Aligning Heritage Science to the Science Curricula

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Contents

1. Introduction

The National Archives (TNA) with the National Heritage Science Forum (NHSF) commissioned this research to build upon and extend existing work aimed at increasing engagement of school-age children with heritage science. The project has an overarching aim of interrogating how UK national curricula can be supported by the interdisciplinary field of heritage science, and to investigate a shift towards breaking down the silos between the teaching of arts and sciences. This explicitly relates to the NHSF's Strategic Framework for Heritage Science in the UK, with its central vision 'that the UK's extraordinarily rich and varied tangible and intangible heritage will be enhanced by better use of science and technology for the benefit of society', enabling more young people to explore heritage through scientific research, to understand the applications of their learning and to broaden aspirations.[1]

2. Methodology

This project was conducted in three stages.

2.1 Stage One

This stage consisted of:

1. A review of literature pertaining to heritage science, STEM (science, technology, engineering and maths) in heritage sector education, and existing materials, resources and research connecting heritage science and education.

2. An interrogation of the primary age curricula for science in England, Northern Ireland, Scotland and Wales, aiming to identify and describe commonalities and differences between them.

These steps were used to inform the definitions provided in this section and the planning of the interviews in Stage Two. Additionally, the curriculum interrogation identified the science topic headings which form part of a matrix showing where specific heritage science activities intersect with the science curricula (Appendix).

2.2 Stage Two

The second stage included online interviews with 21 heritage scientists, learning and outreach professionals and education providers. A further 3 participants contributed via online questionnaire. The interviews were an opportunity to identify science curriculum opportunities existing within heritage science work, to refine the definitions used and to begin populating the draft matrix that resulted from Stage One.

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[1] National Heritage Science Forum (NHSF), *Strategic Framework for Heritage Science in the UK: 2018-2023,* (2018), Available from: https://www.heritagescienceforum.org.uk/what-we-do/strategic-framework [Accessed 26 March 2022], p. 2.

Secondary objectives for these interviews included seeking examples of the engagement with schools and students that was already taking place, gaining insight into perceived links between their work and science curricula from the point of view of the heritage scientists themselves, as well as their views regarding the importance of engaging children in heritage science.

As part of the interviews, the following grid was used to list the content and methods of heritage science according to the relevant area, with the understanding that the divisions were flexible and there would be some overlap.

Table 1: Heritage Science Areas/Methods Grid

Using the previously defined Areas (headings) & Methods (subheadings), heritage science activities can be placed within cells of the following table:

<table>
<tr><th colspan="2" rowspan="3"></th><th colspan="5">The Five Areas of Heritage Science</th></tr>
<tr><th colspan="2">Museum Objects</th><th rowspan="2">Libraries, Archives & Digital</th><th rowspan="2">Archaeology & the Built Environment</th><th rowspan="2">Natural History</th></tr>
<tr><th>Organic</th><th>Inorganic</th></tr>
<tr><th rowspan="6">Methods</th><th>Material Properties</th><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Material Analysis</th><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Deterioration Processes</th><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Preventive Conservation & Management</th><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>New Technologies, Treatments</th><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Sustainability</th><td></td><td></td><td></td><td></td><td></td></tr>
</table>

2.3 Stage Three

The final stage was a full synthesis of results from Stages One and Two, resulting in the heritage science vs. science curricula matrix presented in the appendix.

2.4 Definitions

Heritage Science

> *The term heritage science is used [...] throughout the development of the strategy [...] to encompass all technological and scientific work that can benefit the heritage sector, whether through improved management*

> *decisions, enhanced understanding of significance and cultural value or increased public engagement.*[2]

Heritage science is, then, a transdisciplinary field in which scientific techniques, principles and methods are applied in order to enhance understanding and management of and care for heritage objects, and to do so sustainably.

Other descriptors are sometimes used in place of 'heritage science'. 'Conservation science' is a term often used within museums, galleries and historic buildings and 'preservation' in libraries, archives and archaeological sectors.[3] Both conservation science and preservation activities are included within heritage science, a broader umbrella term which in addition to the aforementioned includes research, access, management, interpretation and engagement. The term 'heritage science' therefore reflects this wider range of roles and responsibilities and will be used throughout the report.

To ensure broad coverage from a range of fields within heritage science, activities were listed under five 'areas' based on work which may take place in different environments or with different types of object or heritage asset. It is recognised that these areas are not exhaustive and that the boundaries between them are not necessarily clearly delineated.

The Five Areas of Heritage Science

The five headings under which heritage science activities are arranged for the purposes of this project are based upon different types of materials that heritage scientists may find themselves working with:

Organic museum objects

In chemistry, organic compounds are any chemical compounds that contain carbon-hydrogen bonds.[4] Organic materials are composed of such compounds and are often derived from living things. These materials are broadly either animal-based or plant-based, with the former including materials made or derived from leather and skin, fur and hair, teeth, bone and shells, and the latter including wood and natural fibres such as cotton, linen and other textiles. It may be worth mentioning plastics as a subset of these plant-based materials, as well as other non-cellular natural organic materials such as amber, wax and latex paint binders.[5]

Inorganic museum objects

Chemically, inorganic compounds are those which do not contain carbon-hydrogen bonds, so this section could be said to include 'everything else'.[6] Examples of inorganic materials which museum objects may be made from include stone, ceramics, glass, metals, metallurgical by-products and inorganic pigments.[7]

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[2] Williams, J., 'Report 1: The role of science in the management of the UK's heritage', *National Heritage Science Strategy*, (2009), Available from: https://www.heritagescienceforum.org.uk/what-we-do/national-heritage-science-strategy, p. 5.

[3] NHSF, *Strategic Framework,* p. 7.

[4] Editors of Encyclopaedia Britannica, 'Organic Compound', *Encyclopaedia Britannica*, (2019). Available from: www.britannica.com [Accessed March 25, 2022].

[5] American Institute for Conservation (AIC), *Organic*, (2010), Available from: https://www.conservation-wiki.com/wiki/Organic [Accessed March 11, 2022].

[6] Editors of Encyclopaedia Britannica, 'Inorganic Compound', *Encyclopaedia Britannica*, (2020). Available from: www.britannica.com [Accessed March 25, 2022].

Libraries, archives & digital

This area refers to information storage and the materials used in doing so, such as books, paper & paintings; photographic materials; and electronic media.[8]

Archaeology & the built environment

Whilst archaeology and the built environment can be considered two distinct fields it was felt that together they encompass 'immovable' heritage: that which cannot be easily moved, such as buildings or examples of outdoor or buried heritage.

Natural history

Biological, paleontological and geological specimens are included under this heading. It is important to clearly define the difference between this and the first area in this list, *organic museum objects*: materials/objects which are or have been themselves 'alive' would be included under the 'natural history' heading, whereas materials which have been *derived from* living things would most usually be listed under 'organic museum objects'.

The Six Methods

The work of each area was broadly categorised under six methods. These are defined below:

Material properties

The physical and chemical properties of the materials or objects being studied.

Material analysis

The methods used to investigate the materials or objects and their properties.

Deterioration processes

Study of how the composition of materials or objects and the environments within which they are stored, transported or displayed impact them and cause them to degrade or deteriorate.

Preventive conservation & management

Study of how to reduce or manage the deterioration of materials and objects.

New technologies, treatments & processes

The development of tools used to investigate materials and objects and the effects of environments upon them, and the processes and conservation treatments used to manage them.

Sustainability

Working to ensure that heritage science work has economic, social, cultural and environmental longevity. These may be referenced to United Nations' 17 Sustainable Development Goals.[9]

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[7] American Institute for Conservation (AIC), *Inorganic Materials*, (2013), Available from: https://www.conservation-wiki.com/wiki/Inorganic_Materials [Accessed March 11, 2022].

[8] American Institute for Conservation (AIC), *Organic*, (2010), Available from: https://www.conservation-wiki.com/wiki/Organic [Accessed March 11, 2022].

[9] United Nations, 'The 17 Goals', *United Nations*, (2015), Available from: https://sdgs.un.org/goals [Accessed March 28, 2022].

3. Findings

3.1 Literature Review

The National Heritage Science Forum (NHSF) published the 'Strategic Framework for Heritage Science in the UK' in 2018.[10] This framework was the successor to the 2010 National Heritage Science Strategy and its underpinning reports.[11] This framework, covering 5 years to 2023, includes the goal of 'a skilled heritage science community', of which one required outcome is the 'increased engagement with heritage science at school age'.[12] The National Archives' Heritage Science and Conservation Research strategic implementation plan aligns with this goal, 'seeking projects and initiatives that allow for mentoring and supervision, working at all education levels, from school age to Early Career Researchers.[13] Existing research has investigated links with England's secondary science curricula, or the enormous health, social and developmental benefits for young people aged 11-15 of engaging with arts and culture.[14] Socio-economic factors affect engagement outside of school, so experiences in and with school are vital to enable all students to access heritage. As yet there is little research linking heritage science to primary school education. The greater opportunity for cross-curricular learning at primary school level in comparison with secondary is a useful avenue to explore, as well as the importance of raising awareness and developing interest early in a child's school career.

