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The most studied house in the world: 12 years of research-led teaching at Hellens Manor, England

Abstract

This article shows how field trips, driven by research-led teaching, can lead to innovation in heritage science and conservation. Drawing from a decade of field trips to Hellens Manor in Herefordshire in the UK, the study highlights several scientific innovations made by students during these visits in areas as diverse as the visualisation and prediction of temperature and relative humidity conditions, the use of portable X-ray fluorescence spectroscopy for mapping historical brick composition, and the application of urea crystallisation thresholds to quantify risks to collections near bat colonies. Additionally, the article showcases notable applications of established techniques, such as mapping glass composition and conducting in-situ imaging. The pedagogy of the field trip at Hellens Manor employs a two-phase process, firstly, defining specific research questions that are both feasible and scientifically interesting, with the potential to inform heritage management, and secondly, fostering creativity in problem-solving within the practical constraints of the trip. This educational model can provide practical experience of the skill of real-world decision-making, which is a gap previously identified in the literature. The findings show the benefits of prioritising accessibility to heritage collections, buildings and sites for educational purposes in a way that ultimately benefits their conservation alongside the fostering of collaborative relationships between educators and heritage site managers. Ultimately, the success of such research-led teaching hinges on aligning a passion for science with the needs and values of heritage.

Keywords
field trips; field work; preventive conservation; heritage science; education; historic houses

Introduction

Field trips are an essential element of education in heritage science and conservation. Learning through field trips can include many different overlapping definitions. Field trips, field work, hands on experience are all definitions of a type of teaching where students are exposed to a new environment, often on location, and provided with new problems and situations,[1] both on and off campus.[2] Field trips allow students to experience theory being put into context and practice.[3] In their study of graduate-level education in preventive conservation in North America, Catharine Hawks and colleagues noted that all the reviewed pedagogical programmes contained practical trips.[4] Field trips to museums and historic sites have been identified as necessary to communicate the practical complexity and the interdisciplinary nature of conservation projects.[5] Decades of research and experience have confirmed the benefits and the challenges of this educational method, with the benefits efficiently summed up by Alice and David Kolb who describe field trips as ‘a process of becoming a member of a community of practice through legitimate peripheral participation’,[6] using the concepts introduced in the seminal work by Jean Lave and Etienne Wenger on situated learning.[7]

1 Emma L. Peasland et al., ‘Student Employability Enhancement through Fieldwork: Purposefully Integrated or a Beneficial Side Effect?’, *Journal of Geography in Higher Education* 48, no. 4 (2023): 633–47.

2 Julie Peacock, Ruth Mewis, and Diedre Rooney, ‘The Use of Campus Based Field Teaching to Provide an Authentic Experience to All Students’, *Journal of Geography in Higher Education* 42, no. 4 (2018): 531–9, https://doi.org/10.1080/03098265.2018.1460805 (accessed 20 April 2025).

3 Ian Scott, Ian Fuller, and Steve Gaskin, ‘Life without Fieldwork: Some Lecturers’ Perceptions of Geography and Environmental Science Fieldwork’, *Journal of Geography in Higher Education* 30, no. 1 (2006): 161–71,

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Field trips also contribute to creating a strong sense of place. The connection the students feel with the site they have studied is resilient: evidence from repeated geoscience field trips shows that this attachment was unaffected by changing instructor or pedagogy, or even by inclement weather.[8] Field trips work best when they weave together problems of different scales, from small technical problems to interactions with a diversity of stakeholders.[9] Often this is achieved with collaborative problem-based activities such as teamwork.[10] The challenges of field trips are also well known, and clearly listed by Cathryn Rudmann, who identifies, among others: the need to define clear goals, the need to allow students sufficient opportunities to experience exploration and discovery, and the need to give due consideration to pre- and post-trip materials.[11] This modest list of pedagogical considerations has been echoed many times in more recent publications, but has rarely been surpassed in its clarity. From the perspective of studcent satisfaction, lectures or laboratory-based practicals are no substitute for the lived experience of problems and the application of skills in the field.[12] Field trips have been shown to contribute to social benefits and stronger relationships between students and staff.[13] Recently, debates have centred around the viability of virtual field trips, especially in connection to the COVID-19 pandemic. Most literature acknowledges that traditional field learning is here to stay, as it can still provide superior learning opportunities,[14] as well as increasing employability of students.[15]

