IMPACT REPORT 2023
PORTABLE SEM IN SCHOOLS PROGRAMME

Supported by

HITACHI STEM GLOBAL OUTREACH

Written by Zoe Kathleen Barr on behalf of

Royal Microscopical Society

In partnership with

CONTENTS

I) INTRODUCTION

INTRODUCING THE HITACHI GLOBAL STEM OUTREACH PROJECT PORTABLE SEM

A highly successful outreach programme focused on bringing research directly to schools through the loan of a portable Scanning Electron Microscope (SEM). Close to 14,000 students and teachers have benefitted from the experience of using high-level technical equipment thanks to the collaborative partners.

Aims of the portable SEM programme:

- Foster awareness, enrichment and research for schools and the wider community for STEM using state of the art research instruments.
- Upskill teachers and enhance curriculum provision through research-based activities.
- Connect researchers with the community and schools.

Delivered outcomes of the project so far:

- Improved awareness and excitement for SEM and imaging science.
- Provided an extended loan, long enough for meaningful depth of use and investigation.
- Reached students across the UK.
- Enabled microscience and microscopy to be embedded in the STEM curriculum
- Encouraged the use of microscopy as a tool for enacting best practice for STEM teaching.

This impact report provides a summary of the impact to date, and the potential for continued benefits to students, teachers, RMS members and the wider scientific community. This report is an assessment of the start of the programme and intends to highlight areas of success and potential expansion and improvement.

The intention of this document is to collate all relevant information on the project including the logistics, the highlights, and future proposals for the Royal Microscopical Society. Individual documents with only relevant information for specific groups are also available. The timeframe examined is the first three academic years and is from the programme beginning in 2020 to the current time of August 2023.

2) PARTNERSHIPS

MADE POSSIBLE THANKS TO OUR COLLABORATIVE PARTNERS

Hitachi Global Partners

Courtesy of HITACHI Global partners the SEM is loaned and fully insured with support for repair and advice. This report further details microscope specifications (Section 4.III) and logistical handling (Section 9.I).

Natural History Museum (NHM)

Provides a logistical hub to check the SEMs and to support teachers in set-up, training, and technical enquiries. The museum contributes technical expertise on SEM use and maintenance, and in outreach and education.

Institute for Research in Schools (IRIS)

Schools participating in the SEM loan are a part of the IRIS network of schools with IRIS as a logistical base for applications. As experts in developing research programmes within schools, data and research from IRIS facilitates the encourages a pedagogical framework for STEM learning via research (Section 7).

Oxford Instruments

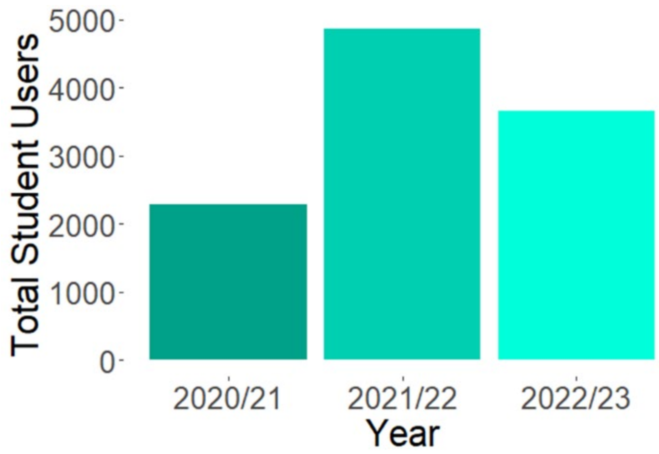
Provision of the Energy Dispersive X-ray Spectrometry (EDX) system, an X-Ray microanaylsis feature. The use of the EDX system extends the curriculum reach (Section 5.I and 7.I) thanks to the additional feature specifications (Section 4.III).

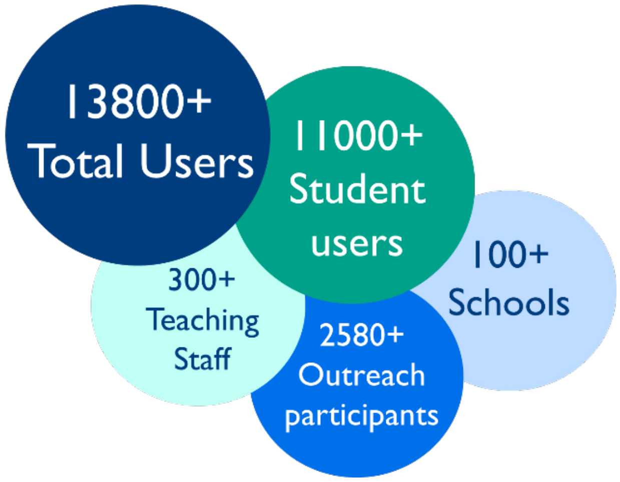
Royal Microscopical Society (RMS)

Support by the RMS includes logistical handing and transport costs. The oversight of the Outreach and Education Committee provides evaluation and encouragement.

3) HEADLINES

A QUICK LOOK AT THE POSITIVE IMPACT PORTABLE SEM OUTREACH IS HAVING

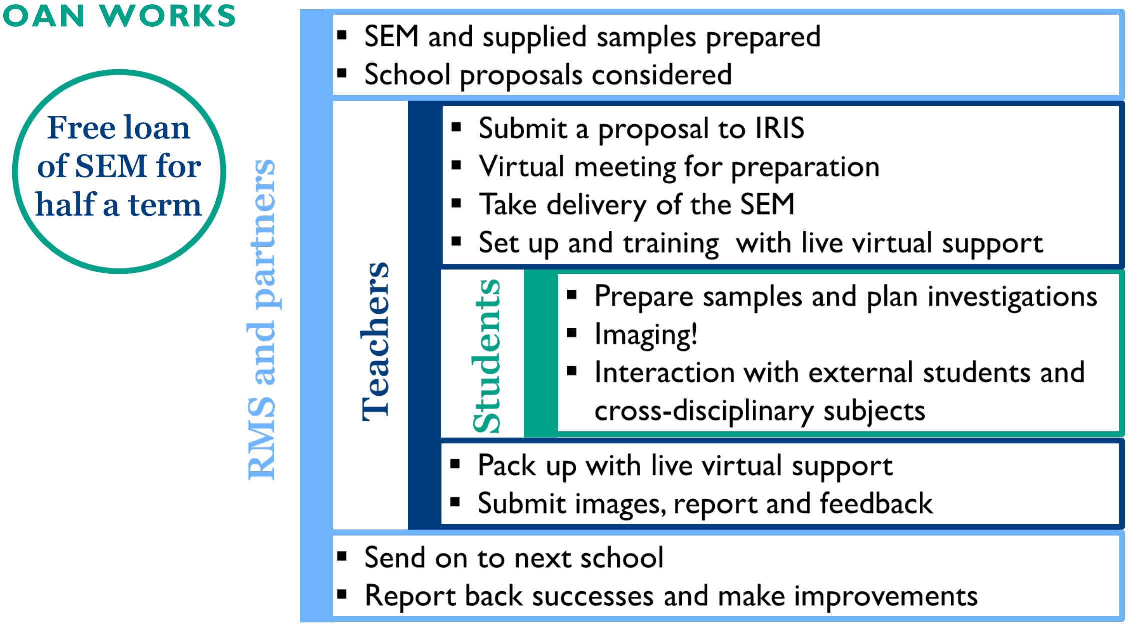




"It has been a great privilege to be able to use the microscope and to share it with other schools, and it has definitely helped inspire our students in their research projects. Science should be all about excitement and discovery, and the results from the Scanning Electron Microscope certainly deliver on both these fronts." – Head of Science, Tonbridge School

"It is (also) a new experience for students who are interested and encourages them to pick careers in sciences. We are happy to be able to benefit from the SEM and create projects using it to get more experience with scientific instruments and tech." - Lampton Academy

HOW THE LOAN WORKS



4) WHAT IS AN SEM?

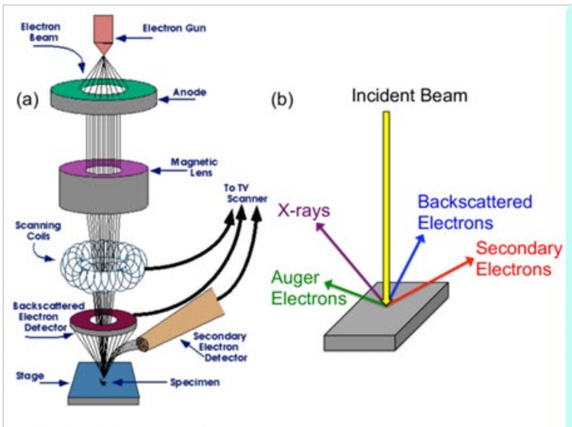
The average human can see objects approximately 0.1mm (100µm) across. Smaller objects require a lens or microscope to magnify them so that we can see them. However, some specimens contain features too small to observe with a light microscope. This is because those features are smaller than the wavelengths of visible light. To see them requires a different type of microscope. A Scanning Electron Microscope (SEM) operates under a vacuum and uses electromagnetic lenses to form and sweep a very fine beam of electrons over the sample surface. In response, the sample releases a variety of different signals as its atoms respond to the electron beam. These signals include secondary electrons (SE), produced near the sample surface, which provide information about the sample topography; back-scattered electrons (BSE), which interact deeper within the sample, provide information about its chemical make-up and characteristic X-rays which give detailed information about its elemental composition.

