How Safe is Your Playground? Analysing Soil in Scottish Schools Through a University Outreach Project

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How Safe is Your Playground? Analysing Soil in Scottish Schools Through a University Outreach Project

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ABSTRACT

School pupils often perceive STEM subjects to be challenging and an interactive project in STEM which is relevant to their own context will stimulate their interest. The Soils in Scottish Schools project allowed pupils to collect samples from their school ground which were then analysed for copper, lead and zinc levels. This year-long project also afforded them the opportunity to develop their employability and investigative skills through working in teams and engagement with real data.

Key words: High School/Introductory Chemistry, Analytical Chemistry, Hands-on Learning, Mass Spectrometry, Metals, Quantitative Analysis

INTRODUCTION

The UK is facing a well-documented STEM skills crisis with the supply of individuals into STEM careers not keeping pace with demand[1]. The UK Commission for Employment and Skills consistently reports that vacancies requiring STEM skills are more likely to be ‘hard to fill’ than vacancies overall[2]. This is a concern as the application of STEM contributes significantly to the UK economy. A number of studies illustrate how areas within STEM add to the economy including the £2.8 billion positive net trade position of the UK pharmaceutical industry[3].

Over a number of years there have been efforts to enhance the STEM qualifications of young people and increase their interest in considering progress to a STEM career. Hoyles *et al*[4] believe that education research has an important role to play in supporting these efforts particularly in developing approaches to teaching that increase pupils’ confidence in STEM. Bodies such as the Wellcome Trust have attempted to understand how STEM interdisciplinary learning could be encouraged within schools. To achieve this they provided bursaries to support schools in developing a range of teaching and learning ideas that help pupils to better understand the connections between the four STEM subjects[5]. The Royal Academy of Engineering [1] undertook a detailed mapping of the STEM education support landscape and identified over 600 organisations that are in some way involved in STEM education. The results of the mapping highlighted the range of ways in which STEM enhancement is made available. A broad spectrum of provision exists from which two useful categories can be identified[6]:

1. Provision from external organisations that seek to enhance formal science learning and takes place in a formal educational environment (the category into which this work falls)
2. Informal provision accessed on a voluntary basis in a range of settings.

Category 1 above is the most common route for STEM enhancement. This is perhaps not surprising as it allows useful links to be made between curriculum content, real-world applications and career pathways. The provision from organisations can be at UK level (e.g. STEM Ambassadors[7]); others are more regional, including UK national regions (e.g. SSERC in Scotland[8]); while others are smaller, providing discrete support for local schools (e.g. Advanced

Higher Hub at Glasgow Caledonian University[9]). Evidence also suggests there are benefits for young people who have more contact with working people while they are at school[7].

A gap analysis by the University of the West of England[10] on the data above indicated that teachers would like to see more activities that cover skills such as problem solving, creativity and group work or collaboration.

Additionally, each national government within the UK has produced its own STEM strategy in recent years[11-14]. Focusing on the Scottish Government[12] three of the six aims they hope to achieve by 2022 are:

- Increased proportion of people undertaking STEM related learning
- Increased number of people who understand the benefits and value of STEM for themselves, their families and their communities and
- Increased collaboration between schools, colleges, universities and employers.

Soil is a key global natural resource that needs to be carefully managed to ensure sustainability for future generations[15]. It provides nutrients to the biosphere, a habitat for organisms and a structural foundation for the built environment. It plays a key role in carbon sequestration – and thus helps to mitigate climate change – and in water purification. A large amount of research has focussed on agricultural soils. However, with more than half the world's citizens now living in cities[16], the study of urban soils has become more prominent. Urban green spaces contribute to biodiversity and the general well-being of urban citizens. However, urban soils are readily degraded and become easily polluted due to emissions from traffic and industrial activities. It is thus important that young people have the opportunity to learn about the importance of soil and the critical role soil chemistry plays in maintaining a healthy environment.

