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1. Introduction

1.1 Background

England's historic environment is revered all around the world for its beauty and its cultural and historical significance. The rich collection of assets, including sites and monuments, range from registered battlefields to shipwrecks, and from listed buildings to ancient parks and gardens. According to research carried out by Visit Britain, the heritage-tourism sector is estimated to support approximately 195,000 full-time equivalent jobs, contributing to £7.4 billion a year to the UK's gross domestic product.

Preserving what remains requires a wide range of specialist knowledge and skills, sensitivity to the local setting and an appreciation of the important role these assets play in maintaining a sense of place for the general public. Knowledge and application of scientific techniques is vital to understanding, identifying and preserving the past for the future. Heritage science does this by closely connecting science with the humanities. It is a cross-disciplinary field incorporating "*all technological and scientific work that can benefit the heritage sector, whether through improved management decisions, enhanced understanding of significance and cultural values or increased public engagement*"[1].

In 2006, the House of Lords Select Committee on Science and Technology conducted an inquiry into science and heritage and recommended that "*the sector should formulate a UK wide strategy for heritage science, covering both movable and immovable heritage*"[2]; also recommended was the "*development of a comprehensive national strategy for heritage science, embracing both the immoveable and moveable heritage, and covering the United Kingdom as a whole*"[3].

A Steering Group was appointed to oversee the development of a *National Heritage Science Strategy* (NHSS) and a series of four iterative reports were published during 2009-10. They focused on:

1. The role of science in the management of the UK's heritage;
2. The use of science to enhance our understanding of the past;
3. Understanding capacity in the heritage science sector; and
4. A vision and strategy for heritage science.

Findings from the third report recommended that "*more could be done to get heritage science examples into the school science curriculum, through classroom and laboratory work, as well as on-site learning, for example, visits to heritage sites and museums with a strong scientific focus*"[4]. The

[1] Definition taken from: http://www.heritagescienceforum.org.uk/
[2] National Heritage Science Strategy (2009): *Understanding capacity in the heritage science sector*
[3] House of Lords, Select Committee on Science and Technology (2006): *Science and Heritage, Report with Evidence*
[4] National Heritage Science Strategy (2009): *Understanding capacity in the heritage science sector*

final NHSS report (2010[5]) converted this recommendation into one of the objectives aimed at building future capacity in heritage science: "*Promote the use of heritage science in school teaching, whether through curricula or schools visits to heritage sites, to help develop the understanding of cultural heritage and inspire future interest in heritage science as a career*"[6].

The *English Heritage Science Strategy* (EHSS) is now jointly owned by Historic England and the English Heritage Trust. It responds specifically to the NHSS objectives by acting "*as a powerful catalyst for sharing of information among English Heritage's*[7] *scientists engaged in practicing and advising on archaeological science, interiors and collections conservation and structural conservation"*[8]. To help train future heritage scientists, and to ensure that heritage science work achieves the greatest public benefit, the EHSS set out the following medium term action – "*consider ways of enhancing the role that heritage science can play in the teaching of science within secondary and tertiary education"*[9].

1.2 Purpose and scope of the study

A key strategic priority of Heritage 2020 (owned and managed by the Historic Environment Forum) is to champion high quality heritage learning experiences for children and young people within and without the classroom, supporting the delivery of the school curriculum and the wider cultural education agenda[10].

This aim of the current project was to review the National Curriculum in England science programmes of study for **key stage 3 (ages 11-14), key stage 4 (15-16; GCSE) and key stage 5 (17-19; AS and A level),** specifically to identify topics and areas where heritage science could be used to deepen understanding, enhance knowledge, and form connections between the subjects being studied. In particular, it set out to identify topics where learning resources which support the core curriculum are few or lacking so that new resources may be developed by Historic England and others to address these gaps in the future.

The scope of the study was limited to the core sciences spanning biology, chemistry and physics. Whilst cross-over opportunities are acknowledged, the scope did not directly examine mathematics, humanities, social sciences, or key stages 1 and 2 (primary) curricula. The work intends to inform, but did not set out to specify, how collections held by both Historic England and English Heritage should be used for developing learning resources.

The project represents an important first step in establishing how heritage science can engage with the science curriculum, inspire the next generation and increase participation in heritage science

[5] National Heritage Science Strategy (2010): *Our Vision and Strategy for Heritage Science*
[6] National Heritage Science Strategy (2010): *Our Vision and Strategy for Heritage Science*
[7] Now Historic England
[8] Department for Culture, Media and Sport Select Committee (2012): *Science and Heritage: Response to the House of Lords Select Committee on Science and Technology*
[9] English Heritage (2013): *English Heritage Science Strategy*
[10] Heritage 2020: Strategic priorities for England's historic environment 2015-2020

activities. At a broader level the project is of interest to the heritage science community in England as a whole as well as young people studying science in schools and colleges. It has the potential to open new vistas for learners whatever their future career path.

1.3 Methodology

Stage 1

The first stage involved a detailed interrogation of National Curriculum documentation whereby all module headings and component sub-headings were populated into a matrix by level and discrete subject. The documents analysed for the research included the following:

- Department for Education (September 2013) *Science programmes of study – key stage 3: National curriculum in England*
- Department for Education (June 2015) *Combined science – GCSE subject content*
- Department for Education (June 2015) Biology, chemistry and physics
- Department for Education (April 2014) *AS and A level subject content for biology, chemistry, physics and psychology*

At AS and A level, a sample of Awarding Organisation (AO) specifications were also reviewed to provide additional insight into the activities and competences learners need to develop as part of reformed subject content and assessments that began being used in September 2015.

- OCR specifications for Biology;
- AQA specifications for Chemistry;
- Edexcel specification for Physics.

Parallel to this, a desk review of heritage science literature was undertaken to define the key concepts and principles of heritage science.

Stage 2

This stage involved cross-referencing the content populated from the science curriculum documentation with the principles of heritage science. This involved a combination of thematic and keyword searching to identify matches, including additional cross-checks against the four National Heritage Science Strategy publications[11].

[11] It should be noted that the remit of the research allowed for the mapping of key concepts and principals of heritage science and not a detailed interrogation of (for example) specific materials, scientific techniques, equipment etc. used as part of heritage science related investigations.

Stage 3

To support and validate the mapping, telephone interviews were conducted with 11 stakeholder organisations spanning heritage and science specialisms, including government agencies, professional bodies, learned societies, subject associations and awarding organisations. In addition, two questionnaire responses were obtained from science teachers and four from the Heritage Science Network (via Historic England).

2. Heritage Science and the Science Curriculum

2.1 Definitions

Definitions of key terms are set out below.

CONCEPT	DEFINITION
Historic Environment:	All aspects of the environment resulting from the interaction between people and places through time, including surviving physical remains of past human activity, whether visible, buried or submerged, and landscaped and planted or managed flora[12].
Heritage Science:	Heritage Science bridges the gap between the humanities and the sciences and has the ability to engage people in science as a tool to find out about the past. This includes how we preserve and manage landscapes, buildings and artefacts so that they can be enjoyed for years to come[13]. It combines a practical approach to experimentation, demanded by working on historic technologies and real-world situations, to deliver robust answers concerning the management and protection of our heritage[14]. Heritage Science encompasses 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[15]. It involves the application of scientific techniques to identify and understand the past and conserve it for the future. It includes archaeological science, conservation science, engineering and imaging techniques.

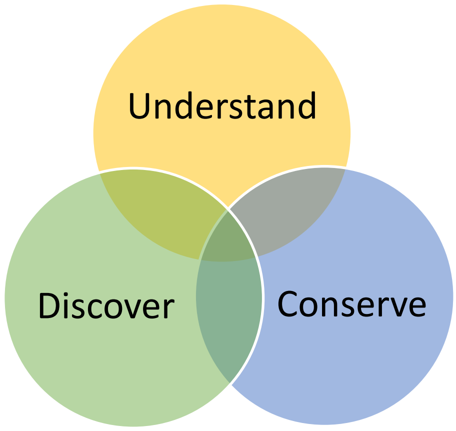
2.2 Heritage science – purpose, key functions and investigative approaches

Heritage science is wide-ranging and intersects with mathematics, humanities and the social sciences. The key purpose and broad functions of heritage science (as defined for the purpose of this research) are summarised below.

[12] Department for Communities and Local Government (2012) *National Planning Policy Framework*
[13] National Heritage Science Strategy (2010) *Our vision and strategy for Heritage Science*
[14] National Heritage Science Strategy (2009) *Report 3: Understanding capacity in the heritage science sector*
[15] English Heritage (2013) *Science Strategy*

Key Purpose of Heritage Science:

The application of scientific techniques and technology to identify and understand the past and conserve it for the future.



Key Function (first level)

A. Understanding existing heritage	**B. Discovering new aspects of heritage**	**C. Conserving, protecting and managing heritage**
Key Function (second level)		
A1 Improved understanding of the interactions between people and the environment through time	**B1** Use of scientific techniques to investigate aspects of heritage (e.g. unmanned aerial vehicles (UAVs) to explore hidden areas in buildings) and geophysics to examine unexplored terrains	**C1** Constructive conservation of existing heritage sites
A2 Use of non-invasive investigative processes that minimise damage	**B2** Application of risk mitigating sensitive technologies to uncover more without damage (e.g. imaging of buried archaeology; non-destructive testing of objects)	**C2** Understanding the interaction between the environment and people and how these factors affect conservation and protection of the historic environment
A3 Development and application of analytical and imaging methods and equipment.	**B3** Use of new information to discover new links to the past.	**C3** The historic environment, and sustainability and climate change, including avoidance of any inappropriate adaptations
A4 Improved understanding of the manufacture, provenance, materials and significance of heritage assets.		

"Heritage science focuses on the materiality of art objects, therefore material science and material properties are the place to start."

Heritage stakeholder

"Heritage science is about understanding the role of science in explaining the significance of heritage assets, such as age, condition, who it was executed by and how to look after these assets in terms of preservation and remedial activities."

Heritage stakeholder

"It's about how the world and environment is changing and the role science plays in everyday life."

Heritage stakeholder

Heritage science themes and investigative approaches

Understanding existing heritage

- Examination and analysis of heritage is made possible through scientific non-invasive techniques, analytical protocols and instruments – whilst avoiding risk and damage[16];
- Development and application of analytical and imaging methods and equipment for non-invasive, non-destructive and portable analysis of artwork and objects of cultural significance to identify component materials, degradation products and deterioration markers[17];
- Improved understanding of the manufacturing processes, provenances, and environmental contexts of material types, objects, and buildings, of cultural significance including their historical significance[18].