I) LET OUR STUDENTS SHOW YOU

Diagrams and workflow from our students' posters

1. Learning about the instrument

Folkstone School for Girls



How a SEM works
This image gives a visual representation of how a Scanning electron microscope works.
Source: Michael Walock https://www.researchgate.net/figure/Schematic-drawing-of-a-the-typical-Scanning-Electron-Microscope-SEM-column-170_fig5_281184428

3. Imaging and analysis for investigation

Lampton School

Fig 1:Sodium Chloride [Room temperature]

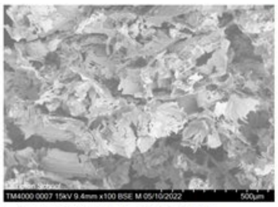


Fig 2: Sodium Chloride [100°C]

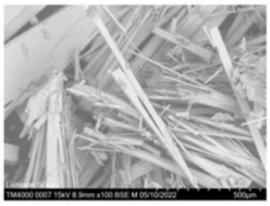


Fig 3: Copper Chloride[Room temperature]

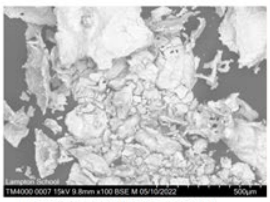
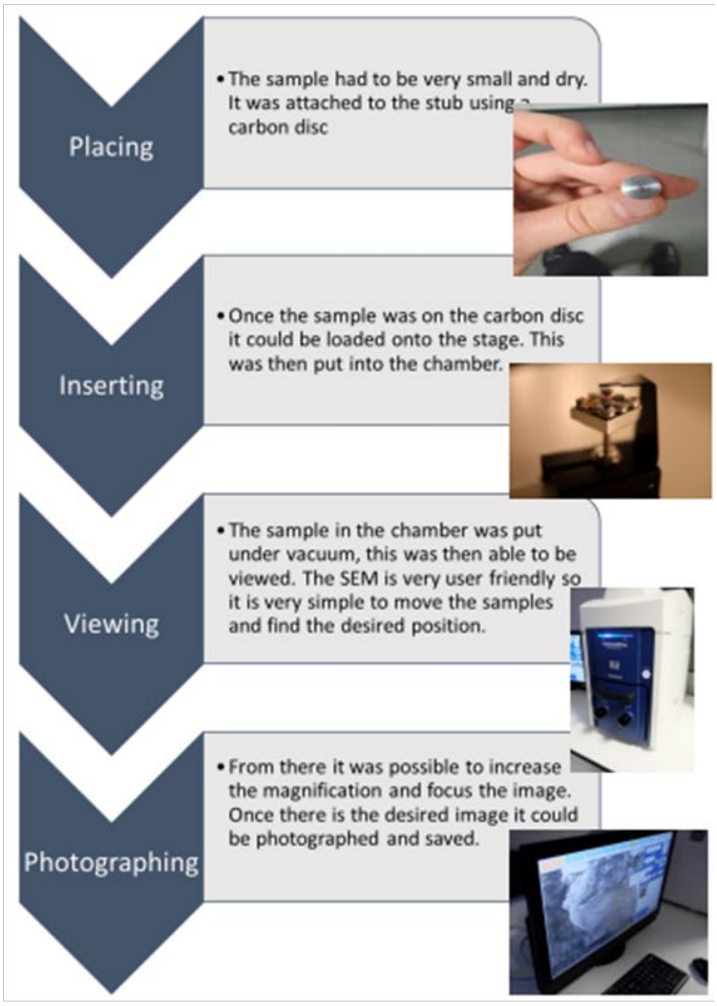


Fig 4: Copper Chloride [100°C]

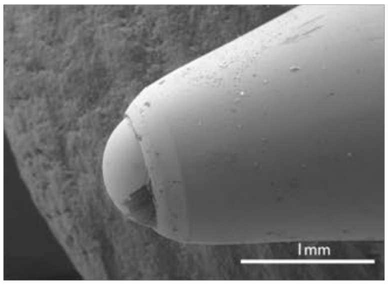
2. Forming a workflow

Liverpool LifeSciences UTC

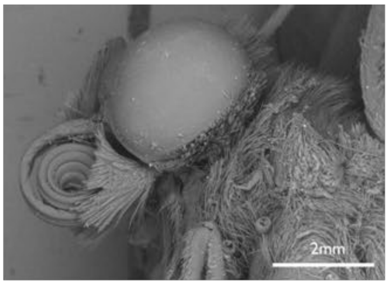


II) WHAT CAN YOU CAPTURE IMAGES OF?