Grimshaw and Mates' recent research highlights that learning about their local history and heritage can help children to develop a sense of place, which is linked to their sense of belonging and identity.[15] This learning does not need to solely take place through the humanities disciplines; it is enriched by and informed by the heritage science that underpins it. Historic England's 2021 evaluation of their 'Heritage Schools' CPD training demonstrates that 98% of teachers agreed or strongly agreed that local heritage learning increases children's sense of place, while 87% agreed or strongly agreed that it raises their aspirations.[16] Engaged citizens with a sense of place contribute then to the sustainability of heritage

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[10] NHSF, *Strategic Framework for Heritage Science in the UK: 2018-2023,* (2018), Available from: https://www.heritagescienceforum.org.uk/what-we-do/strategic-framework

[11] NHSF, *Our Vision and Strategy for Heritage Science,* (2010), Available from: https://www.heritagescienceforum.org.uk/documents/nhss_vision_strategy_web.pdf; Williams, 'Report 1'; Williams, J., 'Report 2: The use of science to enhance our understanding of the past', *National Heritage Science Strategy*, (2009), Available from: https://www.heritagescienceforum.org.uk/what-we-do/national-heritage-science-strategy; Williams, J., 'Report 3: Understanding capacity in the heritage science sector', *National Heritage Science Strategy*, (2009), Available from: https://www.heritagescienceforum.org.uk/what-we-do/national-heritage-science-strategy.

[12] NHSF, *Strategic Framework,* p. 3.

[13] Angelova, L., *Heritage Science and Conservation Research at The National Archives: Strategic Implementation Plan 2021-2025*, (2021), Available from: https://cdn.nationalarchives.gov.uk/documents/heritage-science-and-conservation-research-strategy-2021.pdf

[14] Smith, A. and Pye, K., Pye Tait Consulting, *Heritage Science Resources for the National Curriculum in England: A Review of Science Programmes of Study for Key Stages 3, 4 and 5,* (2016); Mak, H.W. and Fancourt, D., 'Do socio-demographic factors predict children's engagement in arts and culture? Comparisons of in-school and out-of-school participation in the Taking Part Survey', *PLoS ONE,* vol. 16, no. 2, (2021), Available from: https://doi.org/10.1371/journal.pone.0246936

[15] Grimshaw, L. and Mates, L., "It's part of our community, where we live': Urban heritage and children's sense of place', *Urban Studies,* (2021).

[16] How, N. and Bell, N., Qa Research for Historic England, *Heritage Schools 2020-21 Evaluation Research,* (2021).

itself. In their 2021 article 'Perceptions of Heritage', López-Fernández et al state the importance of education as a crucial tool for protecting heritage.[17]

Forming part of the context for this project, the British Educational Research Association (BERA) commission examines the changing perceptions of science and arts, the implications for science education and the possibilities of using traditionally arts-based pedagogies to build inclusive interdisciplinary learning in science.[18] The commission states that the potential of STEM subjects being taught with, and contributing to, arts and humanities subjects needs further exploration, concurring that primary schools are a logical place for this to occur.[19] Heritage science could certainly be used as a tool to bridge these subject areas and to deepen and contextualise arts and humanities. Furthermore, the reverse can also be a useful relationship: STEM or STEAM (science, technology, engineering, arts, maths) learning can be enriched by the arts and humanities content and approaches that are informed by it. The commission highlights the difficulties of defining and separating the disciplines of STEM and in particular STEAM education, but perhaps the most important point identified is that there has been 'little theorizing about the way in which the Arts and STEM can effectively work together to achieve the expected educational and economic outcomes'.[20] Aligning heritage science to the science curriculum may be an early step in allowing these approaches and disciplines to work together, with the potential of improving outcomes.

The Wellcome Trust's *Primary Science Campaign* provides some useful background on the context for the teaching of science in schools. A key part of the campaign was the launching of a free online learning resource platform of activities for teachers, *Explorify,* in 2017.[21] Wellcome's subsequent 'state of the nation' reports have been referenced as part of Ofsted's research review series, in particular the concern that science is being 'squeezed out' of the primary curriculum.[22] Science is taught weekly in most schools with standalone science lessons more common for older age groups in primary schools whilst younger pupils are more likely to study science as part of cross-curricular work.[23] Some science is also taught via themed weeks, events or visits, and taking all methods into account, science is taught on average for 1 hour and 48 minutes per week in English primary schools.[24] Around half of teachers believe that this is not enough, but a similar number also indicate that an increase is not possible due to other curriculum demands.[25] This situation has only worsened as a result of the COVID-

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[17] López-Fernández, J.A., Medina, S., López, M.J., García-Morís, R., 'Perceptions of Heritage among Students of Early Childhood and Primary Education', *Sustainability,* (2021), vol. 13, no. 19, Available from: https://doi.org/10.3390/su131910636, p. 1.

[18] Colucci-Gray, L., Burnard, P., Cooke, C., Davies, R., Gray, D., Trowsdale, J., *BERA Research Commission Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: how can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education?,* (2017), Available from: https://jotrowsdale.files.wordpress.com/2017/11/bera-research-commission-report-steam.pdf.

[19] Colucci-Gray et al, *BERA Research Commission,* p. 12.

[20] Colucci-Gray et al, *BERA Research Commission,* p. 32.

[21] Explorify, (launched 2017), Available from: https://explorify.uk/.

[22] Ofsted, *Research review series: science,* (2021), Available from: https://www.gov.uk/government/publications/research-review-series-science/research-review-series-science#fnref:14.

[23] CFE Research, *Evaluation of the Primary Science Campaign: A report for the Wellcome Trust,* (2020), Available from: https://www.stem.org.uk/resources/elibrary/resource/418204/primary-science-education-wellcome-trust, p. 4.

[24] Ibid.

[25] CFE Research, *Evaluation of the Primary Science Campaign,* p. 5.

19 pandemic, with an agreement amongst teachers that although science was still a priority for their school leaders during and after lockdowns, other subjects such as maths and English were even more of a priority.[26] Concerns remain over lost teaching time in all subjects due to the pandemic, most notably because not all children engaged in remote learning, and so knowledge gaps are wider for some (often those from disadvantaged backgrounds) than for others.[27]

Smith and Pye carried out research with similar purpose and scope to this report, with an important difference being its focus on science at Key Stages 3, 4 & 5 as outlined in the English National Curriculum.[28] One of its outputs was a mapping of heritage science against the secondary science curriculum of England. The report concludes that 'there are opportunities at all key stages (3 to 5) and across biology, chemistry and physics,' and says of its stakeholders that they were 'largely of the view that heritage science should enrich and contextualise the science curriculum rather than 'add' to it'.[29] The authors suggest that of particular interest to learners would be 'discovery' themes, and topics that explore modern global issues. They provide a list of ten recommendations for Historic England which, it can be argued, broadly fall into one of two categories: building, maintaining and strengthening relationships and collaborations with teachers and associated organisations; and deepening research into specific curriculum links and how best to develop resources to take advantage of these. In the intervening 6 years since Smith and Pye's research, changes and shifting priorities in the educational and national landscapes may have affected to what extent progress has been made towards meeting its recommendations across the sector, and this would benefit from further investigation. With regards to educational resources aimed at schools, there remains the need to 'determine the extent of their uptake, nature of use, and perceived value among teachers and learners alike'.[30]

Whilst the educational resources of many organisations in the heritage sector focus predominantly on history, broader humanities and the arts, a number produce science- or STEM-based content, particularly those with the most direct scientific links to their collections and sites. There is further potential to link many of these resources more closely to the curriculum, making them more attractive to schools. In some cases, an opportunity is missed to identify and label science-based (including cross-curricular) resources as such. There is also opportunity for organisations with less obvious scientific content to link to the science curricula via the science that is used in collection care and conservation. There are very few learning resources currently available which are specifically focused on heritage science, although some reference heritage science concepts. Through interviews, it was suggested by several stakeholders that resources are often not easy to find; teachers would need to know where to find them and to have time to search for them.
Some examples of existing educational resources and projects which include or focus on heritage science are detailed below:

[26] CFE Research, *The Impact of COVID-19 on primary science education: A report for the Wellcome Trust,* (2021), Available from: https://www.stem.org.uk/resources/elibrary/resource/418204/primary-science-education-wellcome-trust, p. 62.
[27] CFE Research, *The Impact of COVID-19 on primary science education,* p. 63.
[28] Smith and Pye, *Heritage Science Resources,* https://historicengland.org.uk/research/current/heritage-science/heritage-science-resources-for-the-national-curriculum/
[29] Smith and Pye, *Heritage Science Resources,* p. 30.
[30] Ibid.

- Historic Environment Scotland's 'Go Forth!' educational resources, focused on the three Forth Bridges, make use of 3D laser-scanning technologies and provide a range of high-quality, Scottish curriculum-linked activities and supporting materials.[31]
- The Engine Shed has produced resources for teachers relating to building materials such as stone and how they are investigated and monitored by scientists who help to preserve historic properties. [32]
- The Mary Rose offers a primary-age workshop, 'Materials of the Mary Rose', which uses real and replica artefacts to investigate properties of Tudor materials, whether they were fit for purpose and how they compare to modern materials. The students also use digital microscopes to compare samples.[33]
- Research Scientists and Museum Educators from the Fitzwilliam Museum and Hamilton Kerr Institute worked with primary school teachers as part of the 'Ways of Seeing' research project, which aimed to develop engagement with materials and processes represented in museum collections. Through training teachers this project enabled indirect contact with a large number of children, and also led to the development of a 'workshop in a box' that could be sent out to schools, focusing on the pigments and paints used to create an artwork.[34]
- The National Archives' heritage scientists and educators collaborated to create an activity pack to showcase heritage science in a meaningful way, in celebration of British Science Week 2021. Activities included how to make berry ink and invisible ink to help children learn about many different inks and paints that have been used by different civilisations through the ages.[35]
- British Science Week activity packs for primary age children showcase a range of activities across different scientific fields, with some relevant to heritage science. For example in 2020 the 'Which metal?' activity examined how some metals rust.[36] In 2022, 'Which Plastic?' encouraged children to think about the sustainability of plastics and how scientists are thinking about the past to help plan for the future.[37] Additionally, 'Who Invented Blue?' examined the use of pigments in paint, how they are made and linked this to Rembrandt's paintings.[38] Most specifically, the secondary activity pack in 2020 included 'Conservation Matters', an activity in which students take on the role of a conservator, investigating objects and trying to protect them from deterioration.[39]

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[31] Centre for Digital Documentation and Visualisation LLP, *Go Forth! Digital Learning Resources,* (2018), Available from: https://www.theforthbridges.org/visit/go-forth-digital-learning-resources

[32] Historic Environment Scotland, *Stone - A traditional material,* (modified 2021), Available from: https://www.engineshed.scot/learning/resources-for-teachers/

[33] The Mary Rose, *School and College Workshops,* (2022), Available from: https://maryrose.org/student-and-schools-workshops/#ks1-2.