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[16] AHRC/EPSRC Science and Heritage Programme (2012) *Heritage Research: Defining a new era in science*
[17] R. Wiesinger and M. Schreiner (2015) 'Chemistry for cultural heritage', *Heritage Science*
[18] R. Wiesinger and M. Schreiner (2015) 'Chemistry for cultural heritage', *Heritage Science*

Discovering new aspects of heritage

(Based on the concept that the historic environment is dynamic, not static):

- Discovery of previously unknown sites, which transforms our knowledge and understanding about the past[19];
- Use of scientific techniques so that previously unexplored terrains (e.g. underwater) can be examined and lost heritage and history can be discovered;
- Discovery of hidden mural paintings;
- Remote understanding of heritage hidden below the ground and how that has transformed in recent years[20];

Conserving, protecting and managing heritage

- Investigation of the causes and processes of decay in the historic environment;
- Study of the effects of climate change and the contemporary environment on the historic environment, to understand the risks placed upon objects and sites[21];
- Evaluation of the impact of air pollution on cultural heritage
- Development and evaluation of practical interventions to better conserve existing heritage assets;
- Development of new materials and methods for preserving cultural heritage, ranging from nanoparticles to protective coatings on different heritage materials[22];
- Predictive heritage studies, leading to effective management of the historic environment[23];
- Constructive conservation and sustainable management;
- Improved management decisions, policies and conservation practice[24];

[19] Heritage 2020: Strategic priorities for England's historic environment 2015-2020
[20] Heritage 2020: Strategic priorities for England's historic environment 2015-2020
[21] Heritage 2020: Strategic priorities for England's historic environment 2015-2020
[22] R. Wiesinger and M. Schreiner, 'Chemistry for cultural heritage', *Heritage Science*, 3:35 (2015)
[23] R. Wiesinger and M. Schreiner, 'Chemistry for cultural heritage', *Heritage Science*, 3:35 (2015)
[24] National Heritage Science Strategy (2010) *Our vision and strategy for Heritage Science*

- Improved resilience of historic assets to the impacts of climate change, including better energy efficiency[25].

Agents of material decay on heritage assets[26]:

Heritage Science involves considering the principal causes of decay, how these are monitored, and preventive methods that can reduce the effects of these deterioration agents.

Agents include:

- Water damage;
- Inappropriate relative humidity;
- Inappropriate temperature;
- Light damage;
- Fire damage;
- Biological agents (e.g. mould, fungi and pests);
- Chemical agents (e.g. nitrogen oxides, sulphur dioxide, hydrogen sulphide and volatile organic compounds);
- Physical agents (e.g. handling, construction, vandalism, theft and natural phenomenon).

Scientific/analytical techniques for investigating heritage assets include:

- Chemometrics- importance of mathematical and statistical tools for the extraction of relevant information from chemical data obtained;
- Direct exposure–mass spectrometry;
- Gas chromatography–mass spectrometry;
- Energy dispersive X-ray fluorescence[27];
- Identification of raw materials (often animal hard tissue) in historical objects;
- Micro-Raman spectroscopy;
- Multiband IR and UV fluorescence imaging;
- Micro spectroscopic imaging- characterisation of materials is vital in understanding how they were made and used, their conservation history, origin and mechanisms of material decay[28];
- Radiographic investigation of historic and archaeological textiles[29];
- Reading rolled parchment documents using micro X-ray tomography[30];
- Terahertz imaging, e.g. to investigate murals.

[25] Heritage 2020: Strategic priorities for England's historic environment 2015-2020
[26] National Heritage Science Strategy (2009) *Report 1: The role of science in the management of the UK's heritage*
[27] R. Wiesinger and M. Schreiner, 'Chemistry for cultural heritage', *Heritage Science*, 3:35 (2015)
[28] AHRC/EPSRC Science and Heritage Programme (2012) *Heritage Research: Defining a new era in science*
[29] AHRC/EPSRC Science and Heritage Programme (2012) *Heritage Research: Defining a new era in science*
[30] AHRC/EPSRC Science and Heritage Programme (2012) *Heritage Research: Defining a new era in science*

Four main ways in which heritage science can enhance understanding and engagement with the historic environment[31]:

1. Chronology
   Knowing the age of something, both in and of itself and also relative to other heritage assets, is of central importance.

2. People and the environment
   The scientific investigation of the remains of people themselves and the environment in which they lived tell us more about their lives and how people were influenced by and changed their environment. It is largely focused on the analysis of plant and animal (including human) remains and the sediments in which they are found, which provides information about past diets and environments. In addition, the design and construction of buildings and landscapes tells us about the people and cultures who created them.

3. Understanding materials and technology
   This is about the things people make and use – from buildings and other structures to artefacts, and is concerned largely but not exclusively with materials. The questions are generic, concerning the manufacture, use and modification of all heritage assets. They apply equally to museum objects, works of art, books and manuscripts, built structures and archaeological material.

4. Detecting and imaging heritage assets
   This is about how we locate, record and display heritage assets. It also concerns the assessment of risk and how we plan care and repair.

2.3 Heritage science mapped to science subjects

The Appendix sets out a detailed matrix of heritage science concepts mapped to national curriculum modules in the core science subjects (Biology, Chemistry and Physics) across key stages 3, 4 and 5.

This section (2.3) summarises these concepts by subject. They represent prominent opportunities for the future development of heritage science teaching and of learning materials to support national curriculum delivery in schools.

It is important to note that a growing number of schools are converting to Academies – a key Government policy area. Academies are publicly funded schools (they receive money direct from the government and not the local authority) and do not have to follow the national curriculum. Some academies have sponsors such as businesses, universities, other schools, faith groups or voluntary groups. Sponsors are responsible for improving the performance of their schools.

[31] National Heritage Science Strategy (2009) *Report 2: The use of science to enhance our understanding of the past*

Biology

THEME	HERITAGE SCIENCE CONCEPT
UNDERSTAND:	Dating heritage assets using biological remains and natural products.
	Environmental conditions that were present at any given time and the effect of human activity in shaping and changing that environment.
	Function of skeletons and how this has changed over time.
	Human and plant remains, to build up an understanding of the historic environment and its context.
	Human diet, resource exploitation and past environments.
	Impact of changes in climate and environments.
	People and the historic environment in which they lived, including cause of death.
	The wider environment, to identify environmental conditions at any given time and the effect of human activity in shaping and changing that environment.
DISCOVER:	Use of DNA, to better comprehend heritage assets and remains, and the lives of people in the past, including diseases that they may have faced.
	Visual and low powered microscopic examinations of animal and plant remains from archaeological sites to help identify and quantify species.
CONSERVE:	Past changes in climate and environments to help understand and adapt to current and future changes.
	The study of decomposition, including agents of decay, to inform future preservation decisions regarding heritage assets; also using this information to understand the previous nature of heritage assets and objects, and the extent of their degradation.

Chemistry

THEME	HERITAGE SCIENCE CONCEPT
UNDERSTAND:	Carbon dating to understand when and where events occurred including the introduction of new species and technologies.
	Chromatography and other identification techniques to pinpoint elements and understand materials used.
	Environmental conditions that affect material types, objects and buildings of cultural and historical significance
	The physical environment around the heritage asset.
	Instrumental methods of analysis to identify elements and understand materials used.
DISCOVER:	How things were made, the materials they were made from, and scientific analysis to provide information on the history of objects.
	Use of pH indicators to identify the acidity of materials.
	Use of DNA, to better comprehend heritage assets and remains, and the lives of people in the past, including pests and disease.
	Use of electromagnetic radiation to explore and understand heritage assets, with minimal risk.
CONSERVE:	Acids and being able to test for them, in order to inform conservation strategies for heritage assets.
	Effects of changes in energy procurement on heritage assets and how this can aid their long term conservation.
	How heritage assets interact with their environment, particularly in the case of changing environments through time, and using that knowledge to identify suitable conservation strategies to preserve them for the future.
	How materials deteriorate so as to identify suitable conservation strategies for heritage assets.
	Use of nanoparticles to conserve heritage assets in order to protect them for future generations.

Physics

THEME	HERITAGE SCIENCE CONCEPT
UNDERSTAND:	Effects of climate change and the contemporary environment (humidity, temperature, air movement) on the historic environment, to understand the risks placed upon objects and sites.
	Properties of materials used in heritage sites and their structural relationships such as stresses, strains and loading, including potential risks.
DISCOVER:	Use of scientific techniques to explore previously inaccessible areas.
	Use of Sonar to investigate previously inaccessible areas, and use of radar, magnetometry and other geophysical survey technologies for revealing sub-surface information (sites).
	Use of sound waves and lasers to explore structures such as caves.
	Use of visible and non-visible sections of the electromagnetic spectrum (such as radio waves, X-rays and other forms of imaging) to explore and understand heritage assets, with minimal risk.
CONSERVE:	The effect of light and non-visible sections of the electromagnetic spectrum on heritage objects and assets, in order to improve their conservation in the future.

2.4 Working scientifically

Across all three key stages, the national curriculum requires learners to demonstrate the principles of 'working scientifically'. This presents opportunities for heritage science to provide a context for learners to hone and develop these skills, particularly in relation to part B of the main functions table in section 2.1– 'Discovery'.

Key stage 3 – key concepts for working scientifically:

- Scientific attitudes;
- Experimental skills and investigations;
- Analysis and evaluation;
- Measurement.

The following statement from the national curriculum provides a key priority opportunity for heritage science by using the real world as a context for studying aspects of the curriculum:

- "Ask questions and develop a line of enquiry based on observations of the real world, alongside prior knowledge and experience".

Key stage 4 – key concepts for working scientifically:

- Development of scientific thinking;
- Experimental skills and strategies;
- Analysis and evaluation;
- Scientific vocabulary, quantities, units, symbols and nomenclature.

In particular, the following statements from the national curriculum:

- "Explain every-day and technological applications of science; evaluate associated personal, social, economic and environmental implications; and make decisions based on the evaluation of evidence and arguments"; and

- "Evaluate risks both in practical science and the wider societal context, including perception of risk in relation to data and consequences".

Key stage 5 – key concepts for working scientifically:

- Independent thinking;
- Use and application of scientific methods and practices;
- Numeracy and the application of mathematical concepts in a practical context; and
- Instruments and equipment.

In particular, learners are expected to:

- "Solve problems set in practical contexts"; and
- "Apply scientific knowledge to practical contexts".