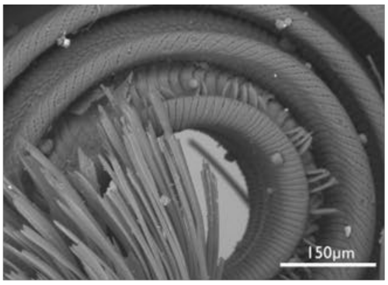
EXAMPLE IMAGES FROM OUR STUDENTS



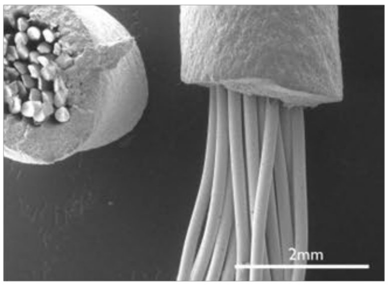
Ballpoint Pen



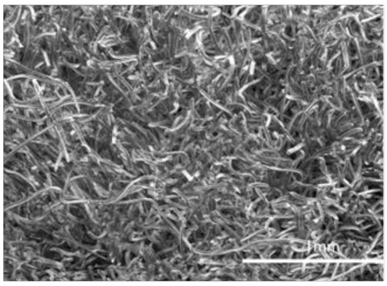
Butterfly



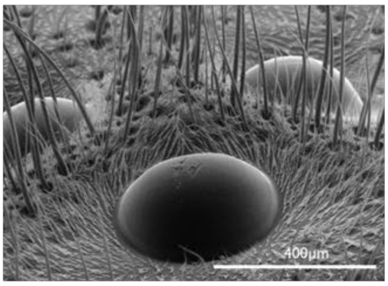
Butterfly Tongue



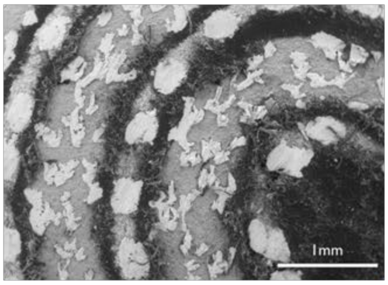
Cable Wire



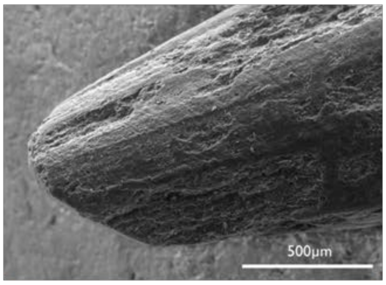
Cigarette Filter



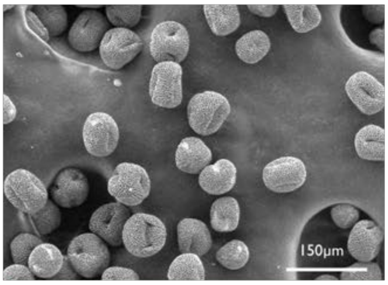
Hornet ocelli



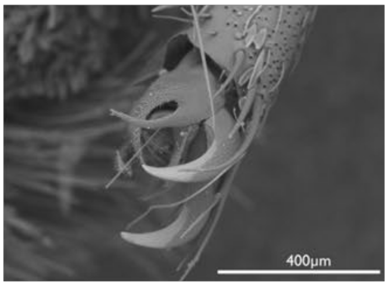
NiMH battery cross-section



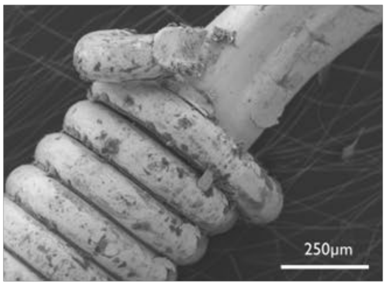
Pencil tip



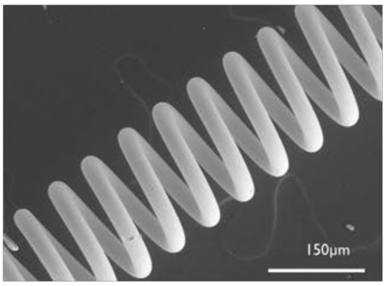
Pollen Grains



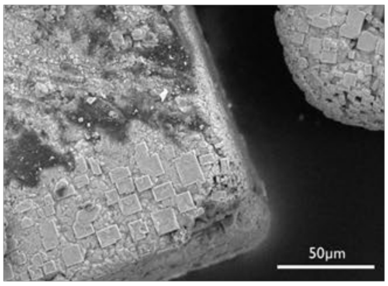
Insect foot



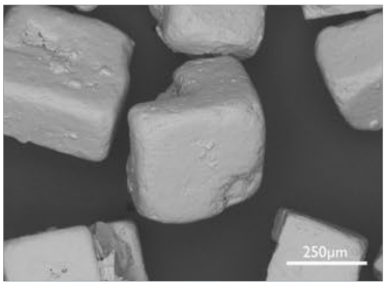
Guitar strings



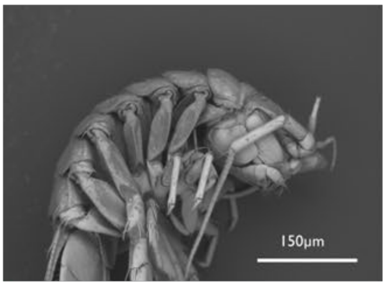
Tungsten Filament



Quartz Crystal



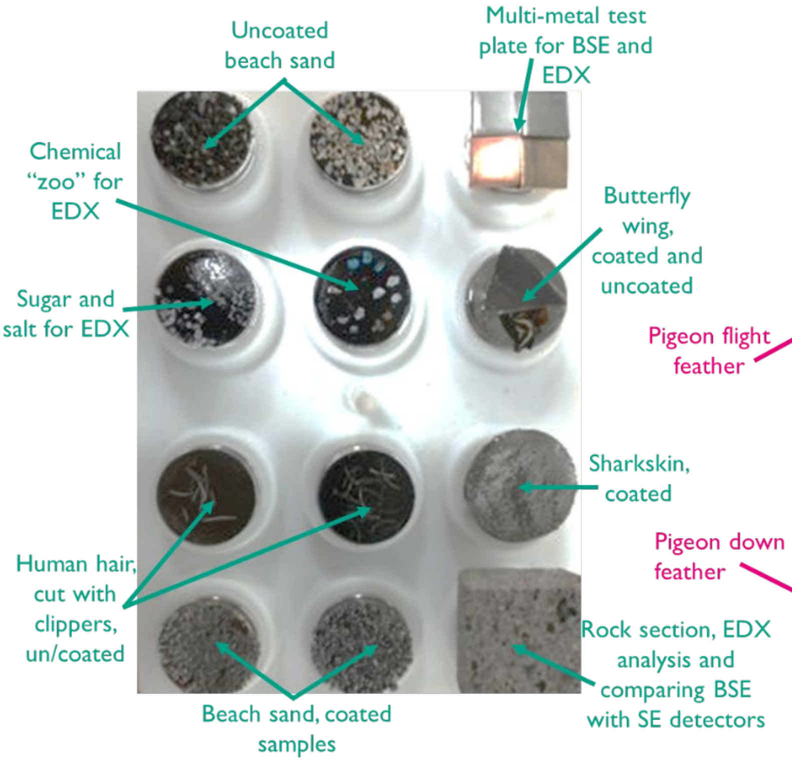
Salt



Water Slater

SAMPLE PREPARATION

Some initial samples are provided and include: sand, hair, feathers, a variety of metals and batteries. The aim of the provided samples is to facilitate training and set up. Each school is encouraged to prepare their own samples which can be any *dried* sample small enough to fit onto a 1pence coin (this is the approximate diameter of an SEM stub) and follow the interests of the student-led research.



Sample Ideas

Fabrics and natural hair from different animals

Small electronic components

Circuit boards, batteries cross-sections, wires of different metals

Soils, Sand and Volcanic Ash (different types of beaches)

Insects

Modern pound coin and its security features

Seeds

Sections cut from Vinyl records

Poppies, Garden centre packets

Pollen

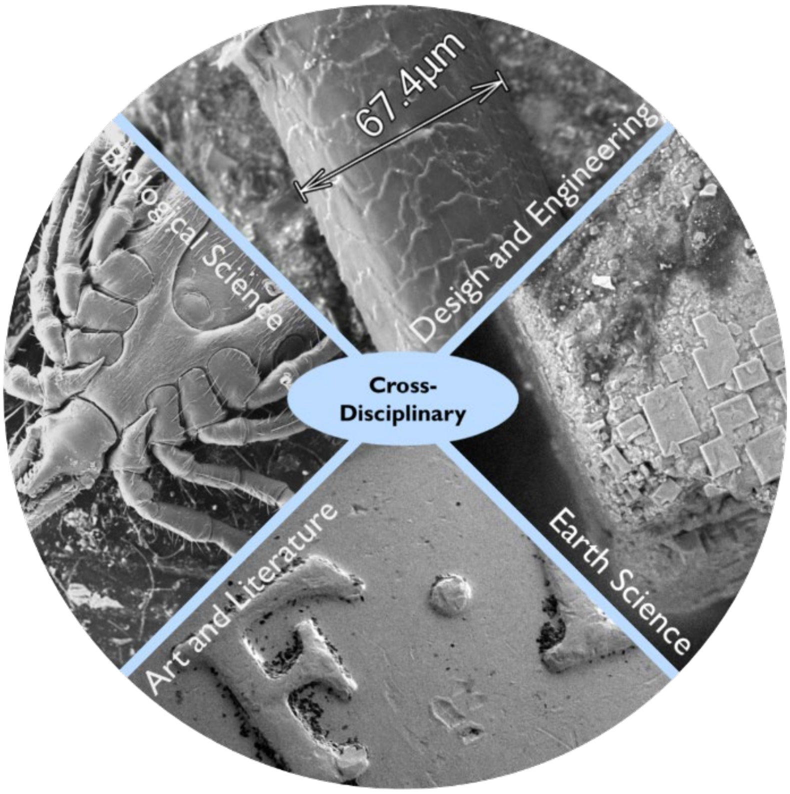
Small Plant Samples

(Top tip: find dried herbs in the supermarket)

These and many more. The student-led curiosity and their investigative questions will determine the samples observed.

CROSS-DISCIPLINARY

The SEM can be, and has been, used across the full range of the curriculum and with this the SEM has been taking science into all spaces. Some project ideas and image examples for disciplines are collected here.



Biological/natural science

Observation of biological structures and experience with spatial scale. *How large is a pollen grain compared to a bee?* Using the EDX system, chemists can obtain elemental information and experience spectroscopy.

Material/ Earth science

Visualisation of the structural difference relating to the known molecular composition and physical properties of geological and manufactured materials. *How does sand from different beaches differ? How uniform is the structure of a rock?*

Design and engineering

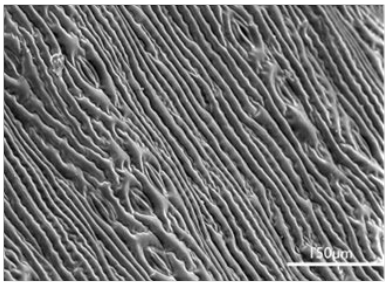
Comparison of the structural properties of materials and metals to compare with the known features. *What does snapped metal look like? How much variation in size can be found in nanofibers?*

Art/Literature

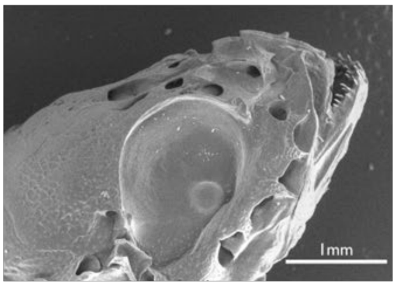
The popularity and enthusiasm for the SEM often spreads across a school or community. Alternative lessons include using the SEM as a prompt for creative writing in English lessons and providing new perspectives and inspiration for work in art.

"It was amazing, they were using metaphor and similes, the language for them was brilliant, using words like delicate!"

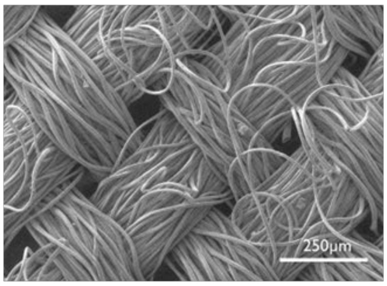
English teacher (Principal of Liverpool Life Sciences) talking about the students using the SEM as stimulus for descriptive languages.



Stomata



Bullhead fisheye



Cotton mask

III) PRODUCT SPECIFICATIONS

FEATURE HIGHLIGHTS

	Why is this important?
Variable Pressure design	Simple sample preparation with no requirements for sample coating
Compact and Portable	Plug-n-Play design. Connect power and use microscope within X minutes
Point analyses and mapping	Added depth to the collected data and expands the type of questions students can investigate

MACHINE DETAILS

Hitachi TM4000 Plus/Plus II

- Tabletop microscope
- 50kg weight, 65cmx50cm dimensions
- Low-vacuum SEM
- Thermal electron gun
- Semiconductor backscattered-electron detector
- Report-preparation software

Nicknames to distinguish between the TM4000 Plus (without EDS) and the TM4000 Plus II (with EDS) are ‘Mulder’ and ‘Scully’ respectively.

	“Mulder”	*“Scully”*
Instrument	TM4000 Plus	TM4000 Plus II
Stage control	Manual stage	Motorised stage
Sample navigation	None	Image navigation
Additional software		Zigzag and stitch montaging software
Stage movement and sample capacity	40 x 35mm (X/Y) 80mm x 50mm (dia/height)	40 x 35mm (X/Y) 80mm x 50mm (dia/height)
Electron gun	Pre-centred tungsten cartridge filament	Pre-centred tungsten cartridge filament
Acceleration voltage	5kV, 10kV, 15kV acceleration voltage presets	5kV, 10kV, 15kV, 20kV presets
Electron detection	SE, BSE and mixed	SE, BSE and mixed
Vacuum system	High vacuum and charge reduction (VP) mode	High vacuum and charge reduction (VP) mode
X-ray micro-analysis	None	Oxford instruments Aztec One EDX system

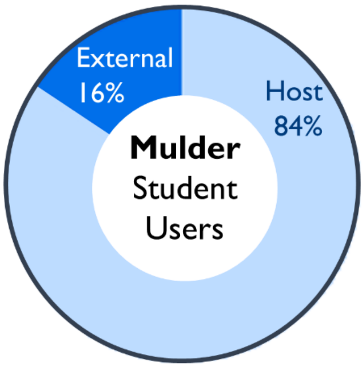
X-RAY MICROANALYSIS SYSTEM

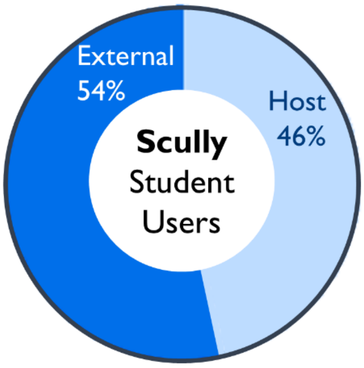
Oxford Instrument's Aztec One EDS system is an X-ray microanalysis system that enables users to obtain elemental information from a sample through the process of Energy Dispersive X-ray Spectroscopy (EDS). The hardware is fully integrated with the SEM and the software independently controls the microscope. The software is easy to use and can provide point analyses (the user defines a point, or series of points to be analysed), line scans (the system analyses composition across a line drawn onto the sample in software) or maps (the system displays the dominant element for each pixel on an image creating a map of elemental distribution across a sample).

