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Good Practice Report

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Responses of teachers in Scotland to the reintroduction of the practical project in the advanced higher chemistry curriculum

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Abstract: Many pupils who study chemistry in Scotland and intend to progress to university undertake a final capstone practical research project as part of their Advanced Higher chemistry qualification. This project work was suspended for several years due to COVID-19, then reintroduced in 2023/24. We surveyed 47 Scottish teachers during this first project year using a mixed-methods survey, and found that resource availability had the biggest impact on projects, with over half of respondents reporting that they asked pupils to buy materials and a third committing their own money. Technician support was seen as critical to success, but project selection was heavily curtailed by the availability of existing equipment or chemicals, even as teachers made good use of available professional development and other forms of support. We finally make recommendations around the resourcing of project work and teacher/technician CPD provision.

Keywords: financial pressures on education; project based learning; secondary school; teaching practice

1 Introduction

1.1 Practical chemistry education

The laboratory is the “signature pedagogy” of chemistry (Gravelle & Fisher, 2012). Practical chemistry is a core component of the chemistry Higher Education experience, with professional bodies in the UK and the USA both stipulating that a chemistry degree must provide between 300 and 400 h of taught practical experience to gain accreditation (ACS, 2023; RSC, 2024).

To make the best use of those hours, extensive scholarship has been undertaken into the pedagogies and purposes of higher education lab learning, generally advocating for structured approaches that build towards an end goal of students conducting authentic research (Seery et al., 2019). These structures generally ramp up the intensity of problem, discovery, or inquiry-based learning throughout a university degree, but there have been numerous examples of bringing experimental design skills into the secondary chemistry curriculum, early higher education, or by involving school pupils in authentic “citizen science” research (Orosz et al., 2023; Szalay & Tóth, 2016; Sella, 2017; Thomson & Lamie, 2022; Seery et al., 2024; van Rens et al., 2010). Higher education systems therefore generally expect, implicitly or explicitly, that incoming students will bring some degree of practical experience with them from their secondary education, potentially even going beyond recipe-following or expository labs. Absences in this provision not only undermine learning generally, but can amplify existing social inequalities through unequal access to high-quality practical schooling (Caushi et al., 2024).

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The link between school and higher practical education was dramatically illustrated when the COVID-19 pandemic imposed a significant disruption to practical education across all sectors and subjects (Betthäuser et al., 2023). Across many subjects and countries, this disruption amplified attainment gaps and social inequality (Golden et al., 2023). The impact on chemistry pupils was pervasive and significant world-wide, and with knock-on effects when those pupils subsequently entered higher education (Beneth & Ukeje, 2021; Cramman et al., 2024; Jiménez Sánchez et al., 2022; Ramadhani et al., 2024).

1.2 Scottish context

Presently, in Scotland, the highest level of Secondary Education chemistry qualification is the Advanced Higher (AH). The qualification sits at SCQF Level 7, aligned with levels 4 & 5 in the England and Wales RQF. Advanced Higher chemistry is not mandatory for progression into chemistry Higher Education in Scotland, but many applicants chose to pursue it as it can ease the transition into university, or qualify for progress directly into the 2nd year of some Scottish chemistry degrees. Advanced Higher sits at the same curriculum level as foundation- or first-year university courses, with a significant aspect of investigative practical experimentation known as the AH project, making up 25 % of the total grade for the qualification (Sneddon & Hill, 2011; SQA, 2021). As the Scottish education system is comparatively small, to the best of the authors knowledge there have been no direct studies into the link between this provision and subsequent higher education practical study.

The national body for the qualification, the Scottish Qualification Authority (SQA), took the decision to remove the project from assessment in the 2020–2021 academic year due to the global COVID-19 pandemic. Projects did not resume until the 2023–24 academic year. The official SQA announcement that project work was to resume came in spring 2023, less than three months before the end of the academic year (SQA, 2023).

1.3 Financial pressures

Secondary teaching is in a time of chronic financial pressure, with 20 % of teachers reporting in a 2019 survey that they spent their own money on classroom supplies at least once a week, and a more recent survey from the Educational Institute of Scotland had nearly 7 in 10 teachers stating they had done so (EIS, 2023; Sellgren, 2019). A recent national survey of secondary science teaching in the UK found that 57 % of teachers in the UK/ROI cited inadequate funding as a major challenge (RSC, 2023). This has had a disproportionately high impact on chemistry in 2023 and 2024, since chemical and consumable costs experienced inflation-linked price rises much higher than general measures of inflation (Burke, 2024).