One Awarding Organisation interviewed for the research pointed out that although the study of theory is quite advanced at A Level, heritage science would have a place through 'working scientifically.

3. Developing Learning and Teaching Resources

"There is so much overlap between heritage science and the curriculum, one is actually spoilt for choice!"

Science stakeholder

3.1 Potential topics and contexts

Set out below are key topics within the science curriculum (bold text), supported by examples of heritage contexts, as mentioned by expert stakeholders, through which these topics may be studied and applied. This is *not intended to be an exhaustive list* and is based on a combination of desk research and stakeholder interviews.

Biology

Cell biology and transport systems – could help learners to understand more about biological artefacts, for example to work with natural history collections one needs to be knowledgeable about cell biology of assets to know how to look after them properly. Archaeological scientists need to understand the structure of the organisms they study in order to identify different types of remains (is it animal, vegetable or mineral) and understand how they change over time.

Earth and atmosphere – climate change/extreme weather/continental drift/geological disturbances and how they affect the location of species and their evolution (including humans)

Ecosystems – this relates to environmental archaeology and where past settlers lived in relation to the ecosystems they exploited. Studies could, for example, look at whether there was sufficient supply of water to populations, whether it was contaminated, and the impact on health and migration. Similarly, over-hunting/farming could reduce the numbers of certain plants and animals in the eco-system, favour others, and impact upon human habitability. Biodiversity is affected by trade and the introduction of new species. Designed landscapes involve the creation of new ecosystems.

Health, disease and development of medicine –could involve looking at populations and demographics and how they changed over time as a result of diseases, developments in medicine, and occupational health. Analysis of minerals absorbed during youth versus older life can also help to identify diets and when infants were weaned from the breast. Additionally, many materials in heritage buildings are made from animal and plant products, leading to problems such as mould growth and microbiological damage, therefore being able to recognise this and develop conservation measures to address this damage is important.

Inheritance, variation and evolution – this also links with the topic of health and disease: good examples could be the potato famine and Dutch Elm disease and the types of genetic and external conditions (such as climate) that can make particular species vulnerable. This links to how humans assess risk and decide which crops to grow and balance risk versus potential profit or survival. Key here is the development of farming from the Neolithic onwards, including natural selection and selection of desired traits by people (breed improvement).

Interactions and interdependencies- whether the interaction between people and the environment is intentional/unintentional; how weed floras developed and the different species controlled; the arrival of new pests and the spread of diseases.

Material cycles and energy/pure and impure substances – how people developed techniques for extracting and purifying metals over time, e.g. discovery and introduction of bronze and how this changed societies; lime production and use, e.g. as mortar in historic buildings; the introduction of iron and steel; glass manufacturing and working; and the nature of impurities and what they tell us about how the substance was made and where the original raw material came from.

Structure and function of living organisms – the study of skeletal remains can help to identify past diseases such as tuberculosis as well as inform debates about manual strength and common injuries; human influence such as increasing the weight of animals to produce more meat, domestication of animals, and to draw links between genetics and evolution.

Biological transport systems - dendrochronology and use of tree rings to date timber buildings. Additionally, the way wood is structured affects its transport systems and. water flow, which helps when looking at how and why historic buildings were structured in the way they were.

Use of non-invasive processes that minimise damage – non-destructive testing of the built environment is based on the interaction of waves and matter

"The topic of 'unexplored terrains' in the curriculum looks exciting, especially underwater terrains and increasing awareness of all the things we don't yet know or have the answers to."

Science stakeholder

Chemistry

Chemical analysis – Chemical analysis can be used to look at rates of decay and where that takes place. In environments that are waterlogged and where oxygen is lacking, chemical reactions are slowed down and preservation takes place. The preservation of bone on archaeological sites depends on the pH of the ground water in complex ways because the mineral component of the bone reacts differently to the protein component. Bone tends to survive best in moderately alkaline to neutral soils and rarely survives in acidic or highly alkaline soils. .

Chemical analysis can also enable analysis relating to structure, bonding properties and matter, for example reinforced concrete is alkaline and prevents steel reinforcement from corroding. If that alkalinity is lessened then chemical changes in the concrete can lead to corrosion, which can cause steel to expand and blow apart the concrete. In early ships, tree-nails held planks together but were subject to rot, whilst later iron nails corroded in sea-water.

Other examples of chemical analysis include spectroscopic techniques to identify the structure of materials, as well as the chemical composition of glass in as a means of dating window glass found in historic buildings. The properties of organic building materials such as timber, plasters with hair, oil based paints etc., can change if exposed to UV light and electro-magnetic waves.

Dye analysis is useful for understanding textiles and how they were made, i.e. there may be a correlation between types of dyes and rates of deterioration e.g. whether or not the dye is acidic.

Rate and extent of chemical change – this could look at carbon pollutants to chart the impact of the industrial revolution, or perhaps the use of lime-based cements. A challenge here would be joining up science and history curriculums.

Chemistry is also relevant in terms of using imaging methods and equipment for examining heritage assets; manufacture of materials such as crude oil and polymer production; and use of chemical isotopes, for example using infra-red techniques on ancient ceramics.

"Investigative techniques would fit well at Key Stage 3, especially if these are linked to the gathering of samples and the techniques used to analyse them (especially separation/ chromatography, qualitative/ quantitative tests)."

Science teacher

Physics

Atomic structure – useful in radio carbon dating and understanding the ways in which steel is forged into stronger forms.

Energy – a key focus here could be the impact of climate change on heritage assets and changes in energy production and use; water resources and how those were used; different forms of energy harvesting – e.g. wind and water (how grain was ground), charcoal production and use , coal, coal-gas, and so on; and use of steam power.

Forces - to understand moving loads, lifting loads, static loading, kinetic energy, and water flow; examination of crack patterns and their direction; the effects of meteorite impacts.

Microscopy – the use of imaging techniques and different types of photography to examine materials and biological remains.

Light and electromagnetic waves – this is a major component in a lot of analytical techniques used in heritage science and could include X rays, infra-red, and UV light studies; use of stained glass to teach refraction, reflection and transmission; how light causes fading and pigment alterations; the use of aerial photography and satellite images to identify heritage sites and a host of related issues such as farming, land erosion, ancient trackways, and burial grounds.

Magnetism and electromagnetism – this could involve looking at changes in the earth's magnetic field over time to date when materials were burned or forged; use of metal detectors; the history of electricity generation and development of the national grid; and how lodestones were used in early navigation.

Waves in matter – Use of transverse waves and compression waves (ultrasound) to uncover more without damage and investigate previously unexplored terrains (e.g. underwater); use of Light Detection and Ranging (Lidar) techniques to identify and detect archaeological sites; also the use of cosmic waves as a means of dating.

Other applications

Archaeology - heritage science includes carbon dating, isotope studies and chemical signature analysis. Other areas include remote sensing and geophysical surveying.

Surveying – the impact of light and electromagnetic waves is an important consideration when investigating both new and old buildings

The link with **arts and humanities and social sciences** is also considered important to understanding and tacking particular problems, such as the acoustics of buildings and understanding sound waves. Technical Art History is one example to understand the materials used and their influence. The cross-over with humanities is also important for making value judgments e.g. ethics in science, using scientific techniques responsibly and thinking of the consequences.

3.2 Examples of existing learning and teaching resources

A number of heritage and science sector bodies have conducted research projects and/or developed learning and teaching resources intended to bring heritage science to life for learners in schools. Prominent examples identified from desk research and interviews are set out below. These are not intended to be exhaustive and more detailed research would be needed to identify the extent of their take-up, nature of their use, and perceived value.

"Accessing resources depends on the teacher. There are lots of resources available online for teachers but those can be overwhelming and it's not all high quality."

Heritage stakeholder

The following Historic England resources could be classified as relating to Heritage Science and used in general terms with regard to 'scientific reasoning' but also possibly through looking at the processes required to create images:

- **Heritage Explorer website**[32] – this offers specially selected and captioned images as well as a range of ready-made teaching activities aimed at key stages 1 through to 5. All the resources are free and it can be accessed by any teacher (or indeed anyone) without the need to subscribe or register; At the time of writing, the Heritage Explorer content is being revised and updated to reflect curriculum changes. All content including, the database of images for education, is being migrated to the Historic England website where it will be available from September 2016.

- **Britain from Above**[33] – a collection of aerial photographs;

- **Local History Packs**[34] – a set of aerial photographs and old maps. They are primarily aimed at Key stages 2-3.

The **Association for Science Education (ASE)** has produced several films and accompanying education resources, such as PowerPoint packs, including teacher guidance and lesson activities. These include:

- **City 1250**[35] (about four children being sent to live in Baghdad in the year 1250);

- **Do you know why you'll never catch smallpox**[36] (which looks at the development of vaccinations);

- **Richard III and the isotope story**[37] (examining where he lived, his lifestyle and what he ate before and after he became King); and

[32]Available at: http://www.heritage-explorer.co.uk/web/he/default.aspx
[33]Available at: http://www.britainfromabove.org.uk/
[34]Available at: https://historicengland.org.uk/services-skills/education/heritage-education-resources/archive-education-resources/
[35]Available at: http://www.1001inventions.com/media/city1250
[36] Available at: https://www.ase.org.uk/news/ase-news/smallpox/
[37] Available at: http://www.schoolscience.co.uk/richardiii

- **1001 inventions and the library of secrets**[38] (a short film starring Sir Ben Kingsley exploring the scientific heritage of Muslim civilisation).

The ASE has also produced a series of resources and worksheets under the banner of 'Cultural Understanding'[39], which recognises how modern science has its roots in many different societies and cultures, drawing on a variety of valid approaches to scientific practice. In addition (and through a partnership with Digital Explorer), it has developed an interactive tour of the Coral Oceans, focusing on what it's like to be an Ocean Explorer to investigate particular science topics. This covers identification, classification, food webs and symbiosis, adaptation and human impacts on the environment. A further project being worked on by the ASE with the Open University and Field Studies Council involves using virtual reality technologies to explore their potential to enhance visits to the field. This approach could be used to scientifically explore a range of rural and urban situations.

The **National Trust** has undertaken work to look at the impact of climate change, light, temperature, moisture and mould on collections. This includes micro fading, whereby tiny parts of buildings are exposed to high intensity light to see how that leads to fading. This is important for the environmental control and management of collections.

Activities run by the **Institute of Conservation** during National Science Week involved bringing groups of children together to help them identify what types of products and materials will last the longest over time based on cultural value and materiality, for example a diamond necklace versus an iPad.