Based on this landscape a project was devised to address the aims outlined above by the Scottish Government. The project would also include practice at the skills desired by teachers[10] and would enhance formal science learning through linking real-world applications to curriculum content[6]. The project would be at a national level and would therefore allow support for areas of the country where pupils are at a socio-economic disadvantage and resources would be created to enable all teachers and schools to engage. Specifically, the aim of this project was to engage with school pupils, who are within the Broad General Education (BGE) phase of their studies, and to help them begin to explore the importance of Scotland's soil in terms of its usage, importance to the economy and management[17]. The theme of the chemistry of soil is particularly relevant to S2 pupils as it aligns to a number of Experiences and Outcomes identified in the BGE, for example SCN 4-18a, SCN 3-05a, SCN 4-05b, SCN 3-16a, SCN 2-16a, and, in particular, the following two[18]:

"Through evaluation of a range of data, I can describe the formation, characteristics and uses of soils, minerals and basic types of rocks." ***SCN 3-17a***

"I have helped to design and carry out practical activities to develop my understanding of chemical reactions involving the Earth's materials. I can explain how we apply knowledge of these reactions in practical ways." ***SCN 3-19b***

There have been numerous soil-focused school projects conducted previously[19-31] but this project is novel in that it involves school soils and school pupils and involved pupils across Scotland in the collection of soil from school grounds for the determination of their copper, lead and zinc contents.

PROJECT DESIGN

Desired Outcomes

Three outcomes for this project were identified:

1. To stimulate interest in environmental and wider STEM issues at the BGE phase of Scottish school learners by providing pupils with the opportunity to broaden their curriculum and explore chemistry within a local context, e.g. their own school.
2. To provide a platform for schools, teachers and their pupils and Strathclyde staff and their pupils to interact at a national level and provide opportunities that would not normally be accessible to the pupils taking part.
3. To develop employability skills in pupils such as working as a team, communication skills problem solving and powers of analysis and to demonstrate career opportunities in the environmental sciences.

Scoping

Initial work was undertaken to gather expressions of interest from the 397 secondary schools in Scotland to ensure there would be adequate interest before developing the project fully. Of the 397 secondary schools in Scotland, 99 schools responded positively. This included schools from remote areas, the Highlands and Islands and those situated within the lower levels of the Scottish Index of Multiple Deprivation. We were also pleased to receive an expression of interest from a school for pupils with learning disabilities as there is very little support for disabled pupils to consider and pursue STEM careers[1]. This level of interest gave us confidence to proceed with the project.

Implementation

The project team was comprised of three members of staff (Christine Davidson, Fraser Scott and Debra Willison) from the Department of Pure and Applied Chemistry at the University of Strathclyde. They were supported by one fourth year integrated Masters student who spent a full academic year on the project and two final year integrated Masters students who spent four months on the project as part of their final year dissertation work.

The project was designed to be delivered over a 12-month period and began in September 2017 by sending a resource pack to all 99 schools that expressed interest during the scoping exercise. The resource pack consisted of a number of soil-related educational activities designed to provide in-class learning opportunities that were directly relevant to this project. These resources are described in more detail in the next section. Schools were free to utilise the resources as they saw fit during the course of the project. Moreover, the opportunity was also provided for schools to engage with Strathclyde student STEM ambassadors, called Strath Science Scouts, to help deliver these resources to classes. Strath Science Scouts is a volunteer programme to promote the study of science to primary and secondary school pupils. They deliver various types of events and activities, all of which are organised and run by current Strathclyde science students.[32]

In order to maintain engagement with schools during the course of the project, we emailed all participating schools with a series of monthly newsletters from October 2017 to May 2018 (eight newsletters in total). These provided profiles of the students analysing the samples,

updates on the progress of the project, quizzes and crosswords and further information about soils science.
To coincide with the release of the first newsletter, we sent the soil sampling protocol, sample bag and pre-paid envelope to return the samples. Each school was instructed to collect a single bulk composite soil sample from a grassy site within the school grounds, remote from buildings, trees, roads and car parks. Samples were received during the period October 2017 to December 2017, and were analysed periodically at the University of Strathclyde until February 2018. In addition to the integrated Masters student, two final year undergraduate students conducted the analysis of the soil samples. Detailed analysis protocols can be found in the supplementary information. However, briefly, samples were pre-treated, digested in aqua regia and then were analysed by inductively coupled plasma mass spectrometry (ICP MS) for concentrations of copper, lead and zinc.

It was thought that a terminal focal point for the project was necessary in order to maintain engagement throughout. Thus, towards the end of the project we encouraged schools to carry out a group poster competition with their participating classes, with posters focusing on the topic of 'Why Is Soil Important?'. Schools were asked to identify a winning team who would be invited to display their poster at the University of Strathclyde during a Grand Environment Day. In the intervening time, an individual report containing the results of the analysis of their own soil sample was shared with each school in June 2018.

The winning teams from each school, along with their teachers, were invited to the Grand Environment Day at the University of Strathclyde in September 2018. This involved presentations from staff and students who were involved in the project and an invited external speaker. Prizes were awarded for the best posters and schools were presented with a final scientific report containing information on the copper, lead and zinc ranges obtained across all samples so they could see where their sample lay within that range.