1.4 Our context

The University of Strathclyde has a long history of supporting the professional development of teachers in Scotland, and as part of this hosts an annual professional development event for secondary chemistry teachers. The event includes a half-day practical session in support of AH projects, consisting of hands-on demonstrations of possible AH project ideas. Every teacher in Scotland is given free access to the entire back-catalogue of projects (48 projects, as of summer 2024). Many project ideas are adapted from chemistry education literature, but we also develop new activities in response to sector pressures, such as the addition of an experiment on the topic of polymers to coincide with an update to the curriculum (Cullen & Scott, 2018).

In advance of the reintroduction of project work, we anticipated that many teachers and technicians would find it challenging to find time and resources to resume project work. Before and immediately after the widely expected announcement that projects would resume, we laid on additional sessions, providing documentation, ideas, and professional development events. These sessions have their own evaluation process, and we also sought to probe the wider landscape of teachers across Scotland.

2 Methodology

2.1 Research questions

With the top-down imposed resumption of AH projects, and the aforementioned changes to the financial landscape since projects previously ran, we sought to investigate the experiences of Scottish teachers delivering AH projects during the 2023–24 academic year. We had two research questions in mind:
(1) Has the ability of a school to support AH chemistry project work been impacted by cost, material availability, or health and safety concerns?
(2) How have teachers resourced, supported and upskilled themselves to support AH project work?

3 Survey design and methodology

A mixed-methods approach was used. A survey was written, with sections probing demographic experience, cost, equipment and chemical availability, health and safety, technical support, and self-reported overall confidence in delivering projects (for the full survey text, see the Supplementary Information). Face and content validity of the survey was ensured as follows. To identify question categories, and specific questions, we first used a panel of subject experts, i.e. practising teachers with AH project experience, for question generation. This was followed by piloting the questions with a further small group of subject experts to refine aspects such as meaning and clarity. Categories were chosen after an initial pilot discussion with teachers who were in the process of supporting projects, and questions were piloted with a small group of teachers and professionals to ensure face and content validity. The survey was not intended to measure a theoretical construct, so construct validity and consistency measures were not appropriate.

Questions were either presented as Likert-type scale questions or free-text prompts. Some free-text prompts were designed to yield short, closed answers or capture lists of techniques, and these underwent simple keyword frequency analysis. Open-ended prompts were analysed by inductive thematic analysis (Braun & Clarke, 2006). Responses were coded by a single author using the methodology of Bree and Gallagher, which follows a similar six-phase process to Braun & Clarke's thematic analysis guidelines, adapted for physical science education research (Bree & Gallagher, 2016). Themes were then reviewed by a co-author who had not previously inspected the raw data, to give a measure of inter-rater reliability. This also provided a measure of investigator triangulation. Investigator triangulation can mitigate bias in qualitative data by using multiple investigators who may not share the same interpretation of data (Denzin, 2017). In this case, one author was a trainee teacher who had been embedded in a school in a previous academic year, with other authors operating mainly in higher education contexts.

3.1 Survey distribution

The survey was granted local ethical approval and distributed *via* Scottish secondary chemistry teacher networks, our own mailing lists, and social media. The recruitment message indicated that the survey was aimed specifically at those who currently teach or support AH chemistry.

The survey ran for two weeks during February 2024, a time window chosen so that almost all teachers were either engaged in supporting projects or had just finished doing so. Waiting until later in the academic cycle also gave teachers the greatest chance of having been able to previously engage with external professional development resources. The survey collected 47 valid responses, which represents approximately 25 % of the schools in Scotland which offer AH chemistry. It may be the case that multiple respondents taught in the same school, but nonetheless, the response rate is a reasonable sampling of AH provision in Scotland.

3.2 Respondent demographics

When asked how many years they had been supporting project work, the median response was 6 years, with a mean of 8.75 (SD 8.9), a broad spread of experience ranging from 0 to 34 years. Notably, nearly 40 % of respondents had less than three years of project experience. This could potentially be a reflection of normal turnover rates, compounded by the COVID-era project hiatus. To preserve participant anonymity, no other demographic data was collected, as governed by local ethical guidelines. Project experience is also not a direct correlation for overall length of career, since anecdotal evidence suggests that Advanced Higher classes tend to be allocated to more experienced teachers overall. Therefore, we can draw no strong inference about how representative the respondents are, when compared to the population of teachers as a whole.