In Hull, the **Heritage Learning**[40] initiative is managed by a team of cultural and creative learning specialists. Together they manage and deliver all of the creative and cultural learning programmes across Hull's eleven museum, gallery and History Centre sites. Heritage Learning is an independent self-funded organisation operating on a not-for-profit basis. Examples of curriculum support aimed at key stage 3 learners include *Magnificent Women! – An Amy Johnson Workshop* (a hands-on practical workshop developed by the Women's Engineering Society designed to encourage students to work together in teams to solve a set of engineering problems). It also runs tours of the Da Vinci Engineered Exhibition, showcasing full scale recreations of Leonardo Da Vinci's flight and wind machines.

Heritage Learning Brighton & Hove[41] joins together organisations across the city to offer schools a comprehensive choice of experiences for their learners. At secondary science level these include:

- Skeletons – 1 hour, onsite or outreach: Why do animals have skeletons? What can we discover about animals by looking at their bones?

[38] Available at: http://www.1001inventions.com/media/video/library
[39] Available at: http://www.ase.org.uk/resources/cultural-understanding/
[40] Available at: http://www.heritage-learning.com/
[41] Available at: http://www.heritagelearningbrighton.org.uk/

- Adaptation and Survival – 1 hour, onsite or outreach: How do different animals adapt to their environment? How does camouflage help them?
- Mini-beasts – 1 hour, onsite or outreach: Can you tell an insect from an arachnid?
- Volk's Electric Railway: Tours include engineering workshops and sheds dating from 1900. Talks include the seafront, technology, history, the environment, solar power.

Journals aimed at science teachers (including European and international publications) appear to occasionally include articles relating to heritage science or cross-disciplinary connections between science and arts/humanities subjects. A notable example is *Science in School* – a European journal for science teachers, which included an article in 2009 titled 'The science of preserving art'[42].

Finally, a range of organisations either produce or signpost schools to online science teaching resources, such as the Education and Training Foundation, SEMTA and Hope Education. In addition, the table below lists examples of organisations that produce resources for which links to heritage science are immediately apparent.

Organisation/website	Coverage of heritage science
Resources published by individual Awarding Organisations, e.g. AQA: http://www.aqa.org.uk/subjects/science/ks3/ks3-science-syllabus/teaching-resources	• Activities relating to a 30,000 year old virus and whether it could wipe out the human race • Applying knowledge of climate change • Environmental factors such as *Ambrosia artemisiifolia* spreading across Europe which badly effects hay fever sufferers– pros & cons of using biological control to halt the invasion
Institute of Physics: http://www.iop.org/education/teacher/resources/ http://www.practicalphysics.org/	• Some links under 'additional resources' reference the British Geological Survey)
National STEM Learning Centre: https://www.stem.org.uk/elibrary/collection/2873/teaching-resources	• Feeding strategies and adaptations of polar bears • Using knowledge of materials and processes to explain and justify building techniques • Death of Angel: Analysing bloody splatters to check type of weapon used and whether time of death was accurate
Nuffield Foundation: http://www.nuffieldfoundation.org/teachers	• PowerPoints and activity worksheets looking at past climates and the effect it has had on tree growth, pollination and use data to estimate patterns of ocean currents • Food preservation, including establishing that decay is cause by microbes and that preservatives reduce microbe activity

[42] http://www.scienceinschool.org/2009/issue12/katylithgow

Royal Society: http://invigorate.royalsociety.org/	• Life's Hidden Order – grouping animals and plants and how they evolved • Diets 300 years ago – how the agricultural revolution increased the amount of food that could be grown. • Science past, present and future – ancient Greek temple and study of ancient artefacts • Poverty and disease in the 18th century
Royal Society of Biology: https://www.rsb.org.uk/index.php/education/teaching-resources/secondary-schools	• Biology changing the world – DNA and vaccination development over time • Evolutionary 'spot the difference' activity
Organisation/website	**Coverage of heritage science**
School Science: www.schoolscience.co.uk	• Chemical calculation – How plankton have shaped life on earth. How they contribute to the global carbon cycle and how rising sea temperatures are altering these creatures and the effect this has on the planet
Science and Plants for Schools: http://www.saps.org.uk/secondary	• Physical changes to plants and how they have evolved in different environments • Plant disease – identifying the cause of brown rot • Activity to take on the role of a pathologist to determine cause of a tree's death
Science Museum: http://www.sciencemuseum.org.uk/educators/classroom-resources	• Exploring the history of medicine, plagues, development of hospitals through time, causes and cures of disease, birth and death – impact and influence of Science & Technology
Science Teacher: www.thescienceteacher.co.uk	• Big ideas of science education – e.g. every object has an effect on another even from a distance. e.g. radiation from the sun causing currents in air and ocean thus affecting climates. • Organ systems and MRI
Teach It Science: http://www.teachitscience.co.uk/	• PowerPoints of tasks to guide students through the implications of extinction • Monitoring and protecting the environment • Dinosaur fossils and related activities to get students to think about the age and size
Web Anywhere: https://www.webanywhere.co.uk/education/teaching-resources/secondary/science	• Rainforest wildlife – facts & info about rainforest animals and people, and how conservation can reduce deforestation.

3.3 Considerations for developing future resources

"What Historic England should be doing is to look at what modules/concepts teachers find difficult or boring to teach and developing resources that animate those areas, thereby ensuring the teachers enjoy teaching and pupils enjoy learning."

Science stakeholder

"We try to put learning into real-world contexts so any link to learning science by solving a real world problem is very appealing. This is just as true at GCSE as it is at Key Stage 3."

Science teacher

Key considerations based on the views of stakeholders interviewed for the research:

- Resources need to allow for the fact the curriculum is already demanding, as it can be hard to fit in additional elements and schools are often pressed for time;
- Teachers would value online resources, PDFs, worksheets and lesson plans that are easy to access, relevant to the curriculum and engaging for learners;
- Online case studies would enable learners to delve deeper into particular subjects;
- Hands-on studies (i.e. involving fieldwork) that really bring science to life have the potential to be especially engaging, although visits may not be feasible at GCSE level, due to curriculum demands, missed lessons and supply cover implications;
- Videos are a good substitute for a visit to a location (supported by worksheets) and can act as a springboard into a written lesson. Again, if this has a problem-solving aspect then this can develop a number of 'How Science Works' ideas;
- Resources should involve real-world problem solving and interpretation, as well as promoting debate and discussion, including ethical issues;
- The global context is needed, i.e. using up-to-date scientific analysis tools to tackle modern issues that face everyone, e.g. diet and lifestyle, and how this is reflected in the human body;

- Ensuring relevance to learners and their own lives would be also help with engagement, such as looking at what learners eat and how that can be read through isotopes in their bones, which could in turn be compared with the bones of an old monk or fisherman for example;

- Heritage science could help particularly when working with lower ability learners where engagement with the subject is not as strong, i.e. to make science more interesting and contextual;

- Teachers are increasingly required to make links between the curriculum and the world of work, therefore job descriptions or person specifications for roles involving both heritage and science could be useful exemplars for classroom discussion;

- Resources should enable learners to think holistically, such as how systems work, through the angle of either biology, chemistry and physics;

- Focused teacher training modules would be useful, such as short films on how to produce a local heritage study;

- More use could be made of enthusiastic people working in the field to support curriculum delivery in schools, especially for teachers that don't have that specialist knowledge.

"It's unlikely that science teachers will be taking students to visit a historic building as they would miss other lessons and supply teachers would need to be factored in. It's a 'nice to have' for secondary age students. But that's not to say pupils couldn't study local historic buildings without leaving the classroom."

Science stakeholder

- Other specific examples of activities might include asking learners to identify examples of invasive and non-invasive processes to conserve heritage assets and justify their decisions; or using heritage science to become detectives for the day, such as how to go about identifying genuine versus fake/replica paintings;

- The **Space for Smarter Government Programme** offers a number of opportunities to develop greater use of satellite data for analysing information and understanding the different wavelengths of the electromagnetic spectrum

3.4 Key partners and potential collaboration opportunities

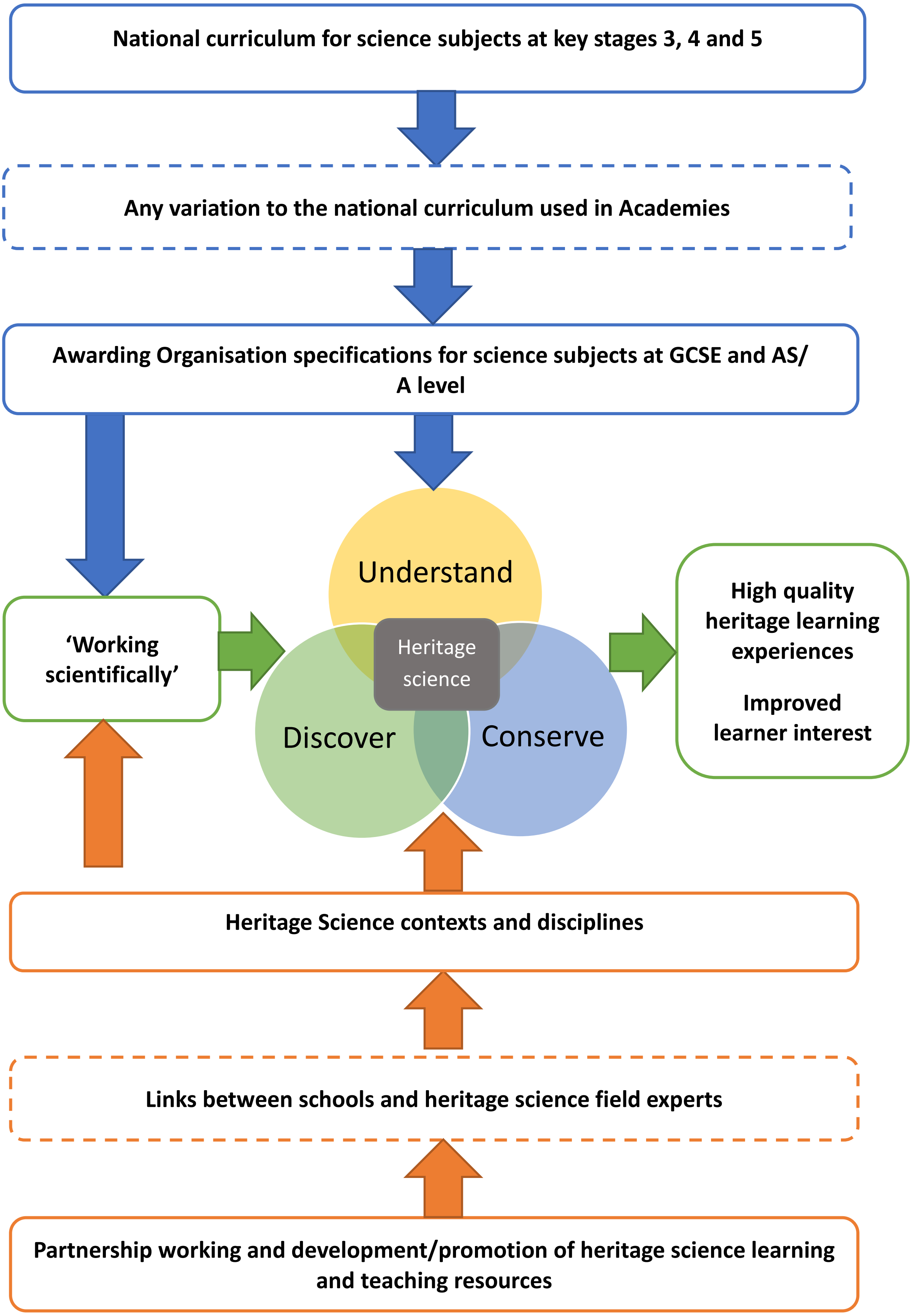
The **National Heritage Science Forum** provides a platform to support the policy, research and professional needs of institutions engaged in heritage science. It brings together many disciplines under the wide-ranging interdisciplinary heritage science umbrella and coordinates policy responses, ensures professional standards, and brokers contact with relevant sector bodies (e.g. between collections conservation and buildings conservation). This remit, supported by the knowledge and expertise of the Forum's Trustees, represents an opportunity for future discussions and coordinating next steps on the heritage science and school curriculum agenda.