[34] Noble, K., Ricciardi, P. and Evans, R., *'Ways of Seeing' at The Fitzwilliam Museum*, (2020), Available from: https://nationalheritagescienceforum.wordpress.com/2020/03/15/ways-of-seeing-at-the-fitzwilliam-museum/

[35] The National Archives, *How to make berry ink,* (2021), Available from: https://www.nationalarchives.gov.uk/education/families/celebrating-british-science-week/how-to-make-berry-ink/

[36] British Science Week, *Primary Activity Pack: Our Diverse Planet,* (2020), Available from: https://www.britishscienceweek.org/app/uploads/2020/02/BSA_BSW_Primary_1019v20-2-1.pdf , p. 22.

[37] British Science Week, *Primary Activity Pack: Innovating for the Future,* (2022), Available from: https://www.britishscienceweek.org/app/uploads/2022/01/BSW21-primary.pdf, p. 30

[38] British Science Week, *Primary Activity Pack: Innovating for the Future,* (2022), p. 24.

[39] British Science Week, *Secondary Activity Pack: Our Diverse Planet,* (2020), Available from: https://www.britishscienceweek.org/app/uploads/2020/01/BSA_BSW_secondary_1119v13.pdf, p. 12.

- The Royal Society of Chemistry with the Victoria and Albert Museum and Chemistry in Action run Chemistry at Work events to allow children to engage with scientists and their work in the real world. The event 'How Science Sees Art' demonstrated how science is used to protect museum objects, how spectroscopic techniques and X-rays are used to reveal stories and the significance of colours.[40]
- Dr Alex Ball of the Natural History Museum led a project investigating how 3D printing could be used to 'replicate' microscopic objects for use in engagement with blind and visually impaired participants. This use of heritage science tools to support learning and engagement opens up many new possibilities for working in this way.[41]
- Dr James Perkins and Dr Alex Ball lead a collaborative project in which portable scanning electron microscopes (SEMs) are loaned to schools and training provided. The SEMs have been used for a variety of purposes including analyses of antique coins, failure modes in metals, studies of insects and looking at 3D printed surfaces.[42]

3.2 Curriculum Interrogation

Stages of education

This report covers Years 1 - 6 in England and Wales, Years 2 - 7 in Northern Ireland and P2 - P7 in Scotland. In England, Northern Ireland and Wales, most children start school in the September after their fourth birthday. In Scotland, where the academic year begins in August, children usually start school between the age of four and a half and five and a half. This depends on whether their birthday is between 1 September-29 February or between 1 March-31 August. For these reasons the ages and stages of education across the UK are not directly parallel between nations; however, approximated equivalents are shown in table 2:

Table 2: Ages and stages of education

<table>
<tr><th>Age[43]</th><th colspan="2">England</th><th colspan="2">Northern Ireland</th><th colspan="2">Scotland</th><th colspan="2">Wales</th></tr>
<tr><td>5[44]</td><td>Reception</td><td>Foundation Stage</td><td>Year 1</td><td rowspan="2">Foundation Stage</td><td>P1</td><td>Early Level</td><td>Reception</td><td rowspan="3">Foundation Phase</td></tr>
<tr><td>6</td><td>Year 1</td><td rowspan="2">Key Stage 1</td><td>Year 2</td><td>P2</td><td rowspan="2">First Level</td><td>Year 1</td></tr>
<tr><td>7</td><td>Year 2</td><td>Year 3</td><td>Key Stage 1</td><td>P3</td><td>Year 2</td></tr>
</table>

[40] Shah, B., *Chemistry at Work: How Science sees art,* (2019), Available from: https://www.vam.ac.uk/blog/caring-for-our-collections/chemistry-at-work-how-science-sees-art

[41] Ball, A., Burton, K., Holloway, C. and Png, K., *Design considerations for 3D-printed models targeting blind and visually impaired participants,* (2021), Available from: https://www.heritagescienceforum.org.uk/documents/BALL_FullSteam.pdf

[42] From interviews.

[43] A median representative of age is given to reflect that some children will be older or younger than the given value. Children in England, Northern Ireland and Wales usually begin their first year of school aged 4 and turn 5 during the academic year, whereas children in Scotland may turn 5 or 6 during their first year.

[44] This report does not cover Reception (England & Wales), Y1 (Northern Ireland) or P1 (Scotland). This row has been included only for reference.

8	Year 3	Lower Key Stage 2	Year 4		P4		Year 3	Key Stage 2
9	Year 4		Year 5	Key Stage 2	P5	Second Level	Year 4	
10	Year 5	Upper Key Stage 2	Year 6		P6		Year 5	
11-12[45]	Year 6		Year 7		P7		Year 6	

Comparison of Curricula

The science curricula of all four nations[46] aims to develop curiosity, scientific knowledge and conceptual understanding, through using enquiry to answer scientific questions about the world around us. In each nation, later stages build on the learning that has taken place in the previous phase, deepening, broadening and introducing new concepts.

In the relevant age phases of 5-11, Northern Ireland is the only nation which takes a cross-curricular approach for sciences and humanities throughout the primary phase. It aims to connect learning together across geography, history, science and technology under the umbrella term 'The World Around Us'.[47]

England's science curriculum states that 'science education provides the foundations for understanding the world through the specific disciplines of biology, chemistry and physics'.[48] Northern Ireland, Scotland and Wales do not mention these disciplines for this age group. All four nations then set out their curricula according to topic (not the disciplines of biology, chemistry and physics, although the topics and objectives themselves usually fit into one of these categories).

In general, the statements from the curriculum for England are the most detailed and prescriptive, setting out objectives which should be delivered in each year of

[45] If children in Scotland were born 1 March-31 August, they may finish P7 aged 12. If they were born 1 Sept-29 Feb, they will finish P7 aged 11. For other nations in the UK the age is calculated from 1 September-31 August and so children in England, Northern Ireland and Wales finish primary education aged 11.

[46] Department for Education (DfE), *Science programmes of study: Key Stages 1 and 2 National Curriculum in England*, (2013), Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/425618/PRIMARY_national_curriculum_-_Science.pdf [Accessed March 14, 2022]; Council for the Curriculum Examinations and Assessment (CCEA), *The Northern Ireland Curriculum Primary*, (2007), Available from: http://www.nicurriculum.org.uk/docs/key_stages_1_and_2/northern_ireland_curriculum_primary.pdf [Accessed March 14, 2022]; Scottish Government, *Curriculum for Excellence: Sciences: Experiences and Outcomes*, (2013), Available from: https://education.gov.scot/Documents/sciences-eo.pdf [Accessed March 14, 2022]; Welsh Government, *Curriculum for Wales: Foundation Phase Framework*, (2015) Available from: https://gov.wales/sites/default/files/publications/2018-02/foundation-phase-framework-revised-2015.pdf [Accessed March 14, 2022]; Welsh Assembly Government, *Science in the National Curriculum for Wales: Key Stages 2-4*, (2008), Available from: https://hwb.gov.wales/api/storage/779c7300-574d-4a12-a518-c873557d6a7a/science-in-the-national-curriculum.pdf [Accessed March 14, 2022].

[47] CCEA, *Northern Ireland Primary Curriculum*, pp. 37-38 & 83-90

[48] DfE, *Science programmes of study*, p. 3.

study, although schools have flexibility to adapt this within key stages, or to advance topics into earlier key stages.

It should be noted that independent schools, free schools and those with academy status are not required to follow the national curriculum. However, many choose to do so to ensure thorough coverage of topics as well as preparation for exams in later years.

Science Topic Organisation

In all UK nations, science learning for this age group is arranged by topic. This is organised differently in each nation, with topic headings and objectives presented at different resolutions. Throughout the primary age range, England's topics are the most specific and therefore numerous, whilst Scotland uses five main organisers and then subtopics within them at First and Second Level. Wales uses three broad organisers for science at Key Stage 2, whilst in the Foundation Stage science is part of a broader area of cross-curricular learning. In Northern Ireland, a similar cross-curricular approach is present throughout Foundation Stage, Key Stage 1 and Key Stage 2, using four strands to explore and connect different areas of learning (Table 3).

Distinct Topics

In order to determine a comprehensive list of science topics encompassing all UK curricula, the highest resolution topics and objectives (England's) were cross-referenced with those of Northern Ireland, Scotland and Wales. The results demonstrated that all science learning at age 5-11 (or 5-12 in Scotland) can be aligned to 14 main topics:

- Plants
- Animals including humans
- Everyday materials and their uses
- Seasonal changes
- Rocks
- Light
- Forces and magnets
- Living things and their habitats
- States of matter
- Sound
- Electricity
- Properties and changes of materials
- Earth and space
- Evolution and inheritance

Despite its place as a concept organiser in Scotland, Topical Science does not contain specific scientific content which is singular to its category and so has not been included as one of the 14 topics.