A timeline of the project is presented in Figure 1.

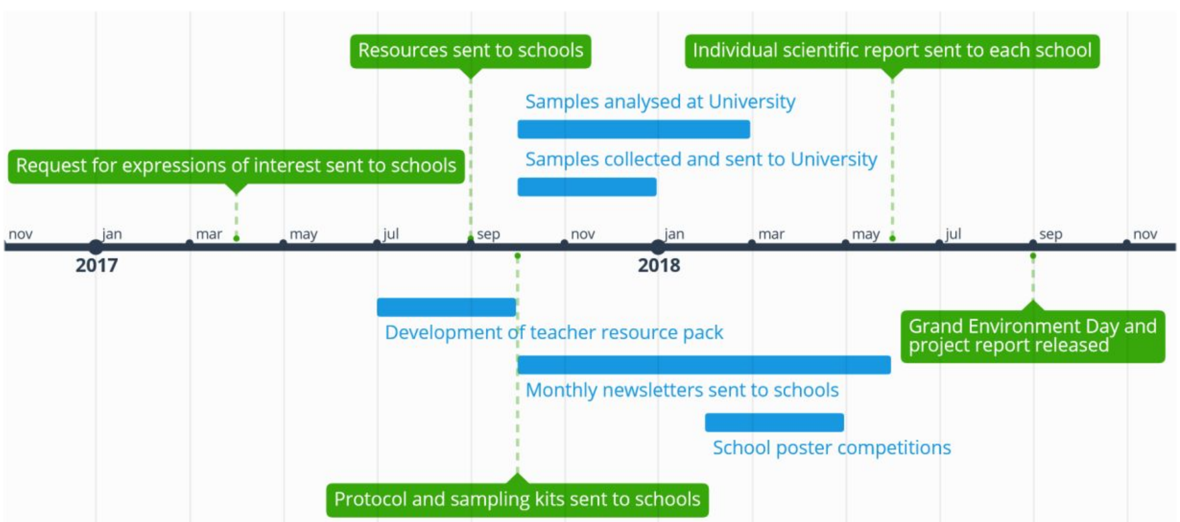

Figure 1. Timeline of project activities

Resource Development

It was recognised that individual schools, indeed individual teachers, organise their curricula in different ways. This is particularly true since the introduction of the Curriculum for Excellence in Scotland where teacher autonomy is of paramount importance[33]. Thus, in order to facilitate a smooth integration of this project within the varied curricula across Scotland it was thought necessary to present a dynamic package of resources with which teachers could decide on the extent of their engagement. Specifically, a minimal core set of resources included an introductory presentation detailing information about the science of soils together with the soil sampling activity. The optional additional resources included a quiz game, two experiments, a data handling exercise, the monthly newsletters and the summary data reports (figure 2). A brief description of each is detailed below.

Figure 2: The range of core and optional resources

CORE RESOURCES

Introductory Presentation

This was provided as a PowerPoint presentation entitled "The Science of Soil, which teachers could use to provide some background information to pupils about the project. This information covered topics such as the physical, chemical and biological characteristics of soil, soil pollution, and details of the analysis that was to be carried out on the provided soil samples.

Soil Sampling Activity

We provided a detailed set of step-by-step instructions for how teachers and pupils could participate in the soil sampling. This included information on how to select an appropriate site for sampling, how to prepare the site, instructions for sample collection, how to restore the site to its original condition and also how to appropriately package the sample for sending. We also provided a sampling record sheet for documenting the information relating to the sampling of their soil.

OPTIONAL RESOURCES

Quiz Game

This was a team-based card game, a "Zap Game", in which the questions asked are related to the information in the *Science of Soils PowerPoint*. The first group is asked a question and if they answer correctly, they receive a point. If the first group does not answer the question correctly, the next group gets a chance to answer the question. If none of the groups know the answer, the teacher reviews the question and answer. Whichever group gets the question correct, they choose a zap card from the pile and get to perform the action written on the card (e.g. "add two points to your score" or "swap points with another team"). The game continues until there are no more cards, or after a set time, and whichever team has the highest score, wins.

Experiment 1: Soil Composition

In this experiment, pupils could analyse the soil sample from their school grounds to find out its composition. Specifically, they were able to determine the percentage of water, organic matter, air and inorganic matter present. Two versions of this resource were provided: one version provided additional instructions on how to carry out the required calculations, to be used if differentiation was required; and the other version did not have these.

