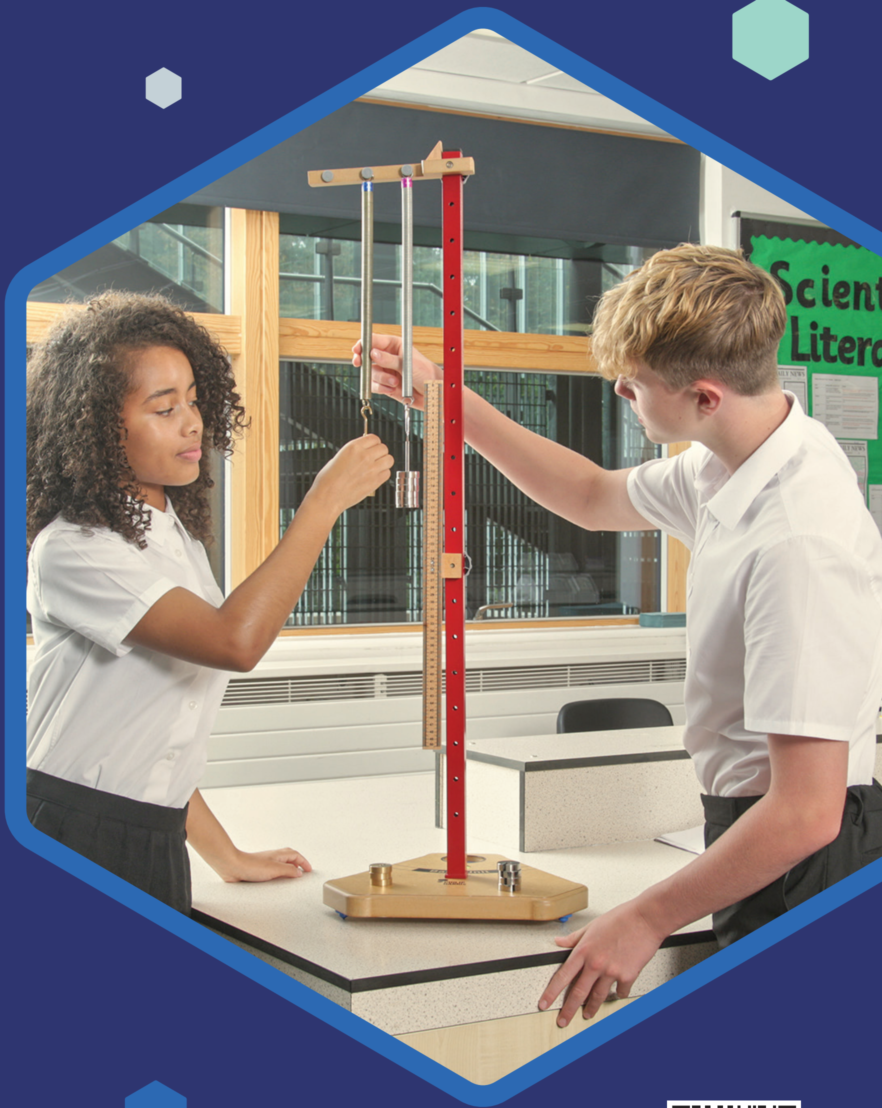

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