Within its science curriculum, Scotland also references two Technology objectives, both of which are highly relevant to heritage science.[49] These are:

> *I can take appropriate action to ensure conservation of materials and resources, considering the impact of my actions on the environment.*
>
> First Level, under 'Earth's Materials', TCH 1-06a

[49] Scottish Government, *Experiences and Outcomes,* pp. 4 & 17.

> *I can analyse how lifestyles can impact on the environment and Earth's resources and can make suggestions about how to live in a more sustainable way.*
>
> Second Level, under 'Energy Sources and Sustainability', TCH 2-06a

Table 3: Science Topic Organisation in the UK Science Curricula

England	Northern Ireland	Scotland	Wales
Topics are specified for each year group (although teachers have flexibility within key stages or may advance topics to earlier key stages). This list does not include repeated topics. *Key Stage 1:* **Plants** **Animals including humans** **Everyday Materials and their uses** **Seasonal Changes** **Living things and their habitats** *Key Stage 2:* **Plants** **Animals including humans** **Rocks** **Light** **Forces and magnets** **Living things and their habitats** **States of matter** **Sound** **Electricity** **Properties and changes of materials** **Earth and Space** **Evolution and inheritance**	**The World Around Us** is presented as four interrelated strands that connect learning across geography, history, science and technology. Science and technology are grouped together. The 4 strands are studied at *Foundation Stage, Key Stage 1 and Key Stage 2*: **Interdependence** **Place** **Movement and Energy** **Change over time**	There are 5 concept organisers: **Planet Earth**: Biodiversity and Interdependence, Energy sources and sustainability, Processes of the planet, Space. **Forces, Electricity and Waves**: Forces, Electricity, Vibrations and waves, **Biological Systems:** Body systems and cells, Inheritance **Materials**: Properties and uses of substances, Earth's materials, Chemical changes **Topical Science**: Topical Science All are studied at both *First and Second Level* (except chemical changes, which is only at Second).	*Foundation Stage:* **Knowledge and Understanding of the World** encompasses geography, history and science learning. Science learning takes place under these topics: **Myself and other living things** **Myself and non-living things** *Key Stage 2:* Objectives are grouped under 3 organisers: **Interdependence of organisms** **The sustainable Earth** **How things work**

Development of the Heritage Science / Science Curriculum Matrix

The 14 distinct science topics were arranged against the 6 heritage science methods. Under each of the 6 heritage science methods, a list of tasks and processes performed by heritage scientists (with examples) was synthesised from the results of the interview sessions. This then enabled the matching of curriculum statements from the UK's science curricula to processes, to show where they can be linked. In each cell, assigned codes indicate the nation, age phase and objective which could most easily be linked to each task. For objectives organised across disciplines (e.g., Northern Ireland's), those most relevant to science were selected, whilst history- and geography-focused objectives were not included. The full matrix can be seen in the appendix. It is intended that the matrix will enable heritage scientists and learning providers to see at a glance where intersections, and therefore opportunities for the creation and dissemination of resources and activities, may occur.

Skills in the curriculum

All 4 nations lay out the scientific skills that should be covered through the curriculum separately to the topic content. In England, methods, processes and skills are grouped under the title of 'Working Scientifically', and should be embedded throughout the full programme of study.[50] 'Working Scientifically' statutory requirements are listed separately for Key Stage 1, Lower Key Stage 2 and Upper Key Stage 2, showing progression.[51] They are developed further at Key Stages 3 and 4.[52] In Northern Ireland, skills are listed under 'Progress in Learning', and demonstrate how children's scientific skills should develop from KS1 to KS2.[53] At Foundation Stage in Northern Ireland, scientific skills are not specifically referenced, but should be 'developed during play and other planned activities/topics and these should be relevant to the children's interests and experiences'.[54] In Scotland, scientific skills are listed in a section of the 'Science: Principles and Practice' document under the heading 'What skills are developed in the sciences?'.[55] The Welsh curriculum for Key Stages 2-4 presents the required skills alongside the curriculum content, and this is similarly the case in the Welsh Foundation Phase Framework.[56]

The scientific skills listed by each nation are broadly similar and have been cross-referenced, grouped and amalgamated to produce figures 1 and 2.

[50] DfE, *Science programmes of study,* p. 4.
[51] DfE, *Science programmes of study,* pp. 6, 14, 25.
[52] DfE, *Science programmes of study,* p. 4.
[53] CCEA, *Northern Ireland Primary Curriculum,* p. 85.
[54] CCEA, *Northern Ireland Primary Curriculum,* p. 37.
[55] Scottish Government, *Curriculum for Excellence: Sciences: Principles and Practice,* (2013), Available from: https://education.gov.scot/Documents/sciences-pp.pdf, p. 3.
[56] Welsh Assembly Government, *Science in the National Curriculum for Wales,* pp. 12-14; Welsh Government, *Curriculum for Wales: Foundation Phase Framework*, pp. 41-42.

Figure 1 (right): Scientific skills summarised from UK science curricula for ages 5-7/8

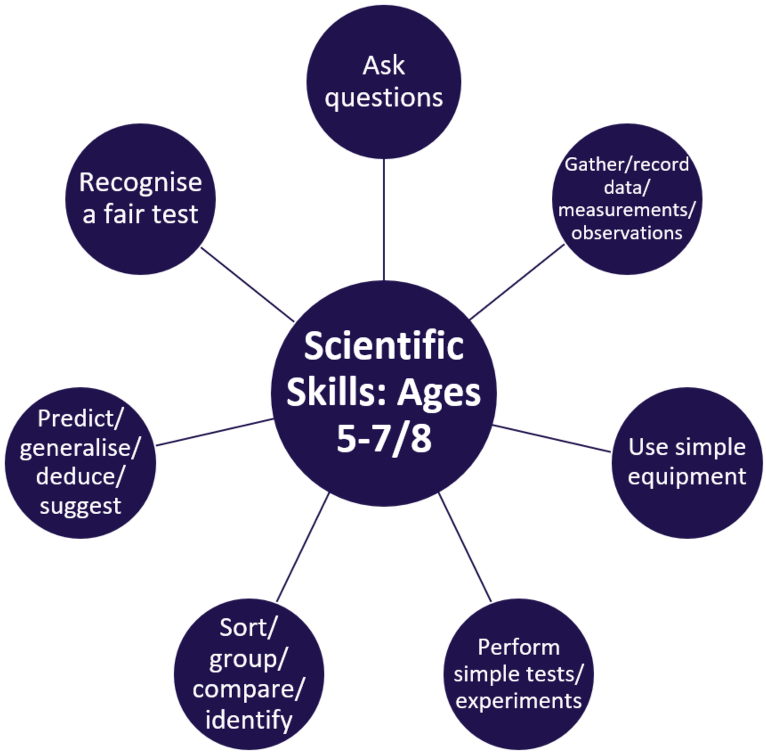
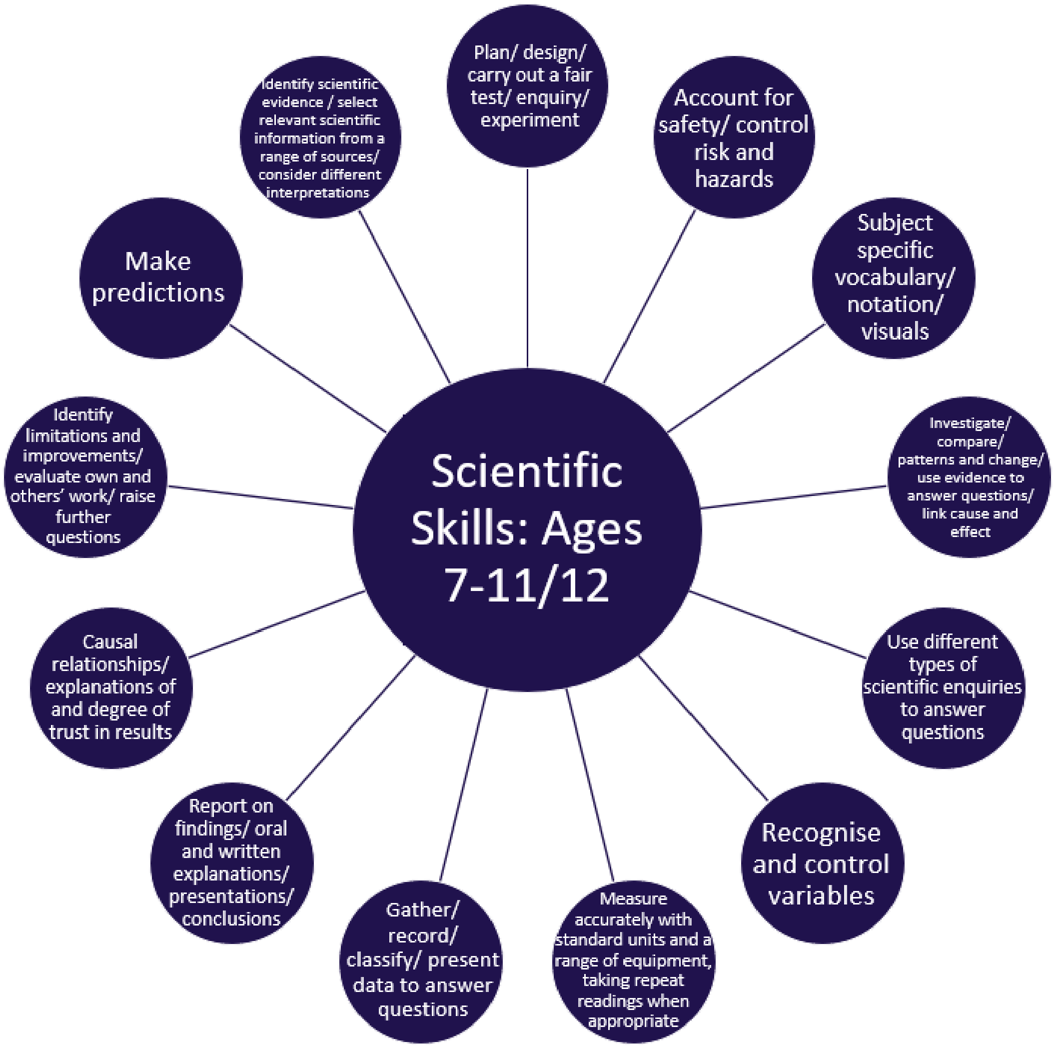