Experiment 2: Soil pH

In this experiment, pupils could determine the pH of their soil sample with a simple procedure using Universal indicator.

Data Handling Exercise

This activity was provided as a means to explicitly embed numeracy within this STEM outreach project. The activity involved drawing graphs from a provided data set and then qualitatively evaluating the data.

Monthly Newsletters

The main aim of the monthly newsletters was to maintain engagement throughout the duration of the project. Each newsletter highlighted the activities that were happening that months, for example providing an overview of the sampling or drawing attention to the poster competition. Additionally, the newsletters were used as a vehicle to introduce the project team by providing profiles of the students analysing the samples, and also for providing updates on the progress of the project. Quizzes, crosswords and further scientific information about soils science also featured in the newsletters.

Reports

Two types of reports were prepared containing:

1. An overall project report, sent to all schools, containing the range of results obtained across all schools participating in the project, together with the ranges for schools in groups A, B and C (as defined later, under Participation).

2. An individual school report, shared with a specific participating school, containing the results for their own sample. Also provided were the range of results for all schools participating in the project; some Cu, Pb and Zn concentrations published studies in the scientific literature; and some example soil guideline values.

RESULTS AND DISCUSSION

Participation

In total 43 schools returned a soil sample over a three-month period. Only 42 samples could be analysed as one school sent in insufficient material for analysis. However, all 99 schools who had initially expressed interest received the resources, monthly newsletters and final report.

Soil samples were received from across Scotland, and participants were predominantly from the highly populous central belt as might have been anticipated. The geographical position of participant schools is shown in Figure 3[34], and based on distance from the University of Strathclyde, Glasgow can be categorised into 3 groups:

- Group A: 16 schools within a 10 mile radius of Glasgow City Centre
- Group B: 11 schools within a 10-30 mile radius of Glasgow City Centre
- Group C: 15 schools which were more than 30 miles distant from Glasgow City Centre

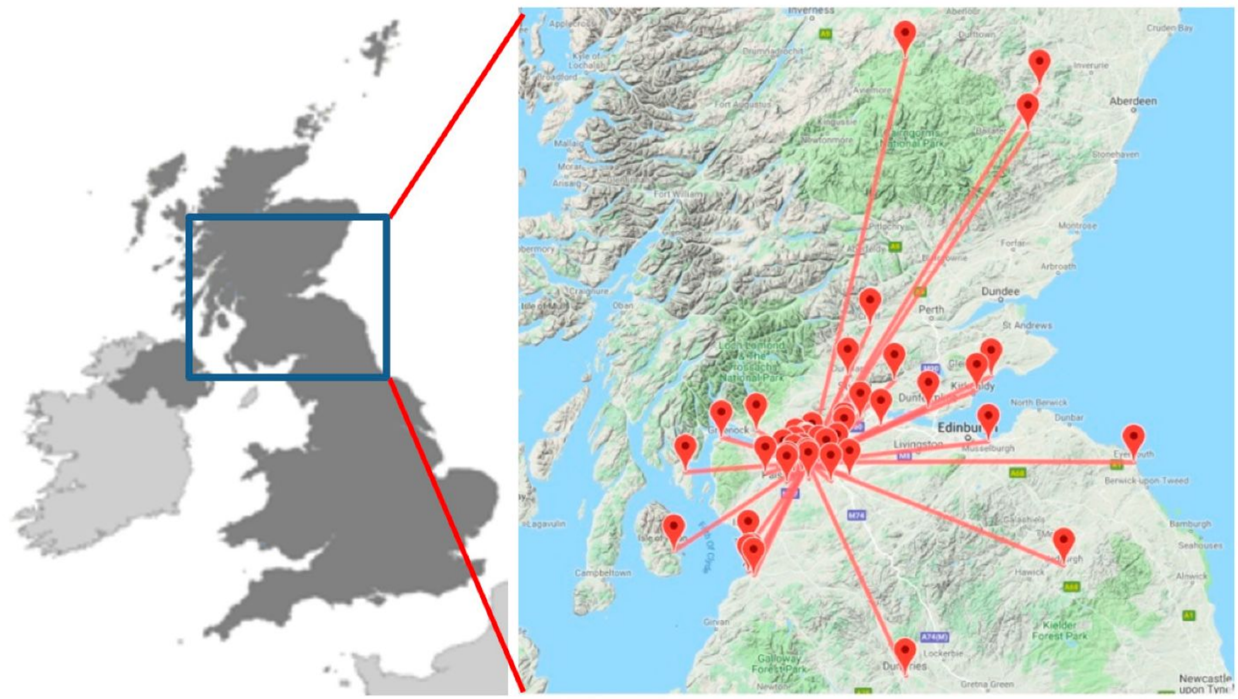

Figure 3. Map showing locations of schools submitting soil samples (sourced via the Creative Common CC BY licence)[34]