The **Centre for Doctoral Training in Science and Engineering in Arts, Heritage and Archaeology (SEAHA)** was designed to respond to a real need for training of interdisciplinary scientists and engineers. The training programme has been co-developed with a number of partner institutions from the industrial, heritage, scientific, engineering and higher education sectors. Many partners are involved in SEAHA bodies such as the Steering Committee and the Advisory Board, to ensure that the Centre delivers the science and engineering that will make a real contribution to heritage organisations and industry. A key meeting point for knowledge sharing is the International SEAHA conference on Science and Engineering in Arts, Heritage and Archaeology (2nd conference took place in summer 2016). The focus of the conference is on heritage science research, innovation and best practice in the interpretation, conservation and management of cultural heritage.

Potential future collaborators on the subject of heritage science in the school curriculum (not intended to be exhaustive):

Association for Science Education	Institute of Physics (IOP)
Awarding organisations	Linnean Society
British Academy	Marine Biological Association
British Ecological Society	National Heritage Science Forum
Centre for Doctoral Training in Science and Engineering in Arts, Heritage and Archaeology (SEAHA)	National Museums (e.g. British Museum)
	National Science Learning Centre
Centre for Innovation and Research in Science Education (CIRSE)	Nautical Archaeology Society (NAS)
	Ofsted science advisers
Council for British Archaeology (CBA)	Open University
Earth Science Education Forum (ESEF)	Research Councils UK
Education and Training Foundation	Royal Society
English Heritage	Royal Society of Biology
Federation of Archaeological Managers and Employers (FAME)	Science Council
Field Studies Council	Society for the Protection of Ancient Buildings (SPAB)
Historic England	The National Trust
Chartered Institute for Archaeologists (CIfA)	The National Archives
Institute of Conservation (ICON)	Vernacular Architecture Group (VAS)
Institute of Historic Building Conservation (IHBC)	

3.5 Summary model – heritage science in schools



4. Conclusions and Recommendations

4.1 Conclusions

The opportunity for future heritage science learning and teaching resources

There is considerable opportunity for developing heritage science resources for the secondary school science curriculum and teachers value very highly materials and resources which engage pupils and support learning within the tight timescales they work in.

Work undertaken through this project to map heritage science concepts to curriculum topics reveals there are opportunities at all key stages (3 to 5) and across biology, chemistry and physics.

Stakeholders interviewed for the research are largely of the view that heritage science should enrich and contextualise the science curriculum rather than "add" to it. All of the concepts identified in section 2.4 and Appendix 1 represent viable opportunities for developing future resources since these broadly align with the content of the science curriculum.

Whilst this report has identified examples of existing heritage science learning and teaching resources aimed at schools, further research would be needed to determine the extent of their uptake, nature of use, and perceived value among teachers and learners alike. Whilst the environmental impact of climate change appears to be a common topic within existing science teaching resources, there is not enough evidence to say that any one area of heritage science is sufficiently catered for, that these resources are being actively used by schools, and that teachers are able to identify where they "fit" in relation to the science curriculum.

Engaging young people with heritage science

Aspects of heritage science related to 'discovery' are expected to be particularly interesting and exciting for learners, i.e. using science to discover something new about the past and what that means for the present. Other topics of interest and relevance would be those which dovetail with modern global issues, such as health and diets, as well as the effects of climate change on people and the environment.

Additionally, the application of scientific processes and techniques to organic and man-made materials can be used to provide answers to some of the big questions that learners would find fascinating, such as how civilisations evolved and their lifestyles.

Shaping future learning and teaching resources

Existing heritage science resources are produced by a number of different organisations and, as things stand, need to compete with other resources from which teachers can select, especially online. Furthermore, the uptake and future use of resources will depend on factors such as the level of individual teacher interest and curiosity, as well as the ease of use of those resources, and the degree to which they are clearly signposted to the science curriculum.

Taking these factors into account, it is important to think not only about what additional resources are needed, but what form they should take and how they can best be developed and promoted so they are seen as relevant, credible, exciting, cost and time effective. Collaborative approaches offer one way – albeit potentially difficult – of achieving more clarity and effectiveness in the resources available to teachers.

Raising awareness and improving partnership working

At present, levels of awareness about the main principles of heritage science appear limited among stakeholders outside the heritage sector, although prompting through this research has stimulated a great deal of interest, particularly among science sector specialists, teachers and awarding organisations. Heritage topics are incredibly extensive and offer a powerful way to enliven the school science curriculum by delivering very different contexts and case studies.

More could therefore be done to educate and inform teachers around the principles of heritage science and to capture their imagination as to the role science plays in shaping heritage assets and helping to answer important questions that are relevant to today's learners. Initial contacts show that teachers are all-too-willing to receive such information and assistance.

4.2 Recommendations

The following recommendations are for Historic England in association with strategic partners:

1. Engage more widely with teachers (such as through an online survey perhaps run on an annual basis), to test out which themes, topics and types of heritage science resources would be most interesting and valuable, what resources are already being used in schools, what works well and what could be improved;

2. Conduct research to further define the heritage science environment in relation to schools, identifying precise subject areas which are in greatest need of support and – specifically – identifying any ways in which Academies are diverging from the national curriculum and whether these offer additional opportunities to promote heritage science;

3. Offer suitable prizes (resources, visits, etc.) to teachers whose suggestions or ideas are taken up and delivered by Historic England/English Heritage;

4. Strengthen existing links between the types of organisations and bodies listed in section 3.4 and potentially set up a combined working group for the coordination of further research, new resource development, testing/piloting, and roll-out/promotion of resources to schools;

5. Consider prioritising the development of new resources on how heritage science can help learners discover something new about their relationship with the past and how that is relevant to contemporary life, such as lifestyle, immigration, health and diets, how societies lived and communicated (e.g. social networking in past civilisations) and topical issues such as environmental conservation/climate change.

6. Develop new resources in formats that are easily accessible for teachers at minimal cost to schools. Preferred options would be electronic packs comprising (for example) PDF case studies, short videos, PowerPoints, teacher guidance, exemplar questions and other support materials as appropriate. There is also enthusiasm for interactive materials such as touch screen and virtual reality tours although these would naturally be more expensive to develop. While site visits and external fieldwork would be valuable, these may be prohibitive at secondary school level due to competing demands, risk of missed lessons in other subjects and the need for supply teacher cover.

7. Consider developing a centralised online hub for publishing and sharing heritage science learning and teaching resources aimed at schools, searchable by key stage, subject and curriculum topic;

8. Develop a strategy for raising awareness and promoting future resources, for example targeting all schools or specific schools where heritage could bring science to life and stimulate the minds of learners. Promotion does not have to be through traditional (expensive) routes but could be based on public relations exercises beginning with a briefing to the press about a “new” programme to engage schools with heritage science and perhaps using prize or award systems to gain national and local publicity;

9. The raising awareness programme might also include partner networks, newsletters aimed at teachers, direct mailings to schools (e.g. Heads of Science) and/or at meetings and events attended by science stakeholders and schools. Consideration should also be given to developing a large panel of “ambassadors” – perhaps university staff or students – who could offer to visit schools to speak on heritage science topics;

10. Given the cross-disciplinary nature of heritage science, encourage cross-subject collaboration and knowledge sharing within schools, such as between teachers of science, mathematics, history and geography. Also encourage schools to make links with industry to support curriculum delivery, such as archaeological contractors, local authority conservation officers/historic environment record officers – especially where ‘education/outreach’ may be a key part of their job description.

Appendix: Mapping – Heritage Science and the Science Curriculum

The following pages present a summary of the national curriculum modules and components for the core science subjects, broadly mapped to heritage science themes. Each key stage and discrete subject is covered in turn, from key stage 3 (ages 11-14), key stage 4 (GCSE) and key stage 5 (AS and A level).

At AS and A level, Awarding Organisation (AO) specifications have been used in place of the national curriculum content. At this level the AO specifications focus more on activities and competences learners need to demonstrate which better supports the mapping process (whereas the national curriculum focuses more on knowledge and understanding.