Figure 2 (below): Scientific skills summarised from UK science curricula for ages 7-11/12



Careers

Of the 4 nations, the science curriculum of Wales gives the greatest emphasis to the importance of developing awareness of the world of work and how this is relevant in science by including a specific section on careers:

> *Science contributes to careers and the world of work by enabling learners to study a range of applications of science, medicine and technology in their everyday life and in the wider world. This gives learners insight into how scientists work and also develops experimental and generic skills needed for the world of work.*[57]

As part of a list of outcomes, Scotland references careers in the document 'Experiences and Outcomes', stating that science learning should 'establish the foundation for more advanced learning and future careers in the sciences and the technologies'.[58] In Northern Ireland, careers and jobs are mentioned briefly in other sections of the curriculum but are not specifically referenced with regards to science. In England, minor references to the work of scientists, given as examples, fall under the non-statutory guidance and refer primarily to historical scientists such as Newton or contemporary scientists whose research pertains to health and lifestyle.[59]

Topical Science

In Scotland, five overarching curriculum organisers are used in science:
- Planet Earth
- Forces, Electricity and Waves
- Biological Systems
- Materials
- Topical Science

Topical Science is described thus:

> *By considering current issues of science, learners increasingly develop their understanding of scientific concepts and their capacity to form informed social, moral and ethical views. They reflect upon and critically evaluate media portrayal of scientific findings.* [60]

It is unique to Scotland that Topical Science has been included as an organiser and as a distinct topic. For all pupils and in particular for future scientists it is clearly an enriching opportunity and vitally important to consider science within its social, moral and ethical context, as well as to be able to evaluate information in the media. Furthermore, this approach may serve as a hook to generate interest from pupils who would not otherwise be keen to engage with science, as it highlights its relevance and importance to everyday life.

Scotland's Topical Science Objectives for this age group are:[61]

[57] Welsh Assembly Government, *Science in the National Curriculum for Wales,* p. 9.
[58] Scottish Government, *Experiences and Outcomes,* p. 1.
[59] DfE, *Science Programmes of study,* pp. 30-32.
[60] Scottish Government, *Experiences and Outcomes,* p. 19.
[61] Ibid.

At First level:

> *I have contributed to discussions of current scientific news items to help develop my awareness of science.*

At Second level:

> *Through research and discussion I have an appreciation of the contribution that individuals are making to scientific discovery and invention and the impact this has made on society.*
>
> *I can report and comment on current scientific news items to develop my knowledge and understanding of topical science.*

Other UK nations do not have a direct parallel to Scotland's Topical Science. The Welsh science curriculum states within its introduction that 'learners should be taught to relate their scientific skills, knowledge and understanding to applications of science in everyday life, including current issues'.[62] In Northern Ireland, an objective of the entire primary curriculum is to 'become aware of the potential impact of media in influencing our personal views, choices and decisions' and so whilst this links to all subjects there is nothing further included within science.[63] The science programmes of study for England make no specific reference to current affairs or their portrayal in the media, besides stating at the outset that social and economic implications of science are taught most appropriately within the wider school curriculum.[64]

Anecdotally it is apparent that many schools and organisations throughout the UK are pushing for and already achieving an increasing prominence of topical science content within their programmes of study, with some using resources such as Twig Science Reporter or BBC Newsround to do so.[65] However Scotland has made an admirable step forward by using Topical Science as a concept organiser. Linked to this, Scotland's science curriculum also has the greatest emphasis on sustainability. Whilst topical science could be interpreted as underpinning all concepts within science, or indeed throughout the curriculum, and therefore could be included in lessons whenever possible on an ad hoc basis or wherever it seems most obvious or accessible, its place as a concept organiser in Scotland alongside the other science topics ensures that it will be taught rigorously, systematically and progressively throughout every stage of school.

3.3. Interviews

6 online interview sessions were carried out in March 2022 with a total of 21 participants from a range of organisations and roles, from heritage scientists through to museum educators, with a further 3 participants contributing via online questionnaire. The purpose of the interview sessions was to understand the range of tasks and processes carried out by heritage scientists, which could then be mapped to the primary school curricula. Interviews with scientists and educators also provided a valuable perspective on how any links were currently made to the science curriculum, and the potential for doing so in the future.

[62] Welsh Assembly Government, *Science in the National Curriculum for Wales,* p. 10.
[63] CCEA, *Northern Ireland Primary Curriculum,* p. 4.
[64] DfE, *Science Programmes of study,* p. 3.
[65] Twig Education and Imperial College London, *Twig Science Reporter*, Available from: https://www.twigsciencereporter.com/; BBC, *Newsround,* Available from: https://www.bbc.co.uk/newsround.

In the interview discussions, the following common themes emerged.

Representation of Heritage Science

- It was felt that there is a lack of awareness of heritage science in society and many people don't know it exists. There can also be a lack of awareness within organisations.
- There is increasing representation of scientific museum-based roles in television and film, but these roles are often misrepresented and mislabelled.
- There is a lack of representation of heritage science in places where many children and young people are consuming a high quantity and quality of content, such as YouTube and TikTok.
- The field of Heritage Science has the potential to help smash stereotypes of people who work in science and what they do.
- There is potential to increase people's awareness of the heritage science that is present in everyday life but often thought of through a different lens.
- It was felt that science is not well represented at higher public levels, highlighting that not only are more scientists needed in the future, but also more 'decision makers' who support science.

> *Accessibility and engagement are definitely part of our work as heritage scientists, not just the research aspect. People are so interested in how things work and are made. Some of our most successful exhibitions are those with live conservation stations.*
>
> Heritage Scientist

Heritage Science as a vehicle to support children's learning

> *We are aware that it is a big ask for schools to engage with something if they cannot see it in the curriculum.*
>
> Heritage Scientist

- It strongly emerged that heritage science is an interdisciplinary field which includes many transferable skills. Curriculum subjects do not have to be pursued in isolation although sometimes it can seem that way.
- The way that heritage science bridges science, humanities and arts subjects has the potential to 'hook' children's interest and develop a sense of wonder via different routes (e.g., using art to increase interest in science, or using science to increase interest in history). Similarly, children can begin to understand the importance of looking after heritage for future generations and that heritage science is the means of doing this.
- The immediate and pressing relevance of the interaction between humanities and science can be brought into sharp focus because heritage scientists use the past to inform the future (e.g., investigating sustainable materials or the effects of climate change).
- Heritage scientists instinctively use the skills that are specified in science curricula throughout their work. They use an investigative approach to solve mysteries and problems and find evidence to support a hypothesis.
- Many moveable heritage collections will have objects that in themselves contribute to science topics, enabling further links to curricula. It is an opportunity to research heritage but using scientific methods.

> *The point of heritage science is to use science to learn things that are not science. It can also take science forward, but that is not the main aim.*
>
> Heritage Scientist

Opportunities in Heritage Science

- Several expressed the wish that children knew there was science in heritage and that scientists do research on heritage objects.
- Heritage scientists expressed their enjoyment of their roles. They relish lifelong learning, the fun of research, the absence of monotony, coming up with new projects and ideas, being curious, interacting with both the real world and the past, the feeling of doing something valuable, and the mental health benefits of working practically with your hands as well as the intellectual side.
- Using problem-solving and forensic techniques, heritage scientists handle, examine and discover new things about amazing objects and people.
- Heritage science is an opportunity to break down the silos of science, humanities and the arts. Children do not have to be 'pigeonholed' into just one of their interests.
- There is the opportunity to interact with lots of different types of people, to travel and to meet people from other cultures.
- Heritage scientists look at the materials of the past to develop the materials of the future.

> *We use a lot of exciting technology and tools in our job. It's not stuck in the past - it's cutting edge!*
>
> Built Environment Officer

Barriers to working with schools

- Capacity within roles and organisations.
- Resources (including funding).
- For non-experts, complex science can sometimes be intimidating.
- Communication can be a barrier as heritage scientists and educators don't necessarily 'speak the same language'.
- Learning programmes in heritage organisations are often most focused on history. Scientific care of collections is not usually thought of as having outreach potential. Specific examples from heritage scientists help educators to understand and see the potential for engaging children in this way.

> *The majority of primary classroom teachers and science subject leads do not have post-GCSE qualifications in science and there is variability in science practice in schools across the country.*[66]

Aspirational ways of working - what would help?