It is pleasing to see the engagement from those schools in Group C as they included schools from rural areas and the Highlands and Islands and provided representation from across Scotland. Eleven of the 16 postcodes in Scotland were represented (68.8%). Of the 43 schools submitting samples, four independent schools and three of the top 50 state schools[35] (16.3%) were included.

The Scottish Funding Council (SFC) fund a national schools programme to help schools with few pupils going on to higher education – the Schools for Higher Education Programme (SHEP)[36]. SHEP supports regional collaboration between schools, colleges and universities to raise awareness of and aspiration to higher education (HE) to increase progression to HE from schools with traditionally low rates. This work is in response to the Commission on Widening

Access, which recommended that universities, colleges, local authorities, schools, SFC-funded access programmes and early years providers should work together to deliver a coordinated approach to access which removes duplication[37]. The programme supports the Senior Phase of Curriculum for Excellence, focused on S3 to S6. The programme covers four regions:

- North programme (Aspire North)
- Fife and Tayside programme (LIFT Off)
- South East programme (LEAPS)
- West programme (FOCUS West)

It was pleasing to note that 23.3% of the schools which submitted samples for this project are SHEP schools and included six FOCUS West, three LEAPS and one LIFT Off schools.
The scientific results of this study have been published elsewhere[34] but generally higher metal concentrations were associated with locations close to the main urban area around Glasgow, with the lowest concentrations being found in areas further from the city. Reassuringly there was no evidence of significant health risk to school children who use these areas for recreation. The pupils and teachers engaged well with the protocol for collecting samples and shared their experiences through photographs (Figure 4). The protocol was clear and the instructions easy to follow with only one school making an error on the sample quantity required.

Figure 4. Pupils collecting soil samples

In total 11 schools submitted posters, whilst nine schools attended the Grand Environment Day.

Grand Environment Day

The Grand Environment Day was attended by 120 teachers and pupils representing nine schools although a further two schools had submitted for the poster competition. Speakers included the students who had worked on the project, Dr Christine Davidson, co-author and Reader in Analytical Geochemistry, and invited external speaker, Professor Iain Stewart from the University of Plymouth. The poster competition was judged by independent, external experts, including Professor Stewart and the top three posters were identified. Teachers from each winning school were given a certificate and a monetary prize to be used to support their teaching and each pupil was awarded a gift voucher, a popular science book and a certificate. Feedback from the event was unanimously positive.

'I just wanted to thank you for a great day today. My students really enjoyed everything they experienced.'

Jedburgh Grammar School

'Thank you very much for the very thought provoking environmental day last week; it was the subject of conversation all the way home.'

St Ambrose High School

'Thank you, we had a great time at the event.'

Paisley Grammar School

The level of participation at the Grand Environment Day was disappointing with only 20.9% of schools who had submitted a sample in attendance. An assumption could have been made that local schools would be more likely to attend due to closer proximity, however, only five of the nine schools came from the central belt with the other 4 schools being located in the Borders (1), Fife (1) and Dumfries (2). A contributing issue was likely to be that the Environment Day was scheduled for September in the next academic year following the start of the project. Some teachers indicated that they no longer taught the particular year group who had participated and that to interrupt their studies to allow them to attend had not been possible.

Feedback Questionnaire

Two separate questionnaires were circulated, a questionnaire for teachers regarding the usefulness of the resources, and a questionnaire for pupils regarding the usefulness of the resources and whether the project had raised their awareness of the science of soils.

Unfortunately, only a small number (5) of teachers completed and returned their questionnaire. Consequently, it was not thought appropriate to attempt to generalise the findings from the questionnaires, nor use them to provide strong validation for the success of the project. However, all of those teachers who did complete the questionnaire did comment favourably on their participation in the project. In particular, several comments aligned well with our intended project outcomes:

'It provided context for the project and experimental work. Useful background provided too.'
'Overall this is a great package to develop data handling skills.'
'Very useful – clear instruction for pupils.'

Teachers also commented on their perceptions of how pupils had enjoyed engaging in the project.