4 Results and discussion

4.1 Constraints on project availability

Teachers were asked how often budgetary constraints impacted their choice of AH project, with 87 % of respondents indicating this happened at least some of the time and 51 % indicating that this happened very often or always (Figure 1, top). This is in line with US-based research into the impact of budget on availability of lab activities (Boesdorfer & Livermore, 2018; Spiegelman, 2018). When then asked a more explicit question about resource availability impacting the choice of available AH projects (Figure 1, middle), 94 % of respondents indicated this happened at least some of the time. With health and safety concerns, responses were more mixed, with only one third of teachers indicating that this always or often had an influence on project delivery (Figure 1, bottom).

Teachers were then asked a series of more detailed questions about the availability of general or specialist equipment and chemicals, with "specialist" explicitly framed as those which supported AH project work. Most (89 %) classrooms had at least one set of basic laboratory equipment, suitable for supporting the early school curriculum (Broad General Education, BGE). There was also good availability of at least access to more specialised equipment (89 %), suitable for aspects of the Higher or Advanced Higher curricula. When prompted, the most frequently cited shortage equipment were quick-fit apparatus, TLC equipment, and colourimeters. Most of these are required by techniques either introduced or expanded at AH level, but may only have been demonstrated previously. For example, many schools may have access to at least one set of quick-fit glassware for demonstrations in lower years.

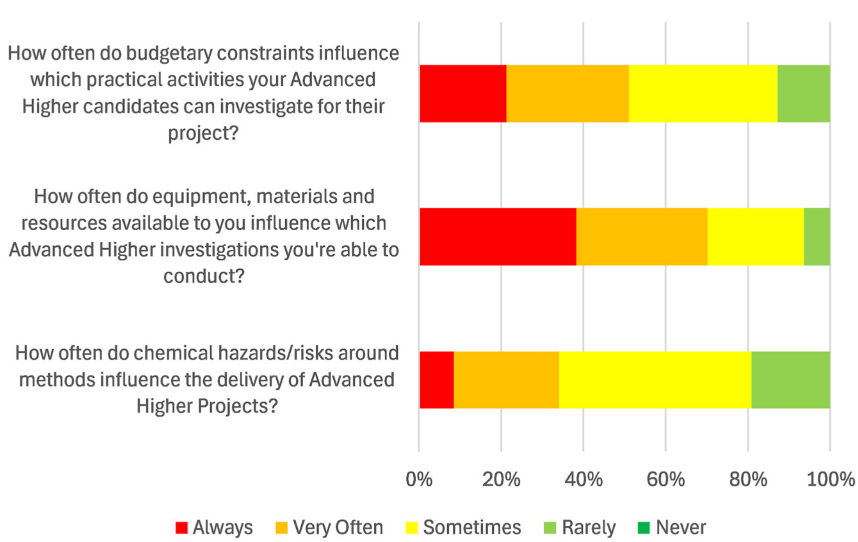

Figure 1: Likert-scale responses to survey questions probing the impact of various factors on the choice or delivery of advanced higher investigations.

Questions around access to basic or specialist chemicals were framed as whether availability restricted the choice of project work available. With that framing, 89 % of respondents reported having basic chemical access for at least some choices, and 74 % reported at least some choices with specialist chemicals as well. However, only 19 % reported having sufficient speciality chemicals for many project choices, versus 51 % for basic. When prompted, specific shortage chemicals were usually organic reagents, solvents, or analytes such as aspirin or caffeine. Lastly, about two-thirds of respondents reported having access to a local university for advanced sample analysis techniques such as infrared or UV/Vis spectroscopy.

When respondents were asked how they would actually obtain speciality chemicals or equipment for AH projects, the top two answers were, expectedly, through procurement or existing resources. However, 24 respondents (51 % of those surveyed) reported asking pupils to spend their own money and 17 (36 %) reported spending their own money (Table 1). This is a stark finding, confirming previous reports that financial pressures are causing teachers to look beyond school budgets to resource teaching (Burke, 2024; EIS, 2023; RSC, 2023; Sellgren, 2019).

Overall, project availability is highly reliant on purchasing, and constrained by the availability of existing materials and equipment from previous purchases. Bringing this into particularly sharp relief is the use of personal cash from students and teachers. Many projects, even when they rely on only routine equipment, may require the purchase of specific analytes or reagents, particularly when they are commercially available.