X-ray microanalysis dramatically opens up additional possibilities for research. EDS is a fundamental technique in geology, geochemistry and palaeontology, forensic and material science, and engineering. Furthermore, by allowing the analysis of unknown samples at an elemental level the integration between SEM and EDS expands the teaching capabilities into chemistry, physics and environmental sciences well beyond what can be achieved through an instrument limited to microscopy. Examples of teaching points include (Section 9.II): the principles behind the organisation of the Periodic Table (orbital shells, atomic number), and the physics of electron excitation that underpin X-ray microanalysis, as well as light emission and fluorescence etcetera.

ROMOTE OPERATION FACILITATES MORE EXTERNAL STUDENT USERS

The motorised stage and image navigation, combined with remote access software, allows the SEM to be remote controlled. This improves accessibility and mitigates against social distancing. An external school is able to participate by entirely controlling the microscope. Reports from schools, and the altered proportion of external students participating reflects this.



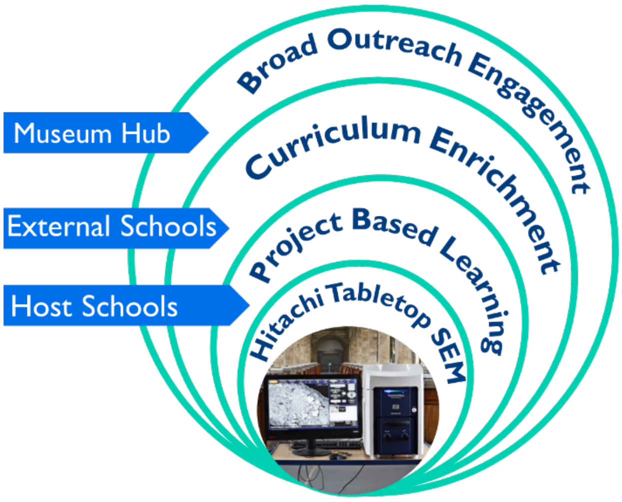


Pictured is the tabletop SEM in the Hintze Hall, illustrating how portable it really is.

5) IMPACT

The Portable SEM in Schools Programme has had a large positive impact with engagement from near 14000 students and more than 100 schools. Here we detail the variety of outreach styles achieve and highlight how the RMS, and our students and teachers have benefited.

I) 4 TYPES OF OUTREACH



The loan of state-of-the-art research equipment facilitates a variety of outreach styles. The extent of the opportunities for outreach have been realised throughout the initial years of the programme. Moving forward, we would like to support our hosting schools to engage with the local research community during their SEM loan. We want to expose students to the different job opportunities in science. The student users are referred to as either from the 'Host School' who have received the SEM loan directly, or from 'External Schools' who are partner schools, generally local, to the Host School. Beyond the school environment there is an audience of outreach participants.

(1) Individual Student Research Projects

An opportunity for Project Based Learning (PBL) and aligning to the IRIS vision for authentic, research-led learning (Section 9.II). Student-led projects are usually conducted by individual students or small groups and commonly integrated as a part of science clubs. Importantly, the extended loan length gifts the student time and opportunity to fail, redesign experiments, and retry projects. The student output can take the form of a report, poster or spoken presentation. IRIS conferences are a valuable opportunity for the students to present their work and encourage the students to reach a concluded output. Furthermore, the project write-up could take the form of an Extended Project Qualification (EPQ).

331 Students
in Independent Research Projects

(2) Lessons and In-Class Demonstrations

There are numerous places within the curriculum the SEM can be directly embedded. This includes specific STEM topics and building familiarity with the practice of 'working scientifically' with respect to the processes and methodology of science. This style of SEM use allows larger numbers of students to be involved and maintains highly meaningful interaction with the equipment. Importantly, the state-of-the-art research equipment is connected directly to the students' day-to-day STEM learning. This provides a personal experience to the student that their theoretical STEM learning is applicable in the real world, and the (sometimes too unrelatable) research-space. Examples include scale and structure in biology, element analysis in chemistry, and electron excitation in physics (more discussed in Section 9.II).

Currently, an RMS diploma candidate (more in Section 5) is developing Ready-to-Use lesson resources. The production of a set of lesson plans for SEM use, hopes to enable teachers to integrate the SEM into a variety of lessons without needing to commit a larger volume of time for lesson planning. The aim is to improve the accessibility of the SEM across the curriculum and include teachers who are especially time-constrained.

(3) Demonstrations and Workshops for Partnering External Schools

The use of the SEM can be extended through use of a 'Hub and Spoke Model' for partnering with external schools. The loan to a host school can result in the collaboration with several external schools in the local area. Broad workshops increase accessibility to the scheme and have provided thousands of children with awe and awareness of scanning electron microscopy. An especially rewarding style of this outreach, with two-fold benefits, occurs when students from the host secondary school, are expert demonstrators and take on the task of showing the SEM to visiting primary school students (pictured right).


Primary school visit

(4) Wide-reaching Public Outreach

The partnership with the Natural History Museum enables the SEM programme to be linked to a network of museums nationwide. Demonstration of the SEM in the museum environment guarantees continued engagement throughout school holiday and the potential to reach other geographical areas of the UK. This was tested by the Natural History Museum loaning to the Potteries Museum (Stoke on Trent) and the Leeds Discovery Centre, and by the school Liverpool Life Sciences UTC loaning to The World Museum and the Catalysts Centre (Widnes). The return to a 'museum home' ensures safe monitoring of maintenance requirements (Section 8).

2600+ Outreach Users

II) FOR THE RMS

The objectives of the Society as detailed in the RMS charter:

To promote the advancement of microscopical science by such means as the discussion and publication of research into improvements in the construction and application of microscopes and into those branches of science where microscopy is important and

To organise educational activities concerned with microscopy for the benefit of the general public and for the science community.

The remit of the Outreach & Education Committee is to promote the use of microscopes in schools, and to raise public awareness and appreciation of microscopes and science through public exhibitions, workshops and talks. Each loan of the SEM achieves this, and more.

An additional area of outreach and education progress in response to the SEM programme, is an RMS diploma candidate developing Ready-to-Use lesson plans for teaching with the SEM. The support of diploma candidates by the RMS is an exemplar for the encouragement of improving microscopical skill, awareness and use. An RMS diploma focused on Microscopy in Education, is a positive advancement for the RMS to address its' role in STEM education.

Recently, collaboration between different international microscopical societies has been growing. Interest and connection resulting from the SEM programme includes the Microscopy Society of America and the Scottish Microscopy Society.

The alignment of the Society objectives with the aims of the SEM programme, ensure the RMS role as a stable and neutral partner. The SEM programme furthers awareness of the Society itself and continues to develop the successful collaborative partnership. The enthusiasm and support RMS Outreach and Education Committee is a consistent motivator for the programme's continuation.

III) IMPACT ON STUDENTS

WHAT DO OUR STUDENTS HAVE TO SAY?

"When my class used the scanning electron microscope it was really interesting and I felt like I was actually doing a project like a scientist"

"It was mind blowing to see things you can't see with the naked eye"

"It was amazing!"

"Very interesting to see things not visible normally"

"I thoroughly enjoyed seeing the microscope in action. It's amazing to see such detailed imagery!"

"As a young black female, I rarely get opportunities like this. Using the electron microscope was an amazing experience. I learned so much in a short period and would be ever so grateful if we could continue using it."

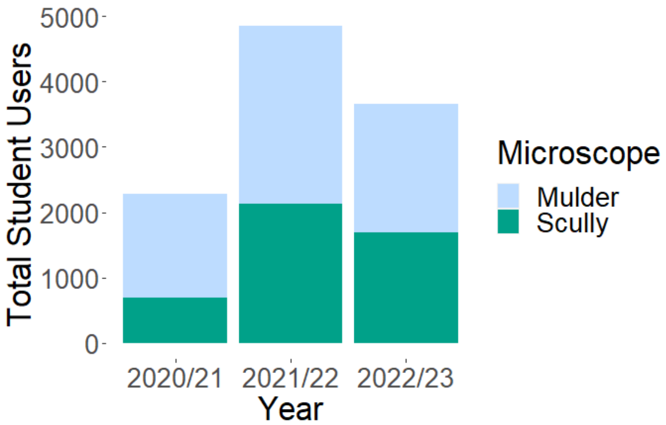
"The SEM really made me think, and realise how complex microorganisms are"

"I liked the SEM as I got to go deeper into my learning and also just trying something new."

"It was amazing! And even better you get to see your own item under the microscope. Fascinating stuff!"

"I enjoyed it. It made me think I was a smart scientist."

"It was incredible to be able to use the microscope myself, an experience I think that many people might never get. I was amazed at what it could do and the levels of magnification that it could achieve."