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail

A1.1 Key stage 3

Key Stage 3 Biology				
Structure and function of living organisms	*The skeletal and muscular systems*		UNDERSTAND: The function of skeletons and how this has changed over time	Human activity can have an effect on skeletons, such as the impact of physical labour and breeding/selecting animals that produce more meat or milk
	Nutrition and digestion		UNDERSTAND: Human diet, resource exploitation and past environments	Analysis of what people ate addresses questions about: where they lived; the exploitation of wild resources; domestication and management of animals and plant resources; shifts in the organisation of food acquisition and provision; changes in individual wealth and status through diet; and the role of plants and animals in ceremonial activities
Interactions and interdependencies	*Relationships in an eco-system*		UNDERSTAND: Environmental conditions that were present at any given time and the effect of human activity in shaping and changing that environment	The scientific investigation of the remains of people, animals and plants, along with the environment in which they lived, tells us more about their lives and how they were influenced by and changed their environment
Genetics and evolution	*Inheritance, chromosomes, DNA and genes*		DISCOVER: DNA, to better comprehend heritage assets and remains, and the lives of people in the past, including diseases that they may have faced	Analysis of DNA can be used to identify sex, show familial relationships, investigate diffusion of the human race and subsequent population migration, and identify some pathogens such as tuberculosis

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
Key Stage 3 Chemistry				
Pure and impure substances	*Simple techniques for separating mixtures: filtration, evaporation, distillation and chromatography*		UNDERSTAND: Chromatography and other identification techniques to pinpoint elements and understand materials used	Chromatographic and mass spectrometric analysis of residues or amorphous organic materials can improve our understanding of those materials
Chemical reactions	*The pH scale for measuring acidity/alkalinity; and indicators*		UNDERSTAND and DISCOVER: Use of PH indicators to identify the acidity of materials	Chemical pollutants affecting movable heritage include acids generated by objects themselves, fuel combustion and even visitors
Energetics	*Energy changes and changes of state*		UNDERSTAND + CONSERVE: The effects of changes in energy procurement on heritage assets and how this can aid their long term conservation	Identify how low energy, low 'tech' methods of environmental management can improve the management of environments in the display, storage and curation of heritage materials
The Periodic Table	*The properties of metals and non-metals*		UNDERSTAND and DISCOVER: How things were made, the materials they were made from, and scientific analysis to provide information on the history of objects	Analysis of compounds, elements and isotopes can provide precise measurements of materials present and their composition. This can be used to understand the properties of materials and their preservation, for provenance studies, and to study composite objects, for example to identify for later additions
Materials	*The properties of ceramics, polymers and composites*	*Compare quantitatively the physical properties of glass and clay ceramics, polymers, composites and metals*	UNDERSTAND: material types, objects, and buildings, of cultural significance including their historical significance	Use of petrographic and chemical techniques can help to characterise archaeological ceramics and glass

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
Earth and atmosphere	*The carbon cycle*		UNDERSTAND: Carbon dating	Analysis of stable isotopes in bone can identify: • Levels of carbon and nitrogen, to provide information about the proportion of meat, fish and vegetables in a person's diet; • The variation between isotope values recorded from bones and teeth (oxygen, strontium and sulphur) can be compared with geological measurements of these isotopes to map population movement
	The production of carbon dioxide by human activity and the impact on climate		CONSERVE: How heritage assets interact with their environment, particularly in the case of changing environments through time, and using that knowledge to identify a suitable conservation strategy to preserve for the future	Pollution affecting the historic built environment has reduced due to a reduction in output of sulphur dioxide, but current urban pollutants (from ozone, nitrogen oxides and black crusts from diesel) are not well understood and management strategies are under-developed
	Earth as a source of limited resources and the efficacy of recycling		Sustainable/ precision farming	Chemical pollutants affect movable heritage assets and the built historic environment. These include by-products from domestic, industrial and automobile fuel combustion, acidic dissolution of calcareous building materials, sooting of buildings and corrosion of metals by road salting and coastal salt spray

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail

Key Stage 3 Physics				
Waves	*Observed waves*		DISCOVER: Sonar to investigate previously inaccessible areas	Offshore geophysical surveys (using acoustic and magnetic survey methods) routinely take place and include marine geophysics
	Sound waves		DISCOVER: scientific technique to explore previously inaccessible areas	
	Energy and waves	*Explain, in qualitative terms, how the differences in velocity, absorption and reflection between different types of waves in solids and liquids can be used both for detection and for exploration of structures which are hidden from direct observation, notably in our bodies, in the earth's core and in deep water*	DISCOVER: Use of electromagnetic radiation to explore and understand heritage assets, with minimal risk	Offshore geophysical surveys (using acoustic and magnetic survey methods) routinely take place and include marine geophysics
	Light waves		DISCOVER: use of electromagnetic radiation to explore and understand heritage assets, with minimal risk	Recent development of radar and infrared/thermal imaging provide a means of distinguishing contrasting building fabrics (identifying voids in walls, blocked doorways, identifying the effects of previous building alterations) and these techniques can reduce the need for intrusive and damaging interventions to building fabric

A1.2 Key stage 4 (GCSE)

GCSE Biology				
Transport systems	*Transport systems in plants*	*Explain the effect of a variety of environmental factors on the rate of water uptake by a plant, to include light intensity, air movement and temperature*	UNDERSTAND: Dating heritage assets using biological remains and natural products	Dendrochronology and analysis of use of tree rings can help to identify the climate and environment in which trees grew, as well as to date timber buildings
Health, disease and the development of medicines	*Health and disease*	*Describe different diseases, and identifying factors*	UNDERSTAND: People and the historic environment in which they lived, including cause of death	Analysis of human skeletal remains can provide information about the life, health and death of individuals and through demographic studies contribute to wider understanding of societies and societal change. Insight into diseases and trauma, such as tuberculosis, dental caries, rickets or occupational trauma, alongside epidemiology of contagious diseases such as the plague
	Communicable diseases	*Explain how communicable diseases (caused by viruses, bacteria, protists and fungi) are spread in animals and plants* *Describe different ways plant diseases can be detected and identified, in the lab and in the field*	DISCOVER: Human and plant remains, to build up an understanding of the historic environment	Visual and low powered microscopic examination of animal and plant remains from archaeological sites, along with identification and quantification of species, can help to understand human diet, resource exploitation and past environments. Can detect the presence of plant diseases in the past e.g. ergot, eel worm

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
Ecosystems	*The principal of material cycling*	*Explain the effects of factors such as temperature and water content on rate of decomposition in aerobic and anaerobic environments*	CONSERVE: The study of deterioration to inform future preservation decisions regarding heritage assets; also using this information for understand the previous nature of heritage assets and objects, and the extent of their degradation Preservation of waterlogged heritage e.g. Must Farm. What survives in different types of deposit	A lot of materials are made from animal products, leading to issues associated with mould growth and microbiological damage to heritage products
	Biodiversity	*Explain both positive and negative human interactions within ecosystems and explain their impact on biodiversity*	UNDERSTAND: The wider environment, to identify environmental conditions at any given time and the effect of human activity in shaping and changing that environment	The scientific investigation of the remains of people, animals and plants, and the environment in which they lived, tells us more about their lives and how they were influenced by and changed their environment
Inheritance, variation and evolution	*Variation and evolution*	*Describe evolution as a change in the inherited characteristics of a population over time through a process of natural selection which may result in the formation of new species*	CONSERVE: Past changes in climate and environments to help understand and adapt to current and future changes UNDERSTAND: Domestication of plants and animals. Development of plant and animal breeding	

Module	**Module component**	**Module component detail (where given)**	**Main heritage science link**	**Additional detail**
GCSE Chemistry				
Structure, bonding and the properties of matter	*Bulk and surface properties of matter including nanoparticles*	Uses of nanoparticles	CONSERVE: Use of nanoparticles to conserve heritage assets in order to protect them for future generations	Corrosion affects outdoor metal objects e.g. statues and can be slowed by applying coatings
Chemical changes	*Identification of common gases*	*Describe tests to identify selected gases including oxygen, hydrogen, carbon dioxide and chlorine*	UNDERSTAND: The physical environment around the heritage asset	To ensure that new display materials do not give off harmful gases these are usually subjected to a standard ('Oddy') test in advance of their use.
Organic chemistry	*Synthetic and naturally occurring polymers, including DNA*		DISCOVER: DNA, to better comprehend heritage assets and remains, and the lives of people in past including the diseases they suffered from	Analysis of DNA can be used to identify sex, show familial relationships, investigate diffusion of the human race and subsequent population migration, and identify some pathogens such as tuberculosis
Chemical analysis	*Assessing purity and separating mixtures*	*Interpret chromatograms, investigate purification techniques, filtration, crystallisation, simple distillation etc.*	UNDERSTAND: Chromatography and other identification techniques to pinpoint elements and understand materials used	Chromatographic and mass spectrometric analysis of residues or amorphous organic materials can improve our understanding of them

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
	Identification of ions by chemical and spectroscopic means	*Flame tests, instrumental methods of analysis*	UNDERSTAND: Instrumental methods of analysis to identify elements and understand materials used	Analysis of stable isotopes in bone: • Levels of carbon and nitrogen can provide information about the proportion of meat, fish and vegetables in a person's diet • The variation between isotope values recorded from bones and teeth (oxygen, strontium and sulphur) can be compared with different geologies to map population movement
Chemical and allied industries	*Using materials*	*Compare quantitatively the physical properties of glass and clay ceramics, polymers, composites and metals*	UNDERSTAND: material types, objects, and buildings, of cultural significance including their historical significance	Use of petrographic and chemical techniques can help to characterise archaeological ceramics and glass
		Describe the conditions which cause corrosion and the process of corrosion and explain how mitigation is achieved by creating a physical barrier to oxygen and water and by sacrificial protection	CONSERVE: How materials deteriorate, to identify suitable conservation strategies for heritage assets	Display of Heritage Iron, demography of collections
Earth and atmospheric science	*Carbon dioxide and methane as greenhouse gases*	*Describe the potential effects of increased levels of carbon dioxide and methane on the Earth's climate and how these effects may be mitigated, including consideration of scale, risk and environmental implications*	CONSERVE: How heritage assets interact with their environment, particularly in the case of changing environments through time, and using that knowledge to identify a suitable conservation strategy to preserve for the future	Chemical pollutants affect movable heritage assets and the built historic environment. These include by-products from domestic, industrial and automobile fuel combustion, acidic dissolution of calcareous building materials, sooting of buildings and corrosion of metals by road salting and coastal salt spray

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
	Common atmospheric pollutants and their sources	*Describe the major sources of carbon monoxide, sulphur dioxide, oxides of nitrogen and particulates in the atmosphere and explain the problems caused by increased amounts of these substances*		Pollution affecting the historic built environment has reduced due to a reduction in output of sulphur dioxide, but current urban pollutants (from ozone, nitrogen oxides and black crusts from diesel) are not well understood and management strategies are under-developed