'The class enjoyed the experiments – something a little different for them. Getting results from uni department was good too. All round a good experience.'
'Overall the pupils were engaged in the project and enjoyed it. As we already cover soils in our BGE course it sat well alongside their learning outcomes. The updates were useful and a good tool for making links between the school and university,'
'The findings have been shared more widely in the school leading to conversations about possible reasons why the metal concentration was higher in certain areas than others. They were interested and it gave them an insight into research ideas and the importance of research.'

Similarly, a very small number of pupils (23) completed and returned their questionnaires, and again we do not wish to analyse these data in depth due to the small number. However, over 90% of pupils found the resources useful and almost 70% commented that their awareness of the science of soils and its related issues had increased due to their participation in the project.

The free text responses from pupils were predominantly positive (19 from 23) and expressed interest, enjoyment or how their perceptions on soil had changed through being involved in the project.

Interest e.g. *'It was interesting to take samples of soil and learn more about its composition.'*
Enjoyment e.g. *'Enjoyed working as a team to learn and create poster.'*
Perception e.g. *'It was good and changed my thoughts on soil.'*

The relatively small number (4) of negative comments had a similarity and included statements such as 'uninspiring', 'boring' and 'not very exciting' with one pupil commenting that it 'didn't really help me understand soils.'

The response rate from the teachers was disappointing and their lack of response no doubt contributed to the poor response rate from the pupils. The workload of teachers and having duties of higher importance is likely to have been an influencing factor. Completing a questionnaire to support a University study will not be a priority for them. We believe, however, the lack of feedback engagement does not correlate with a lack of interest in participating in projects of this kind. We are currently embarked on a similarly operated project investigating the global challenges of clean water and 17 of the 43 schools (39.5%) engaged in the soils project are also engaged with the water project. Interestingly the number of schools involved in this second project (59 schools) has exceeded the 43 schools involved here and there is wider representation across Scotland with 87.5% of all post codes being represented (only the Orkney and Shetland Islands are not included).

CONCLUSIONS AND REFLECTIONS

Three desired outcomes were established at the outset of this project, and it is thought that this project satisfied these as follows:

1. To stimulate interest in environmental and wider STEM issues at the BGE phase of school learners by providing pupils with the opportunity to broaden their curriculum and explore chemistry within a local context, e.g. their own school.

This outcome was achieved through the development of the lesson plan, activities and game and the engagement we established with the schools through the monthly newsletters and poster competition. The comments from both teachers and pupils indicate that we had stimulated interest in environmental issues.

2. To provide a platform for schools, teachers and pupils to interact at a national level and provide opportunities that would not normally be accessible to the pupils taking part.

This outcome was achieved as we had schools from the Highlands and Islands, low progression and special needs sectors all involved. The Grand Environment event allowed the pupils to interact at a national level with other schools.

3. To develop employability skills in pupils such as working as a team, communication skills problem solving and powers of analysis and to demonstrate career opportunities in the environmental sciences.

This outcome was achieved through the nature of the year-long project working with experts and culminating in a scientific poster. This mirrors the types of project pupils could face in the world of work. The talks provided at the Grand Environment event highlighted the career opportunities in the environmental science area.

RSC Outreach Funds, the mechanism of funding of this project, are released in the final week of June each year and this presents a challenge for Projects in Scottish schools since this is the last week of the academic year. While work was undertaken over the summer months to prepare our resources, engagement with the schools did not fully get under way until September 2017. Subsequently our project ran on until September 2018 which meant that pupils had entered their next year of study when attending the Grand Environment event which may have diminished the relevance of the event to their current curriculum and hence affected attendance. In future projects we would ensure that the project is completed within a single academic year and believe more face-to-face engagement would be beneficial, e.g. teachers invited to attend an information session at the start of the project and more visits to schools, or visits from schools to the University, throughout the year.
There was large variation in the quality of posters submitted by the schools and future projects would include additional constructive support in poster preparation.
Teachers are busy and often constrained by their timetables. A number commented that they did not have the opportunity to engage with all of the resources. Those who did engage enhanced their critical thinking and research skills. Future activity will also focus on targeting teachers through Continuous Professional Development to support these areas. The real life data that was collected by pupils, and shared throughout Scotland, and the resources, can be used with other cohorts of pupils in future years by the teachers providing a sustainable output from this project.

ASSOCIATED CONTENT

Supporting Information

All data underpinning this publication are openly available from the University of Strathclyde at https://doi.org/10.15129/c58a7928-a9fe-462d-b3f9-8b5e4df164f4.

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