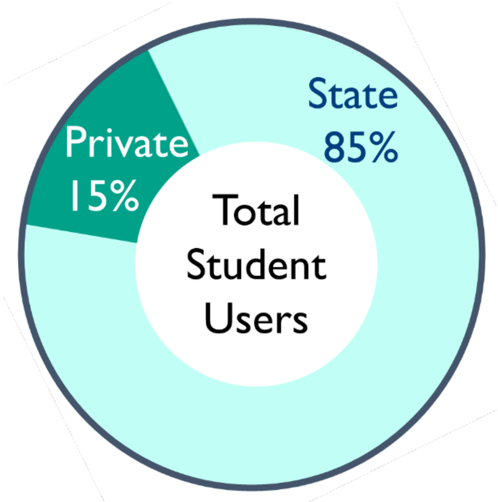
13800+
Total Users (2020-2023)

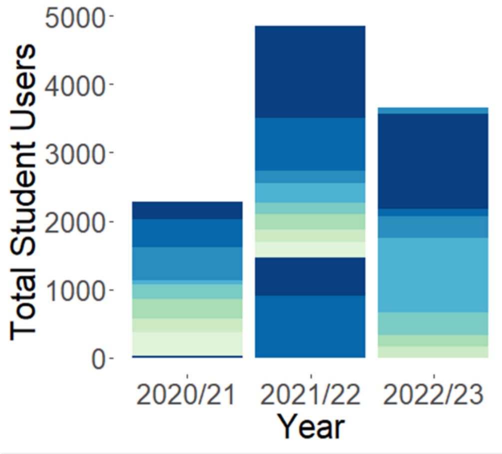
11000+
Student Users

100+
Schools

2580+
Outreach Participants

300+
Teaching Staff





*Each stacked colour is the loan to one host school

28
Host
Schools

STUDENT PROJECT TOPICS

331 Student Projects

- Lead residues in marine molluscs
- Cut surface analysis of different metal wires
- Investigating the ultra hydrophobicity of lotus leaves
- Comparison of the surface of bone, cartilage and tendons
- Is flour vegan? Percentage of insect parts in different types of flour
- Chemical vs structural pigmentation of butterflies
- Structure of spider silk vs caterpillar silk vs plant based silk
- Plant pathogen detection on leaf surfaces
- The effect of pollution on lichen in inner city areas
- Comparing synthesized and shop-bought aspirin
- Microplastics in natural waters
- The effect of temperatures on crystal growth
- How abrasive are whitening toothpastes?

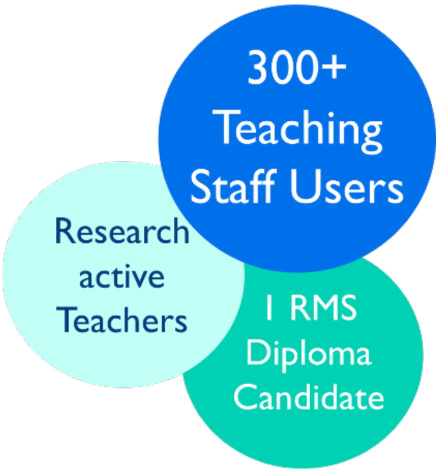
"We have enabled the development of enquiring minds in our students using the SEM. Again, we have given them agency over their work, students are astonished that they are 'allowed' to use this equipment for their work thus developing self-esteem and self-confidence. This was especially the case with some students who would not necessarily comfortable with academic study who have been empowered by this technology to produce excellent work. There are three students in particular for whom I would say that their SEM projects have changed the way they think about themselves and have had a profound effect on life outcomes."

– Liverpool Lifesciences UTC

AWARD WINNING PROJECT

UK Young Scientist of the Year 2022 was awarded to Connie, a year 9 student from Liverpool Life Sciences UTC for her SEM project "comparing the structure of the features of birds from different climates and environments to each other" [1]

IV) IMPACT ON TEACHERS



"It was such a rewarding experience to see the children's faces light up as they observed life sciences unravel right in front of their eyes. The SEM is truly the ultimate tool to spark curiosity in the future generation of scientists."

- Science Technician, Tonbridge School

"Collaboration between staff, academic and industry partners and students on SEM projects has further enhanced the idea of the schools as a safe learning space where all are included and work together to secure good outcomes for all."
– Science teacher, Liverpool Life Sciences UTC

DEVELOPING 'TEACHER SCIENTISTS'

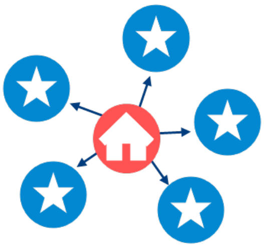
The loan of the SEM and the subsequent research-led science is not only of value to students but provides great benefit to the teaching staff. Integrating research opportunities into teaching has been shown to shift professional identities from 'Science Teacher' to 'Teacher Scientist' by the development of a professional identity that encompasses a wider range of roles [2]. Here, the emphasis is on the return or retention of the individual teacher's identity as a scientist. Various aspects of research involvement are attributed to this: building complex professional networks, taking a mentor role, and remaining up-to-date with the latest research and technology of their field.

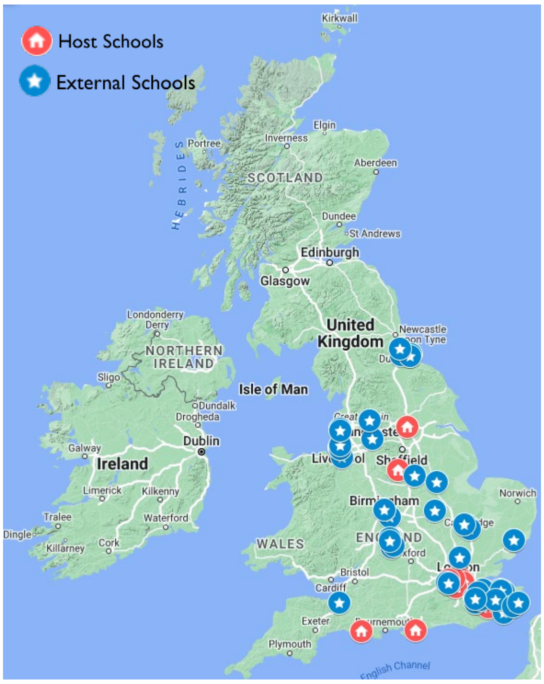
The importance of social identity [3,4] and research [5] in teaching has been shown. The valuable impact of this directs the SEM programme outcomes for upskilling teachers and connecting researchers into the education community.

6) WHERE HAS THE SEM VISITED

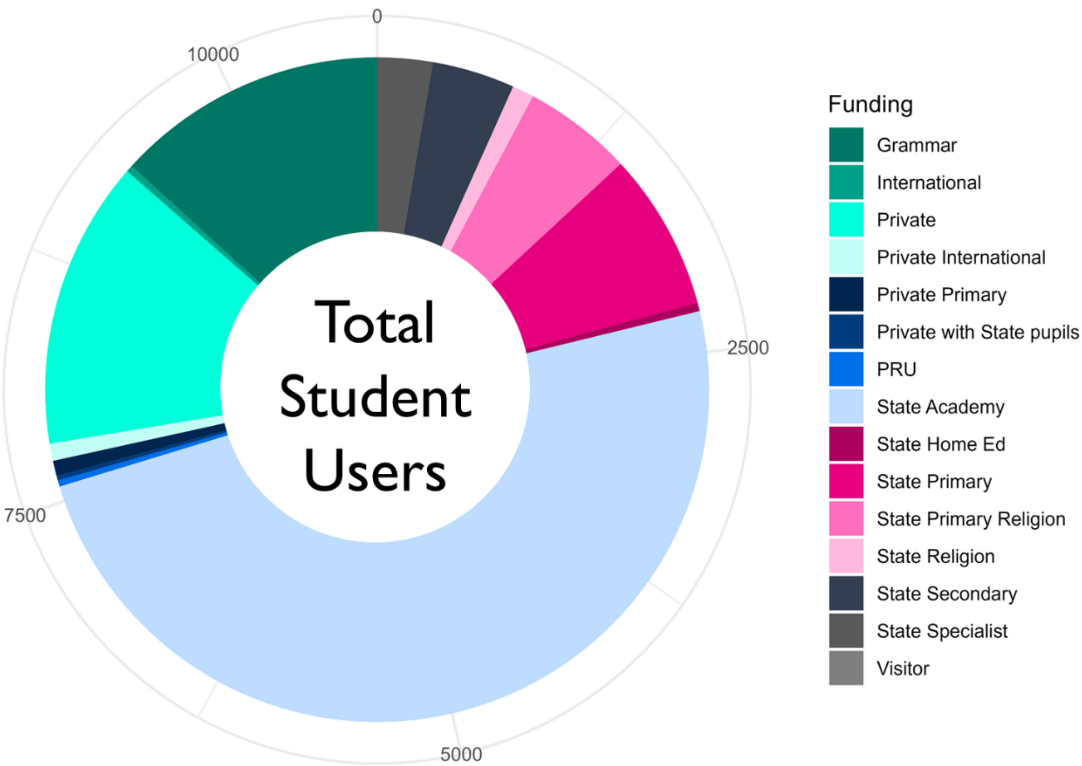
GEOGRAPHICAL SPREAD

The reach of the SEM is expanded by the 'Hub and Spokes' model. Host Schools partner with other local schools to collaborate together and increase the number of student users.



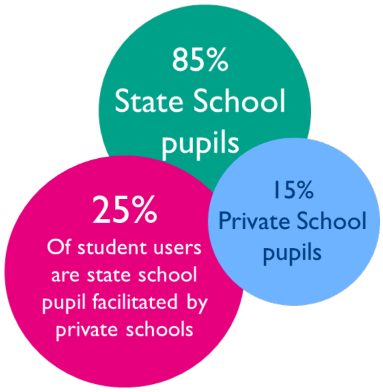


SCHOOL FUNDING TYPE

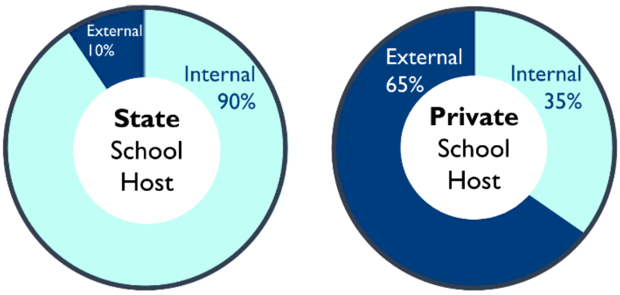


A notable proportion of host schools have been private (independent) schools. in the UK, these are the schools which charge a fee and are run separately from the state funded comprehensives and academies. The demographics of UK school pupils include 6.5% attending privately funded schools [6] although this proportion differs across age group and at 6th Form (Key Stage 4) is as high as 18% in England [7].