4.2 Health and safety considerations

Alongside the previously discussed question probing health and safety considerations impacting on project availability (Figure 1, bottom), we provided a further free-text prompt to elaborate on why they selected that answer. Inductive thematic analysis was used to identify a number of themes in the responses (Table 2).

Themes for risk and hazard revolved around practical constraints, with the first theme highlighting the lack of safe spaces to either conduct experiments or leave reactions running. In particular, mixed-use classrooms often forced pupils into non-classroom spaces, such as the technician's base, which could handle the chemical hazards of the project, but imposed an additional draw on teacher attention and time.

The second main theme highlighted that teachers often took a pragmatic view of hazards and avoided more hazardous project ideas, whether that meant restrictions on the work itself, or on disposal of chemicals afterwards. Rather than concerns about work being intrinsically hazardous, teachers instead focused on the additional complexity introduced by higher-hazard work, and how this was not always reflected in the ability for a pupil to secure a high mark in a project.

Interestingly, all safety themes related to specific reasons for restricting projects, even those derived from teachers who stated that project choice was "rarely" impacted by safety. This could indicate that even teachers who felt they were not overly influenced by hazard/risk were still pre-selecting project topics perceived as "safe".

Table 1: Frequency of choices in response to the question "How would you obtain speciality equipment, materials or chemicals for advanced higher projects? e.g. caffeine sources, Vitamin C, aspirin". Respondents could select multiple options. "Other" responses mostly related to borrowing from other schools, colleges, or local universities.

Source of speciality equipment, materials, or chemicals for advanced higher projects	Number of times selected (*n* = 47)
Technician order	38 (81 %)
Existing materials in setting	32 (68 %)
Student purchases	24 (51 %)
Own cash	17 (36 %)
Petty cash	14 (30 %)
Cannot purchase	5 (11 %)
Other	4 (9 %)

Table 2: Themes, subthemes and quotes for teachers' thoughts around risk and hazard and the impact on projects (n = 47).

Theme	Subtheme	Representative Quotes
Resource, time, or space constraints that restrict safe working	Lack of availability of functioning, or appropriate, fume hoods	*'Fume cupboards in our school are filter type, not chimney to outside so not as good if hazardous gas produced'* *'Only one fume hood (which is pretty standard). This is tough for AH where some practical's really need it. We've had to adapt certain methods to work around this'*
	Shared spaces mean experiments cannot be left	*'No separate S6 lab so pupils have to work in back of room, sometimes with junior classes being taught. Could not leave an experiment set up safely for days/weeks for this reason.'*
	Timetabling constraints mean practical work often has to be completed outwith classroom	*'We only have 2 teaching periods in the timetable for AH that are face to face – this limits what we can do in the lab, so we need to use the technician's room to complete the projects. As this is the case, a member of staff needs to be present at all times, so I need to come off timetable to do this'* *'Pupils have to find time out with timetabled class time to work on their projects. This needs to be at the side of a class or in the technician base. It can be crowded, and we often have to schedule to wait back after school so that there is a member of staff within reach (pupils do risk assess everything too).'*
Avoiding hazards entirely by choice of project	Teachers generally stick to "safe projects" or techniques	*'I tend to stick to analytical projects rather than think about organic solvents/reagents'* *'The potential projects I select are chosen for being safe and straightforward.'*
	Hazardous chemicals add complexity not rewarded by marking schemes	*'I think that no risky project would be undertaken. Students generally want a project that will be simple to write up, rather than investigating something more intense and potentially harmful.'* *I will always try to avoid particularly hazardous chemicals if they are not necessary and don't add to the student's ability to score highly in the Project'*
	Avoiding reagents with high disposal costs	*'Organic (and metal solution) waste is an issue for us, and we store it for the year and have an uplift every summer term'* *'Disposal afterwards – it's very expensive to have waste chemicals removed from schools.'*

4.3 The role of technicians and external training resources

When asked about the involvement of technicians in the delivery of the AH project, keyword analysis showed a wide range of responses, focused on pupil support (Figure SI2). This could be *via* organising, preparing, and ordering resources for their projects, offering advice with their technical experience and expertise, or teaching pupils to use certain techniques/equipment. A few responses here, and elsewhere, mentioned limitations caused by not having access to technicians. Overall, technician support was seen universally as key to project success, in many cases supporting pupils directly. This mirrors previous research supporting the argument that technicians should take active roles in teaching practical science work, particularly in the final years of schooling (Helliar & Harrison, 2010).