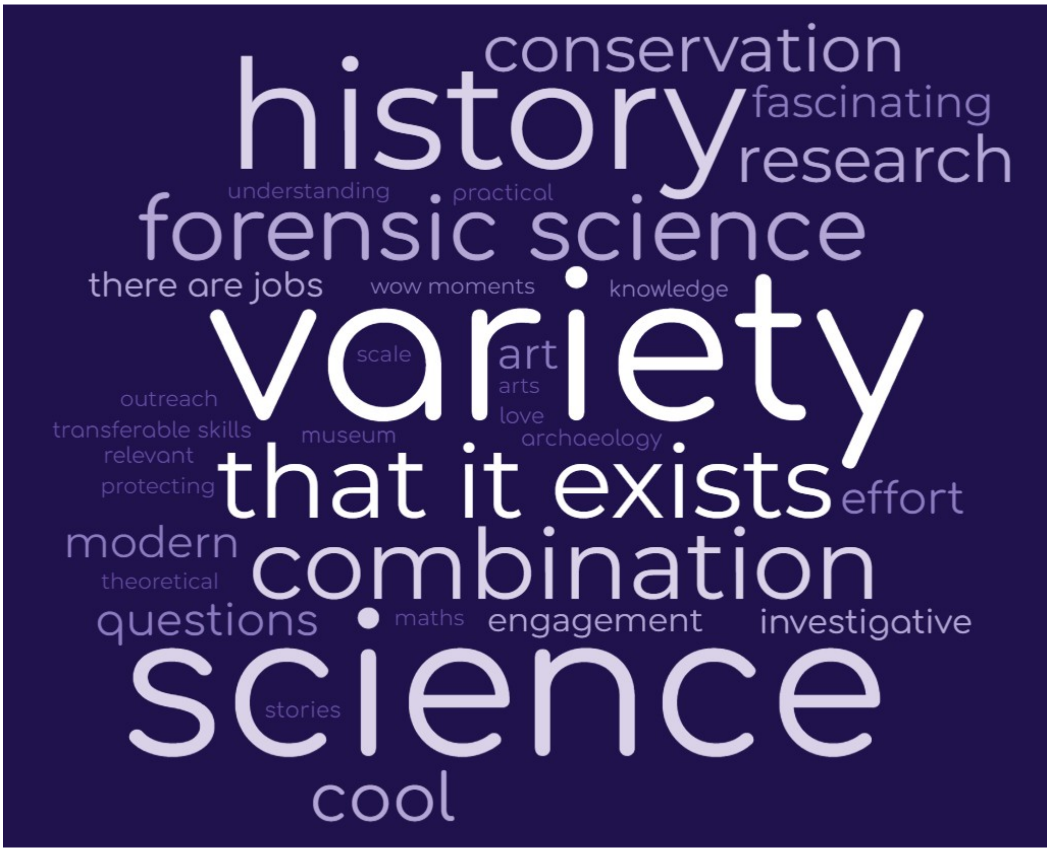
- Increased capacity and budget.
- Sector direction, prioritisation through networks and sharing of resources.
- CPD for teachers to enable further reach.

[66] The Association for Science Education, *ASE Response to the ITT Market Review,* (2021), Available from: https://www.ase.org.uk/news/ase-responds-itt-market-review-consultation, p. 2.

- Sessions or conferences via an organisation such as GEM (Group for Education in Museums).
- Maximising current opportunities within humanities learning programmes, for example emphasising good practice in collection care and object handling.
- Developing a glossary to make heritage science more accessible to non-specialists.
- A centralised location or repository such as a website where teachers can find curriculum-linked resources.
- Publicising heritage science education opportunities through social media and other methods.
- Putting heritage science and scientists in front of people whenever possible (for example, in schools and communities, not just in exhibitions as some people do not choose to visit museums and heritage sites). It is useful for children to see ‘someone like them’ doing a job.
- Symbiotic creation of resources with teachers so that the materials produced are useful and relevant.
- Communication internally and externally, between collections teams, scientists, learning teams and schools, to understand trends in education, how schemes of work are planned and how resources are used.
- Improved links with experts in creative technologies, for example contacts who could help to create an app or make a documentary film as part of an educational resource.

> *There are time crunches at every level, including for teachers. It would be amazing if there could be a role within schools to take on partnership working. Teachers are so pressed for time.*
>
> Museum Educator

Figure 3: Word Cloud showing Interview answers to the question "*What do you wish schoolchildren knew about heritage science*?"



4. Conclusions

4.1 How can heritage science be used to support the curriculum?

The different ways in which school science topics and heritage science processes can be linked could be categorised as follows:

- Directly via scientific concept. The most obvious science topics to link to are ‘everyday uses of materials and ‘properties and changes of materials’. However as shown in the matrix links can be made to almost any topic within the science curriculum.
- Thematically via asset content (e.g., using the content or subject of a painting, object, document or building to link to the curriculum, such as van Gogh's *The Starry Night* which has been used by the Fitzwilliam Museum to link to the primary topic of Earth and Space).
- By focusing on scientific skills (e.g., designing a fair test and using evidence to answer questions).
- Broadly via topical science or careers (e.g., introducing heritage science as a possible career and linking to coverage of heritage science topics in the media).
- Via other subjects (e.g., using science to connect aspects of the history curriculum and to understand its chronological approach).

Using a combination of two or more of these approaches is likely to increase the appeal of educational resources and activities.

The level of specialised content in heritage science means that curriculum science is an appropriate and logical starting point for increasing engagement with school children. 98% of primary schools (according to CFE's sample) have Science Leaders, many of whom are connected via subject networks or training opportunities.[67] Contacts with Initial Teacher Training (ITT) providers and Newly Qualified Teacher (NQT) networks may also help to build relationships with future Science Leaders in addition to class teachers. There is a potential opportunity at present to support schools with post-lockdown catch-up activities, not least in the form of re-engaging children with the curriculum through interesting and relevant real-life examples such as those presented by heritage science.

However, in synthesising the processes, methods and concepts of heritage science with the UK curricula, it becomes apparent that this field has wide cross-curricular relevance in addition to science. For many UK teachers who may not be aware of heritage science, at their first glance it may appear to link to only a small part of science, which in itself is only a small part of the full curriculum that they are required to teach. The cross-curricular opportunities of heritage science are therefore vital to emphasise. Linking to several areas of the curriculum as well as developing transferable skills and raising children's aspirations would make future educational resources even more appealing.

For example, heritage science could link to the following subjects in addition to science:

- Art - learning about great artists, architects and designers in history; understanding different techniques and materials.
- English - using microscopy as a prompt for creative writing.
- Maths - modelling; reading scales and instruments; presenting and interpreting data; mathematics in context.
- History - historical enquiry skills; engaging with local heritage; learning about specific events, societies or time periods.

4.2 Which stages & age groups could be targeted through the identification & dissemination of existing learning resources or creation of new ones?

Heritage science when targeted and simplified appropriately can be relevant to the curriculum at any age group. Younger children aged 5-7/8 are encouraged through the curriculum to develop curiosity about the world around them, and older children build on the knowledge developed in earlier phases. Children aged 7-11/12 are more likely to have developed the background knowledge to be able to access more of the scientific concepts in heritage science and are also more able to understand historical time periods and how people lived differently in the past. Interview discussions implied that sustained interaction with heritage science would be more beneficial than isolated experiences and so a movement towards a breadth of resources across stages could aid this.

CFE's research highlighted that free access to easy-to-use, high-quality resources is 'crucial' in encouraging teachers to use them.[68] In addition, resources need to be easy to find and access. Through future research it would be useful to explore where teachers currently find and select resources, how they are used and emerging trends as to preferred formats, styles and approaches.

[67] CFE Research, *Evaluation of the Primary Science Campaign,* p. 7.

[68] CFE Research, *Evaluation of the Primary Science Campaign,* p. 50.

Existing resources in some humanities learning programmes already make reference to heritage science work, but don't draw attention to it. Looking ahead, existing humanities resources with heritage science links could be identified, curriculum-linked and appropriately tagged to maximise their use and increase awareness.

4.3 How can heritage be used to engage children with science?

The transdisciplinary nature of heritage science increases its potential to introduce science concepts via history and heritage. Many schools are aware of and make use of their local heritage to help children develop a sense of place. Heritage science places scientific concepts within a tangible, relevant context, importantly showing real-world examples of the knowledge and processes being taught. Real-world applications of learning are highly valued and sought out by teachers.

Conversely, children who are already engaging positively with science can apply this interest to understanding why and how heritage is cared for, managed, interpreted and accessed.

Interview discussions and the review of existing resources demonstrated that occasionally opportunities are missed to link educational resources to the curriculum or to identify and maximise their STEM potential. Interviews with heritage scientists indicated that there is a lack of public awareness of heritage science, but that in part this arises from absence of labelling heritage science as heritage science where it does appear in everyday life and public, community and learning engagement. There can also be a lack of awareness within organisations and it is recommended that close, ongoing collaboration is developed between learning teams, scientists, and collections care teams within organisations to build opportunities for increased engagement with school children.