The current climate of STEM teaching staff and resources is an unavoidable component of STEM education today [8]. Private schools' benefit from teaching resources and increased capacity to engage with the programme, however, private schools are required to partner with local state funded schools. New and existing partnerships between private-state schools has enabled large numbers of external school pupils to participate in the SEM loan. Significant numbers of state school pupils have been reached because the resources of a private school facilitated the loan. This is one of the benefits of encouraging the 'Hubs and Spokes' model.

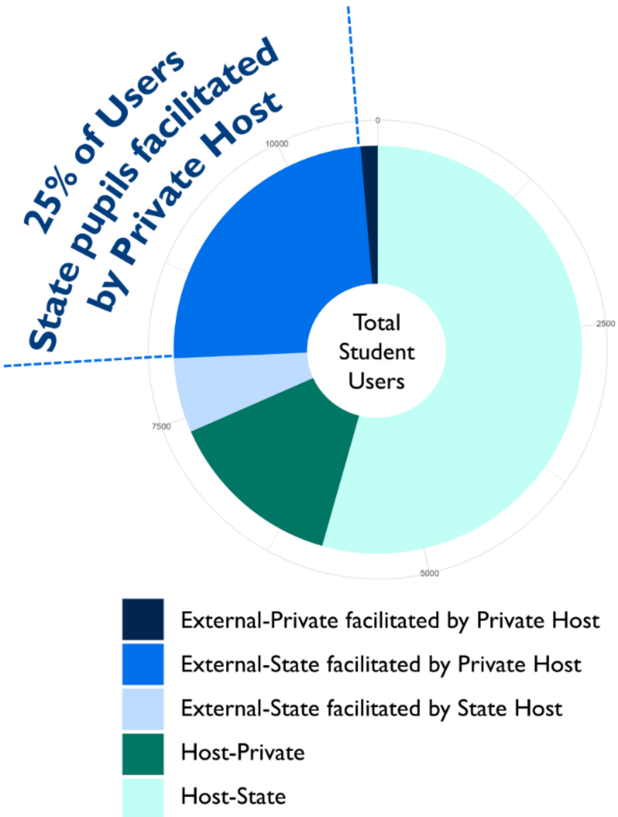


Private schools fulfil their responsibility to be a community hub. When a private school is host, the number of external student users exceeds that of their own internal students. Private schools facilitated engagement with many state school students we might not otherwise be able to reach.



EXTERNAL SCHOOL INVOLVEMENT

This report has detailed the common distribution of outreach styles between host and external schools. Generally external schools are involved in large workshops, in-class teaching or small group visits. This does not include the opportunity for longer-term projects (PBL). School reports show repeat hosting of the SEM allows the school to plan ahead and maximise their time with the SEM. Both where a school is a repeat host, or privately funded and well resourced, we can suggest the involvement of external schools is extended to include individual student projects. For example, by hosting a science club open to students of the host and external school.



7) EDUCATORS PERSEPCTIVE

This report also began investigations into to pedagogical theory which supports the successful engagement with the SEM to support STEM learning.

I) STEM EDUCATION GOALS OF OUR PARTNERS

Hitachi

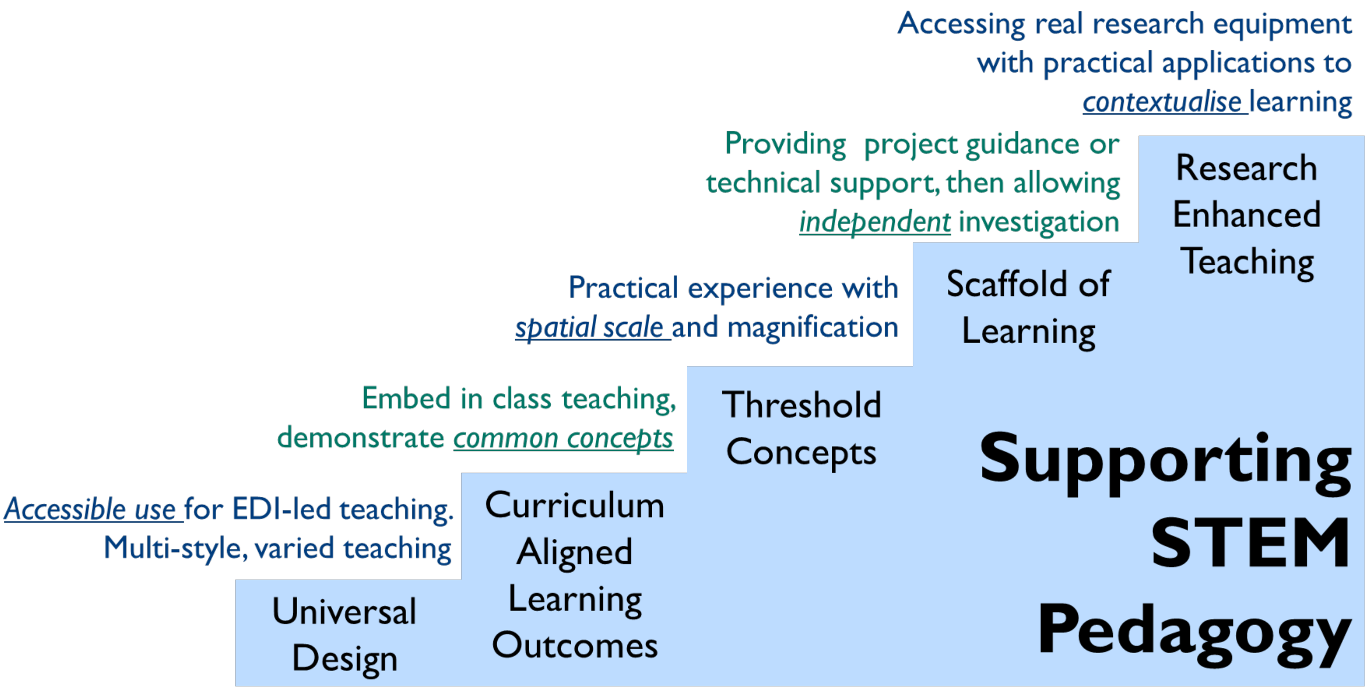
"We want to boost interest in the sciences and inspire more and more children with the ambition to make new breakthroughs in High-Tech."

IRIS

"We want to change the culture in UK education so that authentic research and innovation is part of every young person's experience."

II) PAEDAGOGICAL FRAMEWORK

The best support for STEM education relies on the design of teaching practice which provide the student the most valuable learning opportunities possible. Pedagogical frameworks aim to incorporate the curriculum outcomes, address Equality, Diversity and Inclusion (EDI) and inspire students with enthusiasm for STEM. The SEM programme aligns with the educational goals of our partners and can be utilised as a pedagogical tool in secondary STEM education.



CURRICULUM ALIGNED LEARNING OUTCOMES

Analysis of integration and alignment with the national curriculum has been previously summarised [9]. The national curriculum makes specific references to microscopy [10]. Furthermore, the overarching intended learning outcome of STEM education is an awareness and application of 'working scientifically' [10]. The concept of 'working scientifically' is defined by the following components: scientific attitudes (considering accuracy, precision, reliability and reproducibility), experimental skills and investigations (familiarity with building an experimental workflow), analysis and evaluation (observation, interpretation and identifying questions), and measurement (units and statistics). Each of these components are supported by the SEM because the use of the instrument and development of the experiment, much like in academic research, will naturally encompass all aspects of 'working scientifically'. The instrument centred outreach is the support for this and provides a learning style difficult to replicate in standard lessons.

Examples of in-class use of the SEM to cover curriculum specified topics:

	SEM demonstration of concept	Curriculum specification
Maths	Calculating magnification of a series of images	• Ratio, proportion and rates of change (scale) • Rearrange formula
Biology	Imaging insect spiracles	• Gaseous exchange systems • Surface area and Scale
Chemistry	Using EDS to compare orbital shells and atomic number	• Elements in relation to their position in the Periodic Table
Physics	Principles of the electron beam of SEM	• Light waves • Wave motion
English	Images for creative writing stimulus	• Vocabulary • Metaphor, simile, analogy, imagery, style and effect

THRESHOLD CONCEPTS - SCALE/MAGNIFICATION

Spatial scale and magnification is a concept frequently specified in the curriculum [10], and (to the experienced scientist) is an evident cornerstone of relating structure and function. However, spatial scale is commonly attributed as a threshold concept. Threshold concepts are numerous areas of student learning that are once understood, push the student to a new level of understanding, or to a working at a higher level of SOLO taxonomy [11]. Threshold concepts are, therefore, notoriously difficult to guarantee in intended learning outcomes.

The example of spatial scale as a threshold concept:

- A student comfortably learns two separate topics in biology:
    1. The organ system in the human body
    2. The organelles composing the cell
- These two topics have been learnt separately, and as such minimal connection between the two has been made by the student. This is 'horizonal learning'.
- Intuitively, those who have 'crossed the threshold' (teachers/ scientists/ microscopists) will connect these topics to the hierarchical organisation of multicellular organisms.
- Using the SEM to examine an insect, the student can navigate the spatial scale to observe the range of hierarchical organisation and engage in 'vertical learning' where the two topic become conceptually connected.