We also asked how people upskilled themselves, with most respondents citing Scotland-specific resources (Table 3). For example, the most prevalent response was SSERC, a Scottish educational charity that delivers in-person continuous professional development (CPD) and online resources relating to science teaching and chemical safety. Similarly, the SQA, the accrediting body responsible for the Advanced Higher curriculum itself, was prevalent (SSERC, 2024; SQA, 2024). Overall, existing CPD is well-explored and well-established, and a key component of enabling teacher support for project work.

Table 3: Frequency of choices in response to the question "Which resources have you used to improve your practice and delivery around advanced higher projects, or otherwise upskill yourself?". Respondents could select multiple options. "Other" responses were mostly from teachers who additionally acted as project markers, taking ideas from projects they had previously assessed. Online resources included Strathclyde-branded project support mentioned previously.

Which resources have you used to improve your practice and delivery of AH Projects?	Number of times selected (*n* = 47)
SSERC	41 (87 %)
SQA website	37 (79 %)
Other teachers	35 (74 %)
CPD sessions	28 (60 %)
Technicians	26 (55 %)
Online resources	26 (55 %)
Social media	6 (13 %)
Other	6 (13 %)

4.4 Confidence and overall teacher impressions of AH projects

Teachers were asked to rate their own overall confidence in delivering advanced higher projects. Despite the issues discussed above, teachers still retained a high level of confidence overall, with 79 % reporting feeling very or somewhat confident in conducting AH projects. This was followed up with a further free-text question, for which keyword analysis indicated that confidence was largely due to their own experience, professional background, "understanding standards" (an SQA-led CPD event for AH projects), or having worked as a project marker for the SQA previously (Figure SI1). Overall, this may indicate that while support information is valuable, further provision may not dramatically shift teacher perceptions.

Lastly, teachers were asked an entirely open-ended question: "do you have any other thoughts or comments around advanced higher projects?" The responses contained seven identified themes with several sub-themes (Table 4).

The first and most prevalent theme related to lack of pupil experience. Pupils taking AH during this survey had never sat a practical project before at any level, whereas normally they would have received three consecutive projects at three curriculum levels, culminating in AH projects. Projects were reintroduced in the same year for all three curriculum levels, and the teachers being surveyed were in the process of supporting these pupils in their first ever project experience, so it's not surprising that lack of experience was a concern.

The second main theme related to the process of project selection. Teachers with experience tended to pre-select a few projects, which cut down on the intended freedom that pupils are meant to get in exploring their own lines of interest. More experienced teachers also tend to propose simpler, easier projects which are believed to yield a high mark.

The third main theme related to teachers overall finding the AH project valuable, believing it to encourage independent working and prepare pupils for further work or education.

The fourth and fifth main themes focused on time and resourcing constraints. When small numbers of pupils chose AH chemistry, teachers felt the course was undervalued and given inadequate teaching time, forcing teachers and pupils to sacrifice study or non-contact time as a result. Resourcing was well-explored by the rest of the survey and consequently teachers here only flagged some specific issues with inaccurate equipment, and with specialist reagents only being commercially available in large quantities leading to wastage. Several teachers noted that their local authorities already ran chemical or equipment sharing services, and wished to see this more widespread.

The final theme focused on perceived inequalities between settings. Different council areas were felt to have different budgetary landscapes, and rural settings often had much smaller teaching teams, scattered pupils, and limited or no easy access to university support.

Table 4: themes, subthemes, and quotes for teachers' overall thoughts around advanced higher projects (*n* = 47).