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Appendix - Heritage Science / UK National Curricula Matrix

The final matrix is a very large document. The following screenshots provide a visual overview of its six sections for reference purposes, but for general use and to read the text it is best viewed digitally.[69]

Method & Summary	Processes	for example...	Phase	Plants	Animals including Humans	Everyday materials and uses	Seasonal Changes	Rocks	Light	Forces & Magnets	Living things & habitats	States of Matter	Sound	Electricity	Properties & Changes of Materials	Earth & Space	Evolution & Inheritance	General Opportunities (by process)
Material Properties *What materials heritage objects are made from, as well as their properties and uses, and the things that affect and change these properties.*	**Types of Materials**	**Such as** textiles; paper, parchment & photographic materials; plants, animals, remains & specimens; biological & paleontological; soils, sediments; stone objects, tools & carvings; building materials; rocks, minerals & geological samples; toxic & hazardous materials; composite materials; reference collections; reconstructed objects; modern protection, storage & display materials.	E1:	01 02	03 04 05	07 08		08 22			13 15							Work falling under these headings may provide general opportunities to: - Detail differences and similarities between the properties of different materials, including organic/inorganic materials - Discuss/demonstrate useful/harmful properties of everyday materials to show why they might be used for particular purposes (or why their use is avoided)
			E2:								21 22 56			39				
			N0:	01	01	01 04 09					01							
			N1:															
			N2:	04	04													
			S1:												05			
			S2:					25			01					25		
			W0:	01 02 05	01 02 05	09					05							
			W2:	04	04	10		10			04							
	Properties	**Of materials, such as** density & surface structure; size, shape, thickness; strength, pliability, flexibility, stiffness, hardness, brittleness; vulnerabilities to agents of deterioration.	E1:			09 10 22 23		22			13				09 10			
			E2:	01 56 57	06 56 57	44 46		07		15 16 17 18	21 22	27 28	30 32 33	39 43	07 28 43 44 46		56 57	
			N0:	01 02 03	01 02 03	02 03 04 06 09 03									02 04			
			N1:															
			N2:	04 05	05													
			S1:	01 14	01	15				07 08		16	10 15		15 16			
			S2:	01 20 21	01	25		25		11 12	01 21			11		25	01	
			W0:	01 02		07 08 09 10						10			07 08 09 10			
			W2:			10 11		10		15 16			17		10 11			
	Origins	**Of materials, such as** animal (parchment, leather, paper), plant (dyes, paints, pigments, inks, paper), or geological (rocks, sediments, stone objects).	E1:	02 17	03	07					13 18				10			
			E2:	56 57				08 09			02 57 60	28 45 47			07 48		60 61 62	
			N0:	01	01 05 06	06						05			02 03			
			N1:															
			N2:	04 05	04 05			05										
			S1:									05 16					14	
			S2:			27						08			19 25	25	01 21	
			W0:		02	09						10			07 08 09			
			W2:		04 06	12		12							10			
	Creation	**Of objects from other materials, such as** parchment, paper, dyes, paints, pigments, inks; stone objects & buildings.	E1:	01 02	03 04	07 23												
			E2:	01						55		28 45 47			28 47 48			
			N0:			04						05			03 05			
			N1:		03 05													
			N2:		05					07					09			
			S1:							07		05 16			05			
			S2:			27				10		08		13	19 22 23 27			
			W0:			09 10						10			09 10			
			W2:			10 12		12						14	10 12			
	Comparisons	**Of materials and their properties, such as** different materials, similar materials from different locations or ages, or produced using different technologies or processes.	E1:	01 02	03	10 22		22			13 14				10			
			E2:	56 57	28 56 57	46		07		15 16 17 18 54	02 21 22 40 56 57	27 28 45	32 33 34	39 43 67	07 28 43 44 46 47		56 57 60 61 62	
			N0:	01 02	02	02 04 06						03 05			02 03 04 05			
			N1:															
			N2:					09		09					09			
			S1:		01 14					07 08		05 16	10		05 16		14	
			S2:	20	01	25 26		25		11 12	01 21		15	11 13	08 12 22 23 25 26 27	25	01 21	
			W0:	02	03	07 08						10			07 08 09 10			
			W2:	04 05 06	04	12		10		15 16	04		07 17					
	Conditions	**And their effect on the properties of different types of materials, such as** weather & climate (including climate change); time; manual handling; chemical interaction (e.g. corrosion); mechanical stress & other forces; micromorphology & other biological factors.	E1:	18		23	11 12				14 18 20							
			E2:	02 23	23 62			08	12	15 54	02 23 60	28 29 45	30 31		28 44 45 47 48	53	60 62	
			N0:	01 08	01							03 05			03 05 09			
			N1:	07	06 07					11	07							
			N2:	04 05	04 05		09	05 09		07 09								
			S1:				06			04 07					05 16		14	
			S2:		17 19					12		08	15	11 13	08 19 24 26 27		01 21	
			W0:			10	06		11			10			10			
			W2:	06	06 07		08			15	06		07			08		

[69] https://docs.google.com/spreadsheets/d/14ewXn8LmyCxnS_avmCoft3UxAKdZ2EogpnQxtwftf4s/

				Science Topics														
Method & Summary	**Processes**	**for example...**	**Phase**	**Plants**	**Animals including Humans**	**Everyday materials and uses**	**Seasonal Changes**	**Rocks**	**Light**	**Forces & Magnets**	**Living things & habitats**	**States of Matter**	**Sound**	**Electricity**	**Properties & Changes of Materials**	**Earth & Space**	**Evolution & Inheritance**	**General Opportunities (by process)**
Material Analysis	**Multispectral Imaging**	**Imaging and spectroscopic analysis techniques such as** photography; photogrammetry; chromatography; 3D imaging & modelling; raking & light boxes; properties of light at different wavelengths; thermal imaging; microwave moisture monitoring; ground penetrating radar; ultrasonic waves; spectroscopy; CT scanning; X-radiography; microscopy; laser scanning.	E1:															Work falling under these headings may provide general opportunities to: - demonstrate scientific methods driven by research questions: choosing the right methods, processes and tools for the job, based on materials/ objects being studied & the questions being asked - demonstrate different ways of seeing (e.g. different levels of magnification and/or different wavelengths of light, or even just viewing from different angles reveals different features and uncover different truths) - show the use of scientific methods to solve mysteries - demonstrate interdisciplinary working - show how different species can be differentiated from or connected to each other, including relating extinct species to modern species - show how similar materials can be differentiated from each other
			E2:		23 62				10 11 14 63 64 65				32					
			N0:		01	02 04												
			N1:	06 07	06 07													
			N2:	04 05	04 05													
			S1:						12									
			S2:		17 19			25	16									
			W0:			08			04									
			W2:		06 07				18						10			
	Chemical	**Chemical analysis techniques such as** carbon dating; isotopic analyses; oddy testing.	E1:															
			E2:									28 45 47			28 44 47 48			
			N0:												02 03 05			
			N1:															
			N2:					09										
			S1:									16			16			
			S2:			26 27		25				26		14	22 23 24 26 27			
			W0:															
			W2:					10										
	Biological	**Biological analysis techniques such as** dendrochronology & dendroclimatology; genomics; human remains analysis; ancient DNA; bioarchaeology; skeletal analysis; osteopathology; biocodicology; proteomics (including paledproteomics) & DNA analysis.	E1:	02							13							
			E2:	01 02 04 56 57	06 56 57 62			08 09			56						60 62	
			N0:	01			03								02			
			N1:	06 07			06 07											
			N2:	02 03 04 05			05 08 09	09							09			
			S1:	01 14	01 11 14												14	
			S2:	01 20 21	01 21						01 21		15		08 19			
			W0:	01 02 05	01 02 05													
			W2:	04 05 06	04 05 06		08				04 05		17					
How materials are investigated, including micro and macro methods.	**Physical**	**Physical analysis techniques such as** 3D printing scaled models; materials behaviour such as capillary testing and resistance drilling.	E1:			10 23									10			
			E2:					07		15 16 17 18		27 28 29 45 47	30 31 32 33 34 39 43		07 28 43 45 47 48		60	
			N0:									05			03 05			
			N1:															
			N2:					05		09								
			S1:							07		16	10					
			S2:		15			25		12			15	11 13 14	12 23	25		
			W0:			10						10	12		08 10			
			W2:					10		16			07 17	14	10 12			

				Science Topics														
Method & Summary	**Processes**	**for example...**	**Phase**	**Plants**	**Animals including Humans**	**Everyday materials and uses**	**Seasonal Changes**	**Rocks**	**Light**	**Forces & Magnets**	**Living things & habitats**	**States of Matter**	**Sound**	**Electricity**	**Properties & Changes of Materials**	**Earth & Space**	**Evolution & Inheritance**	**General Opportunities (by process)**
Deterioration Processes *Understanding how materials__ deteriorate, including how properties of materials change over time.*	**Physical Forces**	**Physical causes of deterioration such as** tensile stresses & other forces involved in handling/ storing/ moving objects.	E1:			09 10 23		22										Work falling under these headings may provide general opportunities to: - discuss or demonstrate how things change over time (potential to link to human/animal ageing) - show that damaging effects can build up over time even if they may not be immediately visible (potential link to health) - link to other examples of change over time (both 'good' and 'bad' changes), including periodic (such as those related to seasons)
			E2:					07		15 16 53 54 55		28 29 47	30 31 33 34		28 43 48	53		
			N0:									05			03 05			
			N1:															
			N2:							07								
			S1:							07		05						
			S2:							12						25		
			W0:			10						10	12		10			
			W2:					10		15 16			07 17		12			
	People	**Causes of deterioration originating with the interaction between people and objects, such as** handling damage and prior attempts at conservation.	E1:															
			E2:							53								
			N0:															
			N1:															
			N2:					05										
			S1:															
			S2:															
			W0:												10			
			W2:								07		17					
	Pests	**Animal related causes of deterioration, such as** insect damage.	E1:		15						14 15 16							
			E2:		56						41		30					
			N0:															
			N1:				06 07				07							
			N2:				05 08	05			02							
			S1:															
			S2:										15		19			
			W0:				06											
			W2:								06		07 17					
	Chemical	**Chemical causes of deterioration such as** the effects over time of exposure to & contamination from specific substances; organic & chemical decay (including lipid or protein condensation); loss of DNA; pyrite decay; cellulose and acetate degradation in audio/visual material.	E1:															
			E2:									28 45						
			N0:									03 05						
			N1:															
			N2:					09										
			S1:															
			S2:			26 27						26			26 27			
			W0:															
			W2:															
	Light	**Deterioation caused by exposure to light (potentially at different wavelengths) such as** fading, discolouration, brittleness; may include microfading testing.	E1:				11 12											
			E2:						12									
			N0:				03											
			N1:															
			N2:					09										
			S1:				06		04									
			S2:						16									
			W0:						11									
			W2:				08											
	Environment	**Environmental causes of deterioration such as** incorrect temperature or relative humidity; fire; water (including coastline property damage); hydrology modelling; and deteroration caused or accelerated by local, regional or worldwide environmental and climate change.	E1:				11 12											
			E2:								23	28 29 45 47	30 33		28	52 53		
			N0:	08	08		03					03 05						
			N1:	04 05	04 05													
			N2:				05 09	05		07								
			S1:									05 16			05 16 17	06		
			S2:							12		08	15	11	26			
			W0:	06	06							10			10			
			W2:	06	06						06 07		07 17			08		