Practical experience with the SEM is a valuable way to move student understanding of spatial scale from 'performative' to 'real'.

UNIVERSAL DESIGN - INCLUSIVITY AND WIDENING PARTICIPATION

Universal design of learning is a framework for inclusive teaching practice [12]. The principle of universal design for teaching practice is to provide multiple means of engagement, representation, and action and expression. The work of universal design is to accommodate the needs and abilities of all learners and provide an inclusive learning environment. The main recommended practice for teaching with universal design is to provide options. Therefore, information presentation, learner demonstration and motivations are all aspects that should involve multiple models [12]. The use of the SEM itself introduces an alternative model for information presentation. Furthermore, this is continued with the resulting student outputs of individual projects and peer-to-peer demonstrations, and the support of 'vertical learning' in relation to threshold concepts.

The access to the programme is monitored and private schools fulfil their commitment to outreach and partnership with local state schools (Section 6). IRIS reports 79% of IRIS students as attending state school [13]

A benefit of the programme's universal design is potential contribution to Widening Participation in STEM. Participation in research results in the biggest change in STEM engagement and achievement for the student groups commonly excluded from STEM (disadvantaged and disengaged students) [14]. The SEM inspires future scientists and provides students the chance to become a part of the research community. This fosters student curiosity and a sense of belonging from an earlier age. Follow up of student outcomes is notoriously difficult but the benefits of outreach, and the work of IRIS, is becoming increasingly understood [14].

RESEARCH ENHANCED TEACHING

"Students have had access to this incredible technology in order to further their research projects, which has not only given excellent results but has enhanced the idea that they have agency in the world and can make a difference."

-Liverpool Life Sciences UTC

The Hitachi SEM is a research grade instrument with full capabilities to demonstrate research methodology, technical advancements and undertake original research projects. Research enhanced teaching is considered definitional practice in the higher education sector however the benefits are readily applicable at the secondary school level [14]. Research-enhanced teaching, as supported by the SEM loan, changes the learning experience for the student. This change can be split into two concepts: 'research-led teaching' whereby the content taught relates to the latest field advances, and 'research-orientated teaching' whereby students are incorporated into research practice or projects [15]. Research enhanced teaching provides context to the taught concepts of the curriculum and represents an alternative model to be utilised amongst universal design practices.

Numerous benefits of research enhanced teaching have been highlighted throughout this report and is summarised [14] specifically in relation to the SEM:

- Learning impact: the active and practical participation with research grade equipment increases engagement and improves conceptual understanding of related topics.
- Inspiring careers and pathways: using new instruments, dealing with problems and designing the 'imperfect experiment' is an experience of the realistic research environment. This real perspective on science improves motivation for students to expand their interests and continue with STEM study. Access and awareness of the research careers are openly presented when research institutions and universities build community with schools.

- Attitude to science: 'Good question- let's look under the SEM' is a common suggestion from teachers to students. This changes how the student perceives the world around them, beginning a pattern of following up curiosity and considering the scale of structures.

The best implementation of research in schools embeds practical science [16] and is supported by a learning scaffold [17]. The long-term loan of the SEM provides the time for learning to be scaffolded. Teachers are able to introduce the instrument to students, and gradually reduce support as the student becomes the 'expert-user'. This is highly valued for developing independent, confident learners and is uniquely possible because of the introduction of a new, research-grade instrument.

PROJECT BASED LEARNING

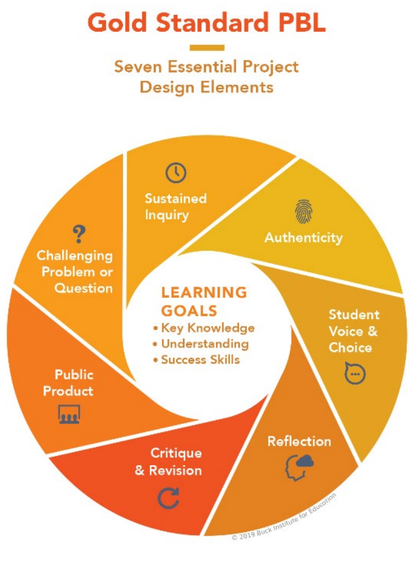
Project Based Learning (PBL), or Practical Independent Research Projects (IRPs), provides the opportunity for student-led practical research. It is a teaching style where students gain skills and knowledge via investigation of an authentic research question. This differs from the common pre-defined protocol, or recipe, style of STEM practical where all outcomes are known and the investigative method is highly prescribed [18]. PBL brings together the other pedagogical ideas discussed included research led teaching and scaffolding of learning [19].

Key benefits for students include [18] :

1. Continued engagement from following their own curiosity.
2. A realistic experience of scientific research
3. Learning from 'inquiry-based science' and 'authentic science'.

Independent research projects resultant from the SEM loan include three aspects. The research-grade equipment of the SEM sits centrally, while the student leads the investigation forward with scaffolding and mentorship from teaching staff.

The numerous aspects of PBL are well summarised (*Gold Standard PBL: Essential Project Design Elements*) and integrated into the SEM programme. For example, the recommended 'sustained inquiry' of PBL is possible because an extended loan, long enough for real use, is specified in the programme aims (Section 1). Authenticity ensured by the Hitachi tabletop SEM being genuine research grade equipment and the encouragement of students' own sample preparation.



The research led participation in PBL with use of the SEM, in partnership with IRIS, gives students the opportunity to participate in the IRIS student conference. Participation in academic conferences is a further development of student skill in an authentic environment [21]. Student skills include social competence and communication and bringing a project to a defined output or endpoint. PBL is a powerful way to utilise the full potential of the SEM for STEM learning and is exemplary of all collaborative partners.

8) PLANNING FOR THE FUTURE

The logistical operation of the programme (Section 9.I) has evolved over the first three years examined by this report. We propose numerous areas for improvement and expansion. Whilst the identified considerations are key, we acknowledge unforeseeable factors will adjust the programme. The successful delivery of the programme outcomes, and the clear scope of the programme aims, provide confidence this programme will continue deliver SEM engagement in schools to facilitate STEM learning.

I) GEOGRAPHICAL SPREAD

Planning for the academic year 2023-24 has already begun with applications accepted and reviewed.

We currently have application with increased geographical spread. The increased interest in Scotland for 2023 is thanks to the communications from the Scottish Microscopy Society. We are reaching out to Wales and the South-West to find interest here.

II) PROPOSED PROJECT EXPANSION AND CONTINUATION

This report has highlighted the positive and far-research impact of the SEM programme. The RMS fully supports the continuation of the programme.

RMS volunteer recruitment

The support of the RMS is in excess of covering the transport costs, reviewing and encouraging the programme. As RMS members, the project leads donate their time-in-kind for the coordination of the programme, training and technical expertise is a large, and invaluable, contribution. The RMS would like to reach out and secure more involvement from RMS members. Particularly from those with experience with SEM or outreach. Expert users located across the UK have the potential to support the service checks and transport between schools. Where the host school is located near a university or institute, the SEM can be checked on-location and sent on directly. The current logistical handling (with return to project lead Alex Ball at the NHM) will remain the default and this alternative would be based on strong involvement and expertise. Furthermore, it has been suggested that numerous tabletop SEMs may be available for partial use in outreach across UK research institutions. We would like to increase awareness of this programme and provide support to ensure this potential outreach is realised.

Learning resources

The development of Ready-to-Use Lesson Plans is underway as a part of an RMS diploma programme (Section 5.I). This will enable easy embedding of the SEM into the curriculum and ensuring full use of the SEM throughout the loan. The resources from our UK- Hitachi STEM Outreach Project can then be shared globally, especially to our partners in the US.

Three region provision

The RMS, collaborative partners and programme leads would like to see this scheme continue to be distributed across the UK and continue the highly-valued work from the beginning years. The use of three portable SEMs would expand the programme and enable coverage of the UK by three proposed regions: UK North, UK South and London Tri-Borough.

III) PROJECT RESILIENCE

This project relies heavily on several key personal and their time-in-kind. However, the simple, positive aims and brilliant impact of the SEM programme to date, has insured continued commitment to the programme.

The RMS Outreach and Education committee provides resilience thanks to their aligned goals. The committee acts as stable governance, a critical friend, and a source of contacts and collaboration.

IV) RESOLVED AND ONGOING LIMITATIONS

Highlighted here are the limitations and challenges the SEM programme encounters. However, with consideration and acknowledgement, each can be well accommodated within the SEM programme organisation.

	Suggested accommodations
Resilience of the Scheme	Provided by the RMS Outreach and Education committee. (Section 8.III)
Retrieving data from schools	Surveys elicited poor response rates. New standardised table for numbers that can be sent within an email (Section 9.II)
Fair geographical coverage of the UK	The continuation and expansion of the scheme will help more children across the UK be reached. Applications and network of schools handled by IRIS.
Equality, Diversity and Inclusion	The ‘Hub model’ for host and external schools enables schools with fewer resources and less capacity to be involved. In-class EDI is supported by the pedagogical framework for SEM use in STEM learning (Section 6).
Schools lack tech confidence	Information about the programme to include the technical requirements with explicit reassurance of the technical accessibility possible.

9) PROGRAMME LOGISTICS

The programme organisation is multifaceted. Each partner and volunteer contribution is essential.

I) LOGISTICAL TIMELINE

One SEM will generally be hosted by 6 different schools, one school for each half-term. This also leaves space in the schedule during the summer for museum or summer school visits.