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
GCSE Physics				
Energy	*Conservation, dissipation and national and global energy sources*		UNDERSTAND: The effects of climate change and the contemporary environment (humidity, temperature, air movement) on the historic environment, to understand the risks placed upon objects and sites	Physical impact on buildings includes inappropriate renovation and energy efficiency retrofitting which can damage the building fabric
Forces	*Forces and their interactions*		UNDERSTAND: Properties of materials used in heritage sites, including potential risks	Corrosion of steel reinforcement within concrete, iron cramps in traditional buildings or the internal iron or steel armatures of stone statues which causes the metal to expand, damaging the material fabric
Waves in matter	*Waves at material interfaces: applications in exploring structures*	*Explain, in qualitative terms, how the differences in velocity, absorption and reflection between different types of waves in solids and liquids can be used both for detection and for exploration of structures which are hidden from direct observation, notably in our bodies, in the earth's core and in deep water*	DISCOVER: Use of scientific techniques to explore previously inaccessible areas	Offshore geophysical surveys (using acoustic and magnetic survey methods) routinely takes place and includes marine geophysics

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
Light and electromagnetic waves	*Interactions of electromagnetic radiation with matter and their applications*	*Give examples of some practical uses of electromagnetic waves in the radio, micro-wave, infra-red, visible, ultra violet, X-ray and gamma-ray regions and describe how ultra violet waves, X-rays and gamma rays can have hazardous effects, notably on human bodily tissues*	DSCOVER: Use of visible and non-visible sections of the electromagnetic spectrum (such as radio, X-rays and other forms of imaging) to explore and understand heritage assets, with minimal risk CONSERVE: Micro-fading and effect of light and non-visible sections of the electromagnetic spectrum on heritage objects and assets, in order to improve their conservation in the future. CONSERVE: Investigative conservation artefacts	Recent development of radar and infrared/thermal imaging have provided for distinguishing contrasting building fabrics (identifying voids in walls, blocked doorways, identifying the effects of previous building alterations) and these techniques can reduce the need for intrusive and damaging interventions to building fabric Ultra Violet, Infrared, near infrared, multispectral and hyper spectral imaging techniques use different wavelengths of light to identify surface and subsurface differences in objects such as manuscripts and paintings. They also enable aerial reconnaissance of archaeological sites Micro fading involves exposing tiny parts of buildings to high intensity light to see the effects of fading. Perceptual change of colour is generally considered to be the acceptable point
Magnetism and electromagnetism	*Microphones and speakers; oscillating currents in detection and generation of radiation*	*Explain the action of the microphone in converting the pressure variations in sound waves into variations in current in electrical circuits, and the reverse effect as used in loudspeakers and headphones*	DISCOVER: Use of sound waves and lasers to explore structures such as caves	Detecting and imaging heritage assets is undertaken through onshore and offshore geophysical survey including sonar/acoustic survey methods

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
Atomic structure	*Absorption and emission of ionizing radiations and of electrons and nuclear particles*	*Recall that some nuclei are unstable and may emit alpha particles, beta particles or neutrons, and electromagnetic radiation as gamma rays; Radioactive decay; Recall the differences in the penetration properties of alpha-particles, beta particles and gamma-rays*	UNDERSTAND: Properties of materials used in the past h, including potential risks	Analysis of compounds, elements and isotopes can provide precise measurements of the materials present and their composition. This can be used: • to understand the properties of materials and their preservation; • for provenance studies; • to study composite objects to look for later additions
	Hazards and uses of radioactive emissions and of background radiation	*Describe the different uses of nuclear radiations*		Radiocarbon dating (c14) which can be used to date any carbon-based organic materials

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail

GCSE Combined Science				
Health, disease and the development of medicines	*Health and disease*	*Describe different diseases, and identifying factors*	UNDERSTAND: People and the historic environment in which they lived in- including cause of death	Analysis of human skeletal remains can provide information about the life, health and death of individuals and through demographic studies contribute to wider understanding of societies and societal change. Insight into diseases and trauma, such as tuberculosis, dental caries, rickets or occupational trauma, alongside the epidemiology of contagious diseases such as the plague
	Communicable diseases	*Explain how communicable diseases (caused by viruses, bacteria, protists and fungi) are spread in animals and plants* *Describe different ways plant diseases can be detected and identified, in the lab and in the field*	DISCOVER: Human and plant remains, to build up understanding of context and historic environment	Visual and low powered microscopic examination of animal and plant remains from archaeological sites and identification and quantification of species to understand human diet, resource exploitation and past environments. Can detect the presence of plant diseases in the past e.g. ergot, eel worm

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Ecosystems	*The principal of material cycling*	*Explain the effects of factors such as temperature and water content on rate of decomposition in aerobic and anaerobic environments*	CONSERVE: The study of degradation to inform future preservation decisions regarding heritage assets; also using this information to understand the previous nature of heritage assets and objects, and the extent of their degradation Preservation of waterlogged heritage e.g. Must Farm. What survives in different types of deposit	A lot of materials are made from animal products, leading to issues associated with mould growth and microbiological damage to heritage products
	Biodiversity	*Explain both positive and negative human interactions within ecosystems and explain their impact on biodiversity*	UNDERSTAND: The wider environment to identify environmental conditions at any given time and the effect of human activity in shaping and changing that environment	The scientific investigation of the remains of people themselves and the environment in which they lived tell us more about their lives and how people were influenced by and changed their environment Biodiversity is affected by trade and the introduction of new species. Designed landscapes involve the creation of new ecosystems
Inheritance, variation and evolution	*Variation and evolution*	*Describe evolution as a change in the inherited characteristics of a population over time through a process of natural selection which may result in the formation of new species*	CONSERVE: Past changes in climate and environments to help understand and adapt to current and future changes	
Chemical changes	*Identification of common gases*	*Describe tests to identify selected gases including oxygen, hydrogen, carbon dioxide and chlorine*	UNDERSTAND: The physical environment around the heritage asset	To ensure that new display materials do not give off harmful gases these are usually subjected to a standard ('Oddy') test in advance of their use

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
Chemical analysis	*Assessing purity and separating mixtures*	*Interpret chromatograms, investigate purification techniques, filtration, crystallisation, simple distillation etc.*	UNDERSTAND: Environmental conditions that affect material types, objects and buildings of cultural and historical significance UNDERSTAND: Chromatography and other identification techniques to pinpoint elements and understand materials used	Chromatographic and mass spectrometric analysis of residues or amorphous organic materials can improve our understanding of them
Earth and atmospheric science	*Carbon dioxide and methane as greenhouse gases*	*Describe the potential effects of increased levels of carbon dioxide and methane on the Earth's climate and how these effects may be mitigated, including consideration of scale, risk and environmental implications*	CONSERVE: How heritage assets interact with their environment, particularly in the case of changing environments through time, and using that knowledge to identify a suitable conservation strategy to preserve them for the future	Chemical pollutants affect movable heritage assets and the built historic environment. These include by-products from domestic, industrial and automobile fuel combustion, acidic dissolution of calcareous building materials, sooting of buildings and corrosion of metals by road salting and coastal salt spray
	Common atmospheric pollutants and their sources	*Describe the major sources of carbon monoxide, sulphur dioxide, oxides of nitrogen and particulates in the atmosphere and explain the problems caused by increased amounts of these substances*		Pollution affecting the historic built environment has reduced due to a reduction in output of sulphur dioxide, but current urban pollutants (from ozone, nitrogen oxides and black crusts from diesel) are not well understood and management strategies are under-developed.

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Energy	*Conservation, dissipation and national and global energy sources*		UNDERSTAND: The effects of climate change and the contemporary environment on the historic environment, to understand the risks placed upon objects and sites	Physical impact on buildings includes inappropriate renovation and energy efficiency retrofitting which can damage the building fabric
Forces	*Forces and their interactions*		UNDERSTAND: Properties of materials used in heritage sites and their structural relationships such as stresses, strains and loading, including potential risks	Corrosion of steel reinforcement within concrete, iron cramps in traditional buildings or the internal iron or steel armatures of stone statues which causes the metal to expand, damaging the material fabric

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
Light and electromagnetic waves	*Interactions of electromagnetic radiation with matter and their applications*	*Give examples of some practical uses of electromagnetic waves in the radio, micro-wave, infra-red, visible, ultra violet, X-ray and gamma-ray regions and describe how ultra violet waves, X-rays and gamma rays can have hazardous effects, notably on human bodily tissues*	DISCOVER: Use of electromagnetic radiation to explore and understand heritage assets, with minimal risk UNDERSTAND + CONSERVE: Micro-fading and the effect of light and non-visible sections of the electromagnetic spectrum on heritage objects and assets, in order to improve their conservation in the future.	Recent development of radar and infrared/thermal imaging have provided for distinguishing contrasting building fabrics (identifying voids in walls, blocked doorways, identifying the effects of previous building alterations) and these techniques can reduce the need for intrusive and damaging interventions to building fabric Ultra Violet, Infrared, near infrared, multispectral and hyper spectral imaging techniques use different wavelengths of light to identify surface and subsurface differences in objects such as manuscripts and paintings. They also enable aerial reconnaissance of archaeological sites Micro fading involves exposing tiny parts of buildings to high intensity light to see the effects of fading. Perceptual change of colour is generally considered to be the acceptable point
Atomic structure	*Absorption and emission of ionizing radiations and of electrons and nuclear particles*	*Recall that some nuclei are unstable and may emit alpha particles, beta particles or neutrons, and electromagnetic radiation as gamma rays; Radioactive decay; Recall the differences in the penetration properties of alpha-particles, beta particles and gamma-rays*	UNDERSTAND: Properties of materials used in heritage sites, including potential risks	Analysis of compounds, elements and isotopes can provide precise measurements of the materials present and their composition. This can be used: • to understand the properties of materials and its state of degradation; • for provenance studies; • to study composite objects to look for later additions

A1.3 Key stage 5 (AS and A level)

AS level Biology				
Foundations in biology	*Biological molecules*	*The chemical elements that make up biological molecules* *The key inorganic ions that are involved in biological processes* *Carrying out and interpreting biuret test for proteins, iodine test for starch, emulsion test for lipids*	UNDERSTAND: Human diet, resource exploitation and past environments	Residues (i.e. lipids) in pottery from animal fatty acids and plant leaf waxes can demonstrate what has been cooked in a pot, not just for immediate consumption, but, for example, the use of pots for processing foodstuffs such as milk-based products DNA and protein studies can identify species from skin/leather remains or the use of egg or glues as binders
		Quantitative methods to determine the concentration of a chemical substance in a solution	UNDERSTAND: Chromatography and other identification techniques to pinpoint elements and understand materials used	Chromatographic and mass spectrometric analysis of residues or amorphous organic materials: Spans food based fats, oils and waxes on pots used for cooking and storage; and other dyes, gums, resins, pitches, bitumen, polymers, used for example in clothing, cosmetics or burial rituals
		Principles and uses of paper and thin layer chromatography to separate biological molecules/compounds (including practical investigation)		