				Science Topics														
Method & Summary	**Processes**	**for example...**	**Phase**	**Plants**	**Animals including Humans**	**Everyday materials and uses**	**Seasonal Changes**	**Rocks**	**Light**	**Forces & Magnets**	**Living things & habitats**	**States of Matter**	**Sound**	**Electricity**	**Properties & Changes of Materials**	**Earth & Space**	**Evolution & Inheritance**	**General Opportunities (by process)**
Preventive Conservation & Management	**Monitoring**	**Methods of keeping track of deterioration such as** environmental, light & vibration monitoring.	E1:				11 12											Work falling under these headings may provide general opportunities to: - explore habitats & conditions for life (e.g. what makes an insect want to live in/eat an object!) - discuss/demonstrate how we can learn about things non-invasively / non-destructively - link small-scale environmental monitoring (e.g. of an archive or exhibition space) to larger-scale environmental/climate changes - linking repair & remediation to re-use and recycling - discuss when we might want things to last a long time, and when we might want them to deteriorate rapidly
			E2:	23	23				11 12 14 63 64 65	54	23	28 29	30 31 32 33 34	35 36 37 38 39 43 66 67	28			
			N0:	01							01	03						
			N1:		12													
			N2:				09	09		09								
			S1:	03					04 12	04 07		05	10	09		06		
			S2:			27			16			26	15	11 13		09		
			W0:						04 11				12					
			W2:	06	06					15 16			07 17	14		08		
	Modelling	**Methods for modelling and predicting deterioration and other changes such as** climate, environmental and other hazard prediction; designing & creating replicas; decay modelling for organic artefacts; 3D modelling & printing; and data analysis techniques.	E1:				11 12											
			E2:						14 65	20		29 47	30 32 33 34	39 43 66 67				
			N0:								01	03 05						
			N1:															
			N2:	05	05			09										
			S1:				06			07		16	10		05 16	06		
			S2:								01	08		11		09	01 21	
			W0:															
			W2:											14		08		
	Preventing Damage	**Methods for preventing or reducing damage such as** decreasing light levels; appropriate handling techniques; insect & pest management; and sample preservation (drying, freezing, formaldehyde, taxidermy, etc).	E1:								13 14 20							
			E2:	23	23				12 65		02 23	29 45						
			N0:	01 08	01 08							03 05						
			N1:	07	07													
			N2:	04	04													
			S1:															
			S2:							10		26	15	13	19			
			W0:															
			W2:	04 06	04 06					15 16	06 07		07 17	14				
Slowing, stopping or reversing the deterioration and degradation of materials.	**Repairing Damage**	**Methods for repairing existing damage such as** 3D printing, copying & restoring faded text.	E1:															
			E2:									45 47			44 45 47			
			N0:															
			N1:															
			N2:															
			S1:															
			S2:			27						26			23 27			
			W0:												10			
			W2:												12			

				Science Topics														
Method & Summary	**Processes**	**for example...**	**Phase**	**Plants**	**Animals including Humans**	**Everyday materials and uses**	**Seasonal Changes**	**Rocks**	**Light**	**Forces & Magnets**	**Living things & habitats**	**States of Matter**	**Sound**	**Electricity**	**Properties & Changes of Materials**	**Earth & Space**	**Evolution & Inheritance**	**General Opportunities (by process)**
Sustainability	**Learning from the Past**	**Through activities such as** investigating historically sustainable practices; understanding climate change & its impact on people, locations, materials & buildings, and working to mitigate these impacts; understanding material properties & decay.	E1:				12											Work falling under these headings may provide general opportunities to: - develop understanding of the nature, processes and methods of science through different types of science enquiries that help to answer scientific questions about the world - add to the scientific knowledge required to understand the uses and implications of science, today and for the future - demonstrate that environments can change and that this can sometimes pose dangers to living things - present more abstract ideas, demonstrating how these ideas help to understand and predict how the world operates Whilst there are some opportunities associated with the *Digital Preservation* process it is a sparsely populated section. It may, however, prove more fruitful as a source of cross-curricula content intersecting with computing curricula.
			E2:								23 60			35				
			N0:	05	05		03					03						
			N1:				06 07			11								
			N2:				05 08 09	09		09								
			S1:			17			04	04		05						
			S2:							05 06 07	01	08						
			W0:															
			W2:				08								13	08		
	Understanding the Present	**Via techniques such as** using sensors to record change & create models for prediction; keeping abreast of rapid changes in technology; questioning current standards in line with sustainability agendas; assessing personal & organisational carbon footprints; investigating objects with minimal intervention & non destructive analysis techniques in order to prolong their lifespan.	E1:				11 12				14 15							
			E2:								23	27 28		35 36 37 38 66 67				
			N0:	05	05						01 07	03						
			N1:							11								
			N2:				09	09		09	02							
			S1:			17	06		04	04				09				
			S2:							05 06 07		26		11 13				
			W0:															
			W2:	04 05 06	04 05 06						04 06 07		07 17	14	13	08		
Research, development and delivery of processes and technologies designed to make heritage science more sustainable financially and in environmental terms, as well as with regards to the longevity of the objects under its care.	**Reducing Energy Use & Waste**	**By, for example**, looking to find more efficient ways to maintain environmental conditions by testing, gathering evidence, & implementing new processes & technologies; retrofitting heating (etc) to historic properties with consideration of energy efficiency and use of renewable energy sources; and using reclaimed materials to repair historic buildings and other heritage objects.	E1:															
			E2:								23			38 39				
			N0:	05	05													
			N1:															
			N2:															
			S1:			17				04				09				
			S2:						07	05 06 07		26		11 13				
			W0:															
			W2:								07		07 17	14	13	08		
	Digital Preservation	**Using tools & techniques such as** digitisation and digital storage of data, images, videos; and 3D modelling & printing.	E1:															
			E2:						10 11 63 64				31 33 34					
			N0:															
			N1:															
			N2:															
			S1:						12									
			S2:						16					13				
			W0:						04 11									
			W2:						18				17	14				

				Science Topics														
Method & Summary	**Processes**	**for example...**	**Phase**	**Plants**	**Animals including Humans**	**Everyday materials and uses**	**Seasonal Changes**	**Rocks**	**Light**	**Forces & Magnets**	**Living things & habitats**	**States of Matter**	**Sound**	**Electricity**	**Properties & Changes of Materials**	**Earth & Space**	**Evolution & Inheritance**	**General Opportunities (by process)**
Notes - The objectives listed for each combination of row/column headings are suggested starting points for curriculum links: any objectives must be assessed against the specific activities being undertaken in any given situation. - Specific heritage science activities may well contain aspects of different processes (rows). - The science curriculum topics (columns) do not represent any official subject headings from the science curricula referenced: they have been devised from an interrogation of those curricula in order to make it more easily navigable. This means that there may be objectives, processes or activities that fit into more than one of these categories.		**General Opportunities (by topic):**		Forms of life can both help and hinder heritage science in various ways: pests, moulds and seeds amongst collections & archives; the animal and plant origins of some materials; understanding the efficiency of some natural processes and using this to inform devlopments in sustainable practices.		Many materials that children are familiar with will be used by heritage scientists in ways and for purposes that they are not at all familiar with.	Familiar cycles, such as the seasons, water cycle and rock cycle, could be used to introduce or develop understanding of other cyclic/feedback dependent processes, either where they directly intersect or as analogies.		The properties of visible light can be used as an introduction to invisible parts of the electromagnetic spectrum.	Forces are behind every physical interaction that happens in the universe. Some of those interactions cause damage; some happen very slowly over time. There are opportunities to compare physical interactions relevant to heritage science activities and those which are familiar to children.	Archives & collections can be attractive micro-habitats for living things: working to make them less attractive habitats in order to preserve collections may be compared and contrasted with changes in natural habitats and the environment at large.	Heritage science activities often involve either attempting to change something's state, or working to avoid a change of state: such activities may provide analogies and examples for understanding how this might happen, and justifications for learning about it.	Exploration of analogies between sound and other forms of energy that propagate via waves.	Links to other areas of STEM and Computing, looking at how specific instruments work in terms of their construction and electric circuits.	The properties of materials and how they can change is a major driver for the evolution of humans as social animals. For example, the presumably chance discovery of copper via smelting with carbon led to the copper, bronze and later iron ages which saw major developments in humans in terms of tool production, fashioning jewellery and precious items and the development of currency.	The Earth's position in space and its relationship with other celestial objects is an excellent example of how human beings' increasing grasp of science have changed ideas and beliefs about our place in the universe and our importance as beings. For example, the work of Galileo using the scientific method to propose a heliocentric solar system model demonstrating that previous beliefs were incorrect.	Understanding of evolution and inheritance enables us to recognise that living things have changed over time and that fossils provide information about living things that inhabited the Earth millions of years ago. We realise that living things produce offspring of the same kind, but normally offspring vary and are not identical to their parents and we can identify how animals and plants are adapted to suit their environment in different ways and that that adaptation is a consequence of evolution.	Overall, activities may include a number of opportunities to link topics on science curricula to other subjects. For example, the collection of data, its analysis, making conclusions and predictions, and presentation of those findings are activities with clear connections with both mathematics and computing curricula.