The yearly process is as follows:

(1) IRIS- Applications received form schools via the IRIS website
(2) RMS office, NHM, IRIS- Biannual stakeholder meetings to review the applications
(3) Alex Ball (NHM/RMS)- Contact to school to confirm or decline
(4) James Perkins (QEGS, Head of Science)- Arrangement of schedule with each school. Care is taken to align with the schools' commitments and term dates
(5) RMS office, Alex Ball- Delivery of the SEM by courier on a pallet.
(6) Alex Ball- Return of SEM to NHM for checking. Scheduled as 1-2 week gap between loans.

This logistical operation is the current best compromise to keep costs low and be confident in the state of the microscope. The selected courier style is more cost effective but delivery is not accurate to the day. This causes some delay and extension to the time the SEM is waiting at the NHM. The state of the SEM in between each school is ensured by its return to Alex Ball, NHM. However, as suggested (Section 8.II) RMS volunteers with similar expertise, who are local to host schools, could ensure these checks and make delivery direct from school-to-school possible.

II) COSTINGS

The exact costs of the programme running are evolving but detailed here are the major costing considerations.

Instrument

The current arrangement is a loan of the Hitachi TM4000 Plus courtesy of Hitachi US. Insurance is included and servicing has been arranged in the UK as required.

Funding for the purchase of another tabletop SEM will secure the longevity of the programme. The following will be considered:

- The listed owner
- Service contract
- Insurance
- Predicted instrument lifetime (likely reduced as a consequence of movement and usage)

EDX system

Currently supplied from Oxford Instruments.

Transport

The RMS have financially supported the programme by covering the courier expenses. Across the three years the price has differed but the current average for each relocation of the SEM is approximately £80.00.

	Cost	Number of hosts
2020-21	£1040.41	9
2021-22*	£1799.71	12
2022-23	£TBC	8

* Throughout 2021-22 academic year two microscopes were used.

Time Committed

It must be recognised the time the project leads contribute is of enormous value. This includes the time taken to cover:

- Applications and School Communication
- Training and technical support
- Instrument checking, packing and servicing.

For the above, this report notes gratitude to the NHM for supporting Alex Ball's and to senior leadership of Queen Elizabeth's Grammar School for supporting James Perkins.

- RMS office coordination of courier (Required approximately monthly, 1 hour)

10) APPENDIX

Further information can also be requested as we invite feedback and ideas.

I) FEEDBACK COLLECTION

Current records are difficult to analyse for quantitative data of impact. This is common in schools outreach because of the time-constraints of teachers, and the often immeasurable nature of impact. This report has clarified the various styles of outreach a host school can achieve and therefore recommends the following data collection method. Experience has shown that surveys result in low response rates and so the request for a report, with minimal guidance is ideal. This allows a school lead to demonstrate the extent of the SEM use and invest their time in the most appropriate way for them. However, completion of the following table, within an email, will benefit the continued monitoring of the programme success.

Host School	Student Users	
	Staff Users	
External Schools	Student Users	
	Staff Users	
	School names	
Positive impact score (1- disagree, 10- brilliant)		

II) APPLICATION AND LOAN REQUIREMENTS

SEM APPLICATION FORM

All applicants must either be a current IRIS school or agree to join IRIS. Contact Richard Phillips for further information. Find out more about IRIS here or click to join.

First name:	**Last name:**
Name of School/Organisation:	**Contact e-mail address:**
Are you a current IRIS school?	Yes/No
Address:	**Phone number:**
Student / Participant age range:	**How many students/participants do you expect?**

Previous experience with scanning electron microscopy (mark an X as applicable)				
None:	**Some understanding:**	**Some experience:**	**Regular user:**	**Expert user:**

Proposal summary (500 words max)
Guidance: Here we are expecting a basic outline of what you intend to do. Will there be a series of individual student research projects, for example Crest Awards? Are you going to work with other schools? You might propose that your school acts as a hub and other schools will visit (either virtually or in person) to use the SEM. Is the SEM going to be used in part of a Science Club?
Requested date range for loan (e.g. term dates):

What are your planned outcomes? (200 words max)
Guidance: Here we would like to know if you plan to write up the research, perhaps as part of a Crest Award report, or as an application to a research journal. Perhaps you are going to publish the work in a blog on a web page, or via social media. Maybe you will want to create a short film? Will you be working with any external organisations, perhaps a local university or higher education college, or a local industry? If so, do you envisage continuing this relationship after the project is ended? As part of this project, IRIS and NHM encourage your students to produce an output of their SEM research, be it a conference poster or presentation. Support for this is available from the IRIS Regional Engagement Lead in your area.

Proposal detail (1500 words max)
Guidance: Here we'd like to see a fuller and more rounded explanation of the project. Are there any technical problems you might need to solve? In simpler terms you could simply use this space to bring together the different parts of the application form, so you could explain how many pupils will be involved, what you plan to do and over what time frame. You might include any plans you have to use the SEM for teaching or outreach. Finally, you can detail your expected outcomes. We will use this form to help you and us to complete a report at the end of the project.

III) REFERENCES

FURTHER INFORMATION

Hitachi High-Tech Science Education Support

www.hitachi-hightech.com/global/en/science-edu/

Energy Dispersive X-ray Spectrometry (EDX) from Oxford Instruments

nano.oxinst.com/campaigns/what-is-eds/edx

Royal Microscopical Society Diploma

www.rms.org.uk/opportunities/rms-diploma.html

Extended Project Qualification (EPQ)

www.aqa.org.uk/subjects/projects/project-qualifications/EPQ-7993/introduction

Scottish Microscopy Society

scottishmicroscopygroup.org.uk/

REFERENCE LIST

1. The Big Winners of The Big Bang Competition 2022 - The Big Bang Available online: https://www.thebigbang.org.uk/the-big-bang-competition/2022-winners/ (accessed on 3 August 2023).
2. Rushton, E.A.C.; Reiss, M.J. From Science Teacher to 'Teacher Scientist': Exploring the Experiences of Research-Active Science Teachers in the UK. *International Journal of Science Education* **2019**, *41*, 1541–1561, doi:10.1080/09500693.2019.1615656.
3. Beauchamp, C.; Thomas, L. Understanding Teacher Identity: An Overview of Issues in the Literature and Implications for Teacher Education. *Cambridge Journal of Education* **2009**, *39*, 175–189, doi:10.1080/03057640902902252.
4. *Self and Social Identity in Educational Contexts*; Bizumic, K.I.M., Michael J. Platow, Boris, Ed.; Routledge: London, 2017; ISBN 978-1-315-74691-3.
5. Parker, B.; Fox, E.; Rushton, E.A.C. IRIS – Promoting Young Peoples' Participation and Attainment in STEM and Reigniting Teachers' Passion for Science Education. *Impact. The Journal of the Chartered College of Teaching* **2018**, *2*.
6. Schools, Pupils and Their Characteristics, Academic Year 2022/23 Available online: https://explore-education-statistics.service.gov.uk/find-statistics/school-pupils-and-their-characteristics (accessed on 3 August 2023).
7. Fact Finder Tool on Private Education - PEPF Available online: https://www.pepf.co.uk/fact-finder/facts-and-figures/ (accessed on 3 August 2023).
8. Allen, D.R.; Sims, S. Improving Science Teacher Retention:
9. Report and Matrix: Aligning Heritage Science to UK Primary Science Curricula | National Heritage Science Forum Available online: https://www.heritagescienceforum.org.uk/what-we-do/aligning-heritage-science-to-uk-primary-science-curricula (accessed on 3 August 2023).

10. National Curriculum in England: Science Programmes of Study Available online: https://www.gov.uk/government/publications/national-curriculum-in-england-science-programmes-of-study/national-curriculum-in-england-science-programmes-of-study (accessed on 21 July 2023).
11. Biggs, J.; Tang, C. *Teaching for Quality Learning at University: What the Student Does*; 2007;
12. Universal Design for Learning | Center for Teaching Innovation Available online: https://teaching.cornell.edu/teaching-resources/designing-your-course/universal-design-learning (accessed on 21 July 2023).
13. Our Impact / Institute for Research in Schools. *IRIS*.
14. STEM Research & Innovation Framework. *IRIS*.
15. Research-Informed Teaching Available online: https://www.plymouth.ac.uk/about-us/teaching-and-learning/guidance-and-resources/research-informed-teaching (accessed on 3 August 2023).
16. Good Practical Science | Education | Gatsby Available online: https://www.gatsby.org.uk/education/programmes/support-for-practical-science-in-schools (accessed on 4 August 2023).
17. Scaffolding in Education: A Teacher's Guide Available online: https://www.structural-learning.com/post/scaffolding-in-education-a-teachers-guide (accessed on 4 August 2023).
18. Bennett, J.; Dunlop, L.; Knox, K.J.; Reiss, M.J.; Torrance Jenkins, R. Practical Independent Research Projects in Science: A Synthesis and Evaluation of the Evidence of Impact on High School Students. *International Journal of Science Education* **2018**, *40*, 1755–1773, doi:10.1080/09500693.2018.1511936.
19. Kokotsaki, D.; Menzies, V.; Wiggins, A. Project-Based Learning: A Review of the Literature. *Improving Schools* **2016**, *19*, 267–277, doi:10.1177/1365480216659733.
20. Gold Standard PBL: Essential Project Design Elements Available online: https://www.pblworks.org/what-is-pbl/gold-standard-project-design (accessed on 21 July 2023).
21. Rushton, E.A.C.; Charters, L.; Reiss, M.J. The Experiences of Active Participation in Academic Conferences for High School Science Students. *Research in Science & Technological Education* **2021**, *39*, 90–108, doi:10.1080/02635143.2019.1657395.

IV) ACKNOWLEDGEMENTS

The writing of a concise report may have failed to acknowledge the contribution of others involved however here we thank all for their involvement with this programme.

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