Theme	Subtheme	Representative Quotes
Pupil experience	COVID-19 pandemic limiting practical experience.	*'Should not have been reintroduced this year as pupils have limited practical experience following COVID'*
	Pupils lacking experience working independently due to lack of project type work in previous qualifications.	*'There has been an impact on the return of projects to a year group who have not has similar independent work previous'*
Choosing projects	Experienced staff tend to choose the same projects.	*'As an experienced AH staff member, I do tend to stick with the same projects which cuts down on pupils' autonomy'*
	Choosing simple, easier projects which score high marks.	*'Some simpler, more straightforward options would be appreciated, especially when things that score well tend to be less complicated'*
Value of advanced higher projects	Invaluable aspect of the advanced higher course	*'Think at advanced higher levels the projects are invaluable to helping the pupils practical and investigative/research skills'*
	Encourage pupils to be independent	*'I do think these give pupils more of an insight into what a more independent working is going to be like'*
	Prepare pupils well for further education in science or to work in a lab post-secondary education.	*'Projects are very good experience for pupils, especially for those moving onto further education or a science career'*
Time to deliver an advanced higher project	Smaller number of pupils often means less teaching periods	*'In my school I am only allocated 2 teaching periods a week due to small numbers of pupils choosing the subject'*
	Advanced higher courses generally undervalued in schools and have fewer teaching periods allocated	*'Advanced Higher courses are undervalued by senior leaders in schools. More staff time should be allocated to advanced higher classes.'*
	Teachers and pupils tend to give up non-contact periods to cover time needed to do project	*'Myself and the other chemistry teacher give up non-contact each to cover the course. Projects are usually done in pupils own study time.'*
Cost of chemicals and equipment	can only buy chemicals in large quantities which leads to waste	*'Buying in 500 g of a chemical that then gets left on the shelf for 20 years before having to be paid to dispose of'*
	Centralised hubs to share chemicals or borrow from universities.	*'We have as an authority pulled together a list of specific equipment/ materials for AH across different schools. It would be useful to have central hubs for specific experiments either in schools or at universities'*
	Insufficient or inaccurate equipment	*'We do not have class sets of quick-fit apparatus. Melting point apparatus is shared between up to 6 schools and the best balances we have are 2 d.p'*
Inequality between settings	Poor access to university settings for sample analysis for rural schools	*'It's unfair that schools in the central belt have access to university labs to complete their experiments whereas rural schools can't facilitate this'*
	Budget depending on area in which the setting is, and whether the school is state or independent.	*'It is a bit of a postcode lottery and very dependent on the budget in the school. Massive inequity between public and private. Most remote schools struggle with visiting university due to time/cost.'*
	More rural settings struggle to have that in-house support due to lack of staff.	*'It has been extremely challenging delivering these for the first time in my rural setting with little support.'*

Overall, respondents universally felt that projects were valuable, but came with financial, logistical and practical challenges that could disproportionately impact pupils in poorer or more remote areas, a worrying finding when considering previous research on "educational debt" discrimination and its transmission through to Higher Education (Caushi et al., 2024).

5 Limitations

The findings may be of interest, and useful reflective prompts, for those working throughout the secondary education sector; however, the specifics are likely only to be directly relevant for the Scottish secondary education sector, specifically chemistry, and not widely generalisable. The survey ran for a single time period during a single academic year, and responses may not be representative of Scottish chemistry teachers as a whole.

6 Conclusions and recommendations

The reintroduction of Advanced Higher chemistry projects in Scottish high schools served to exacerbate financial pressures, noting that over half of respondents reporting that they asked pupils to buy materials and a third committing their own money.

Almost always, project availability was limited to those that could run with existing materials or equipment, or those borrowed from other schools or nearby universities. The high costs or potential hazards of solvents and speciality organic reagents were given as particular concerns. Health and safety concerns also restricted what projects could be supported, mostly through needing non-classroom spaces for reactions to run safely outwith scheduled lessons. Respondents also reported that their senior management teams did not always appreciate these challenges.

Teachers found technicians invaluable to supporting AH project pupils, from arranging access to speciality chemicals and equipment to directly supporting pupils themselves by demonstrating techniques or providing project supervision. Teachers also made use of a very wide range of upskilling resources, from formal training, to online resource from professional bodies, to colleagues.

6.1 Recommendations for practitioners

As the key change studied – the reintroduction of the AH chemistry project – was an external imposed change, recommendations for teachers and technicians are necessarily limited. However, we did identify many examples of good practice from respondents. Specifically, CPD, technician colleagues, and local authority and university networks all enabled greater confidence and ease in teachers and it may be reasonable that any teacher who is required to deliver project work should explore these avenues.

6.2 Recommendations for professional bodies

A significant factor that clearly emerged from the current research was the valuable role of technicians in supporting AH projects and beyond. However, although there are some professional development opportunities for teachers, there are currently very limited opportunities for technician-specific development. In the UK, there has been a recent drive to better recognise the valuable role of technicians through the Technician Commitment, however this is focused on higher education and research rather than schools or colleges (The Technician Commitment, 2024; Vere, 2022, 2024). Schools, councils, sector bodies, and other interested organisations should give consideration to the valuable role of technicians in supporting pupil project work, and the wider science curriculum, and consider implementing technician-specific CPD.