Module	**Module component**	**Module component detail (where given)**	**Main heritage science link**	**Additional detail**
	Nucleotides and nucleic acids	*The structure and nature of DNA*	UNDERSTAND: Human, animal and plant remains, in order to build up understanding of the historic environment	Modern DNA and protein research is rapidly evolving, driven by analytical developments notably in high throughput sequencing and bioinformatics Analysis of DNA which can be used to identify sex, show familial relationships, investigate diffusion of the human race and subsequent population migrations, as well as identify some pathogens such as tuberculosis
Biodiversity, evolution and disease	*Communicable diseases, disease prevention and the immune system*	*The different kinds of pathogen that can cause communicable diseases in plants and animals (bacteria causing tuberculosis, fungi etc.)*		Analysis of human skeletal remains can provide information about the life, health and death of individuals and through demographic studies contribute to wider understanding of societies and societal change. Insight into diseases and trauma, such as tuberculosis, dental caries, rickets or occupational trauma, alongside epidemiology of contagious diseases such as the plague Dutch elm disease and its effects, ergot infestation, potato famine

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
	Biodiversity	*The factors affecting biodiversity, to include human population growth, agriculture (monoculture) and climate change*	UNDERSTAND: The wider environment to identify environmental conditions at any given time and the effect of human activity in shaping and changing that environment UNDERSTAND: Human diet, resource exploitation and past environments	Analysis of what people ate addresses questions about: where they lived; the exploitation of wild resources; domestication and management of animals and plant resources; shifts in the organisation of food acquisition and provision; changes in individual wealth and status through diet; and the role of plants and animals in ceremonial activities
	Classification and evolution	*Different types of adaptions for organisms to their environment*	UNDERSTAND: The impact of changes in climate and environments	Past changes in climate and environments can help us to understand and adapt to current and future changes
		The mechanism by which natural selection can affect the characteristics of a population over time	UNDERSTAND: Process of domestication of plants and animals. Development of plant and animal breeding	Evolution of crop plants. Adaptation to new climates, interbreeding with wild populations, deliberate selection of desirable traits

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
A level Biology				
Foundations in Biology	*Cell structure*	*The use of microscopy to observe and investigate different types of cell and cell structure in a range of eukaryotic organisms*	DISCOVER: Visual and low powered microscopic examinations of animal and plant remains from archaeological sites to help identify and quantify species	Commonly microscopy techniques include optical, cross-sections, polarising light microscopy, ultraviolet fluorescence microscopy and SEM), X-radiography and instrumental analysis
		The use of staining in light microscopy, to identify different cellular components and cell types		
	Biological molecules	*The chemical elements that make up biological molecules*	UNDERSTAND: Human diet, resource exploitation and past environments	Residues (i.e. lipids) in pottery from animal fatty acids and plant leaf waxes can demonstrate what has been cooked in a pot, not just for immediate consumption, but, for example, the use of pots for processing foodstuffs such as milk-based products DNA and protein studies can identify species from skin/leather remains or the use of egg or glues as binders
		The key inorganic ions that are involved in biological processes		
		Carrying out and interpreting biuret test for proteins, iodine test for starch, emulsion test for lipids		
		Quantitative methods to determine the concentration of a chemical substance in a solution	UNDERSTAND: Chromatography and other identification techniques to pinpoint elements and understand materials used	Chromatographic and mass spectrometric analysis of residues or amorphous organic materials: Spans food based fats, oils and waxes on pots used for cooking and storage; and other dyes, gums, resins,

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
		Principles and uses of paper and thin layer chromatography to separate biological molecules/compounds (including practical investigation)		pitches, bitumen, polymers, used for example in clothing, cosmetics or burial rituals
	Nucleotides and nucleic acids	*The structure and nature of DNA*	UNDERSTAND: Human, animal and plant remains in order to build up understanding of the historic environment	Modern DNA and protein research is rapidly evolving, driven by analytical developments notably in high throughput sequencing and bioinformatics Analysis of DNA which can be used to identify sex, show familial relationships, investigate diffusion of the human race and subsequent population migrations, as well as identify some pathogens such as tuberculosis
Biodiversity, evolution and disease	*Communicable diseases, disease prevention and the immune system*	*The different kinds of pathogen that can cause communicable diseases in plants and animals (bacteria causing tuberculosis, fungi etc.)*		Analysis of human skeletal remains can provide information about the life, health and death of individuals and through demographic studies contribute to wider understanding of societies and societal change. Insight into diseases and trauma, such as tuberculosis, dental caries, rickets or occupational trauma, alongside epidemiology of contagious diseases such as the plague

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
	Biodiversity	*The factors affecting biodiversity, to include human population growth, agriculture (monoculture) and climate change*	UNDERSTAND: The wider environment to identify environmental conditions at any given time and the effect of human activity in shaping and changing that environment	Analysis of what people ate addresses questions about: where they lived; the exploitation of wild resources; domestication and management of animals and plant resources; shifts in the organisation of food acquisition and provision; changes in individual wealth and status through diet; and the role of plants and animals in ceremonial activities
	Classification and evolution	*Different types of adaptions of organisms to their environment*	UNDERSTAND: The impact of changes in climate and environment	Past changes in climate and environment can help us to understand and adapt to current and future changes. Development of arable weed floras
		The mechanism by which natural selection can affect the characteristics of a population over time	DISCOVER: Process of domestication of plants and animals. Development of plant and animal breeding	Adaptation to new climates, interbreeding with wild populations, deliberate selection of desirable traits
	Populations and sustainability		UNDERSTAND: The wider environment to identify environmental conditions at any given time and the effect of human activity in shaping and changing that environment	The scientific investigation of the remains of people themselves and the environment in which they lived tell us more about their lives and how people were influenced by and changed their environment

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail

AS level Chemistry				
Atomic Structure	*Mass number and isotopes*	*Mass spectrometry can be used to identify elements*	UNDERSTAND: Using techniques to pinpoint elements and understand materials used	Chromatographic and mass spectrometric analysis of residues or amorphous organic materials can improve our understanding of them
Analytical Techniques	*Mass spectrometry*			
	Infrared spectroscopy	*Bonds in a molecule absorb infrared radiation at characteristic wavenumbers*	DISCOVER: Use of electromagnetic radiation to explore and understand heritage assets, with minimal risk/damage	Recent developments of radar and infrared / thermal imaging have provided methods for distinguishing contrasting building fabrics Infrared imaging techniques use different wavelengths of light to identify surface and subsurface differences in objects such as manuscripts and paintings. They also enable aerial reconnaissance of archaeological sites

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail

A level Chemistry				
Unit 4	*Acids and bases*	*pH curves, titrations and indicators*	UNDERSTAND + CONSERVE: Acids, and being able to test for them, in order to inform conservation strategies for heritage assets	Chemical pollutants impacting movable heritage include acids generated by objects themselves, fuel combustion and even visitors
	Amino Acids	*Acid and base properties*	UNDERSTAND: Using instrumental methods of analysis to identify elements and understand materials used	Dating of single amino acids is currently being developed as a method to avoid issues of contamination, thus improving the accuracy of dating human bone
	Structure Determination	*Proteins*		Amino acid analysis of the Doomsday Book has helped to understand more of the making and the meaning of this manuscript as well as to determine its current condition DNA and protein studies can identify species from skin/leather remains or the use of egg or glues as binders
	Structure Determination	*Infrared spectroscopy*	UNDERSTAND: Environmental conditions that affect material types, objects and buildings of cultural and historical significance UNDERSTAND: Chromatography and other identification techniques to pinpoint elements and understand materials used	Chromatographic and mass spectrometric analysis of residues or amorphous organic materials can improve our understanding of them
		Nuclear magnetic resonance spectroscopy		Infrared imaging techniques use different wavelengths of light to identify surface and subsurface differences in objects such as manuscripts and paintings. They also enable aerial reconnaissance of archaeological sites

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
	Structure Determination	*Chromatography*		Chromatographic and mass spectrometric analysis of residues or amorphous organic materials can improve our understanding of them

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
AS Physics				
Materials	*Stress on an object*		UNDERSTAND: Properties of materials used in heritage sites and their structural relationships such as stresses, strains and loading, including potential risks	Corrosion of steel reinforcement within concrete, iron cramps in traditional buildings or the internal iron or steel armatures of stone statues which causes the metal to expand, damaging the material fabric
Waves and Particle Nature of Light	*Amplitude, frequency, period, speed and wavelength*		DISCOVER: scientific technique to explore previously inaccessible areas	Detecting and imaging heritage assets is undertaken through onshore and offshore geophysical survey including sonar/acoustic survey methods
	Intensity of radiation		UNDERSTAND + CONSERVE: Micro-fading and observing the effect of light on heritage objects and assets, in order to improve their conservation in the future	Micro fading involves exposing tiny parts of buildings to high intensity light to see the effects of fading. Perceptual change of colour is generally considered to be the acceptable point

Module	Module component	Module component detail (where given)	Main heritage science link	Additional detail
A level Physics				
Materials	*Force extension and force-compression graphs*		UNDERSTAND: Properties of materials used in heritage sites and their structural relationships such as stresses, strains and loading, including potential risks	Corrosion of steel reinforcement within concrete, iron cramps in traditional buildings or the internal iron or steel armatures of stone statues which causes the metal to expand, damaging the material fabric
Waves and Particle Nature of Light	*Intensity of radiation equation*		DISCOVER: Use of electromagnetic radiation to explore and understand heritage assets, with minimal risk CONSERVE: Micro-fading and observing the effect of light on heritage objects and assets	Recent development of radar and infrared/thermal imaging have provided for distinguishing contrasting building fabrics (identifying voids in walls, blocked doorways, identifying the effects of previous building alterations) and these techniques can reduce the need for intrusive and damaging interventions to building fabric Ultra Violet, Infrared, near infrared, multispectral and hyper spectral imaging techniques use different wavelengths of light to identify surface and subsurface differences in objects such as manuscripts and paintings. They also enable aerial reconnaissance of archaeological sites Micro fading involves exposing tiny parts of buildings to high intensity light to see the effects of fading. Perceptual change of colour is generally considered to be the acceptable point