The survey findings also raised a number of possibilities for future improvements in how projects are resourced or run. However, any changes to the wider landscape would need to be enacted at the level of national government, or other government-influenced institutions such as the Scottish Qualification Authority (SQA) or Education Scotland. The SQA is due to restructure into a new body, Qualifications Scotland, and the observations in this work should be considered by this new body as part of any future curriculum or resourcing review of Advanced Higher chemistry, or science project work more generally.

6.3 Future research

Lastly, the findings raised a number of new research areas:

- If schools are often relying on local authority or university networks to deliver the AH curriculum, does this introduce further inequality to rural or remote schools?
- Are AH qualifications valued in schools, and do teachers have an adequate allocation of time to deliver them, and are they appropriately resourced with space or money?
- Beyond project work, do current school budgets allow for the proper financing of chemistry qualifications? It could be valuable to identify minimum equipment requirements, lifetimes, and associated costs.
- Do teachers feel confident enough in the safety aspects of AH project work, or project work in general, and are they supported with enough subject-specific professional development?
- If teachers and pupils are spending out of pocket to support core teaching activities, what effect does this have on the education of those from low socio-economic backgrounds?

Supplementary Information

Full survey questions and some additional charts and tables are available as a separate file. The full set of responses, with cross-correlation information removed to prevent effective de-anonymisation, is available as a separate file.

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Research ethics: The research related to human use has complied with all the relevant national regulations, institutional policies, and in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' Departmental Ethics Committee, approval number DEC23/PAC05.
Informed consent: Informed consent was obtained from all individuals included in this study.
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References

ACS. (2023). *ACS Guidelines for Bachelor's Degree Programs*. https://www.acs.org/education/policies/acs-approval-program/guidelines.html [Accessed 12 September 2024].

Beneth, K. C., & Ukeje, A. O. (2021). Impact of Covid-19 pandemic on the teaching and assessment of chemistry practical in secondary Schools in Enugu State. *African Journal of Theory and Practice of Educational Assessment (AJTPEA)*, *10*.

Betthäuser, B. A., Bach-Mortensen, A. M., & Engzell, P. (2023). A systematic review and meta-analysis of the evidence on learning during the COVID-19 pandemic. *Nature Human Behaviour*, *7*(3), 375–385.

Boesdorfer, S. B., & Livermore, R. A. (2018). Secondary school chemistry teacher's current use of laboratory activities and the impact of expense on their laboratory choices. *Chemistry Education Research and Practice*, *19*(1), 135–148.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*, 101–177.

Bree, R. T., & Gallagher, G. (2016). Using Microsoft Excel to code and thematically analyse qualitative data: A simple, cost-effective approach. *All Ireland Journal of Higher Education*, *8*(2), 2811.

Burke, M. (2024). The chemicals cost crisis. In *Education in Chemistry*. Royal Society of Chemistry.

Caushi, K., Torres, D., & Abrams, B. (2024). Examining educational debts in student preparation for general chemistry. *Journal of Chemical Education*, *101*(4), 1425–1434.

Cramman, H., Arenas, B., Awais, R., Balaban, C., Cropper, C., Dennis, F. M., Finch, K., Gray, H. F., Kitchen, G., & Norman, K. (2024). Post-16 students' experience of practical science during the COVID-19 pandemic and the impact on students' self-efficacy in practical work. *Enhancing Teaching and Learning in Higher Education*. https://doi.org/10.62707/aishej.v8i2.281.

Cullen, J., & Scott, F. J. (2018). Preparation of a polymeric foam: An activity designed to increase teachers' awareness of the utility of condensation polymerization. *Journal of Chemical Education*, *95*(3), 419–422.

Denzin, N. K. (2017). *The research act: A theoretical introduction to sociological methods*. Routledge.

EIS. (2023). 2023 EIS member survey: Workload, health and wellbeing, and the cost of living crisis. https://www.eis.org.uk/Content/images/Research/2023MemberSurvey.pdf [Accessed 4 September 2024].

Golden, A. R., Srisarajivakul, E. N., Hasselle, A. J., Pfund, R. A., & Knox, J. (2023). What was a gap is now a chasm: Remote schooling, the digital divide, and educational inequities resulting from the COVID-19 pandemic. *Current Opinion in Psychology*, *52*, 101632.

Gravelle, S., & Fisher, M. A. (2012). Signature pedagogies in chemistry. In *Exploring More Signature Pedagogies* (pp. 112–125). Routledge.

Helliar, A. T., & Harrison, T. G. (2010). A wider role for technicians in science practical work with school students? *Acta Didactica Napocensia*, *4*(4), 1–10.

Jiménez Sánchez, E., Montes-López, E., & Santos Sánchez, M. J. (2022). Impact of the COVID-19 confinement on the physics and Chemistry didactic in high schools. *Sustainability*, *14*(11), 6754.

Orosz, G., Németh, V., Kovács, L., Somogyi, Z., & Korom, E. (2023). Guided inquiry-based learning in secondary-school chemistry classes: A case study. *Chemistry Education Research and Practice*, *24*(1), 50–70.

Ramadhani, D. G., Yamtinah, S., Saputro, S., Sarwanto, S., & Masykuri, M. (2024). From screen to bench: Unpacking the shifts in chemistry learning experiences during the COVID-19 transition. *Chemistry Teacher International*, *6*(1), 19–33.

RSC. (2023). *The Science Teaching Survey 2023*. Royal Society of Chemistry. https://www.rsc.org/policy-evidence-campaigns/chemistry-education/education-reports-surveys-campaigns/the-science-teaching-survey/ [Accessed 26 July 2024].

RSC. (2024). *Accredited Degree Programmes*. https://www.rsc.org/membership-and-community/degree-accreditation/ [Accessed 12 September 2024].

Seery, M. K., Agustian, H. Y., Christiansen, F. V., Gammelgaard, B., & Malm, R. H. (2024). 10 Guiding principles for learning in the laboratory. *Chemistry Education Research and Practice*. https://doi.org/10.1039/D3RP00245D.

Seery, M. K., Agustian, H. Y., & Zhang, X. (2019). A framework for learning in the chemistry laboratory. *Israel Journal of Chemistry*, *59*(6-7), 546–553.

Sella, A. (2017). Rethinking practical classes. *Nature Reviews Chemistry*, *1*(11), 0090.

Sellgren, K. (2019). Teachers 'paying for resources out of own money'. *BBC News (BBC News)*. https://www.bbc.co.uk/news/education-47964154 [Accessed 26 July 2024].

Sneddon, P. H., & Hill, R. A. (2011). Perceptions, views and opinions of university students about chemistry learning during practical work at school. *Chemistry Education Research and Practice*, *12*(3), 312–321.

Spiegelman, M. (2018). Public school teacher spending on classroom supplies. Data Point. NCES 2018-097. National Center for Education Statistics.

SQA. (2021). Advanced higher chemistry course specification. SQA, Ed.

SQA. (2023). Coursework to return for Scotland's learners next session. https://www.sqa.org.uk/sqa/104788.html [Accessed 26 July 2024].

SQA. (2024). About the SQA. https://www.sqa.org.uk/sqa/5656.html [Accessed 26 July 2024].

SSERC. (2024). SSERC main website. https://www.sserc.org.uk/ [Accessed 26 July 2024].

Szalay, L., & Tóth, Z. (2016). An inquiry-based approach of traditional 'step-by-step' experiments. *Chemistry Education Research and Practice*, *17*(4), 923–961.

The Technician Commitment. (2024). https://www.techniciancommitment.org.uk/ [Accessed 31 July 2024].

Thomson, P. I. T., & Lamie, P. (2022). Introducing elements of inquiry and experimental design in the first year of an undergraduate laboratory program. *Journal of Chemical Education*, *99*(12), 4118–4123.

van Rens, L., Pilot, A., & van der Schee, J. (2010). A framework for teaching scientific inquiry in upper secondary school chemistry. *Journal of Research in Science Teaching*, *47*(7), 788–806.

Vere, K. (2022). *The Technician Commitment: its emergence, enactment and impact*. University of Nottingham.

Vere, K. (2024). Changing the culture for technicians. In *Technicians in Higher Education and Research: An Insight into Technical Careers, Roles and Contributions*. Milton Park: Routlege, Taylor & Francis. https://www.routledge.com/Technicians-in-Higher-Education-and-Research-An-Insight-into-Technical-Careers-Roles-and-Contributions/Vere/p/book/9781032282855?srsltid=AfmBOooqIQD7wRupopBkPso5T9Ie7JIXFTDU1_WjIpxIxwLAkSlw1nek.

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