The educational benefits of field trips are clear. However, less has been written about their additional impacts, such as the benefits to stakeholders and the generation of new knowledge. In a framework of research-led teaching, it is only natural that pedagogical activities can generate new knowledge.[16] Furthermore, if a teaching activity occurs in the context of a site visit, it is also to be expected that outcomes will become useful to stakeholders connected to that site. In the case of heritage sites and museums, this can include outcomes related to interpretation, management and conservation of the site or collections. The pedagogical benefits of field trips are frequently evaluated with focus groups and surveys of students.[17]

While field trips have been recognised as a highly valuable teaching tool in heritage science and conservation, they have not been explored in great depth in the literature. This article describes the pedagogical approach to teaching at Hellens Manor in Herefordshire in the UK and demonstrates how the practical constraints of a real-world case study foster both skilled heritage scientists and innovative research. The number of authors contributing to this article is evidence of the volume of work undertaken over the 12 years of trips to Hellens. By showcasing the research outcomes of this approach, it becomes possible to assess its success both scientifically and pedagogically.

Conducting effective heritage science, whether focussed on preventative conservation, collection care, managing or preventing damage to cultural materials—or other of the many applications of science in heritage—requires a clear understanding of technical systems as well as institutional goals and collaborative decision-making.[18] The diverse needs of heritage spaces and objects call for different approaches and strategies.

In heritage management and conservation, multiple objectives often take precedence over simply maximising the lifespan of an object or building. Depending on the context and specific needs of the heritage site, goals may vary and can frequently encompass education, outreach and public engagement. As a result, the aims, methods and tools used in studies will differ, and lead to different results.[19] Developing the ability to select appropriate technologies and strategies for a given heritage inter-

https://www.tandfonline.com/doi/abs/10.1080/03098260500499832 (accessed 13 April 2025); Sladana Anđelković, Vojislav Dedjanski, and Biljana Pejic, 'Pedagogical Benefits of Fieldwork of the Students at the Faculty of Geography in the Light of the Bologna Process', *Journal of Geography in Higher Education* 42, no. 1 (2018): 110–25.

4 Catharine A. Hawks, Bruno P. Pouliot, and Stephen L. Williams, 'North American Graduate-level Education in Preventive Conservation', *Collections* 2, no. 2 (2005): 95–116.

5 Luc Schueremans and Koenraad Van Balen, 'Forms and Methods of Education in the Field of Heritage Conservation at KULeuven', *Transylvania Nostra Journal* 4, no. 12 (2009): 3–8.

6 Jean Lave and Etienne Wenger, *Situated Learning: Legitimate Peripheral Participation* (Cambridge: Cambridge University Press, 1991).

7 Alison Rae Jolley, 'Student Experience and Sense of Place on Geoscience Field Trips' (unpublished PhD thesis, University of Canterbury, New Zealand, 2017).

8 Anthony Samuel et al., 'Experiencing the Macromarketing Dimensions of Sustainability: Lessons Learned from Field Trips to the Ultra Novel', *Journal of Marketing Education* 44, no. 3 (2022): 322–36.

9 Brendon Munge, Glyn Thomas, and Deborah Heck, 'Outdoor Fieldwork in Higher Education: Learning from Multidisciplinary Experience', *Journal of Experiential Education* 41, no. 1 (2017): 39–53, https://doi.org/10.1177/1053825917742165 (accessed 20 April 2025).

10 Jabari Jones and Susan Washko, 'More Than Fun in the Sun: The Pedagogy of Field Trips Improves Student Learning in Higher Education', *Journal of Geoscience Education* (2021): 1–14.

11 Cathryn L. Rudmann, 'A Review of the Use and Implementation of Science Field Trips', *School Science and Mathematics* 94, no. 3 (1994): 138–41.

12 Graham W. Scott et al., 'The Value of Fieldwork in Life and Environmental Sciences in the Context of Higher Education: A Case Study in Learning About Biodiversity', *Journal of Science Education and Technology* 21, no. 1 (2012): 11–21, http://www.jstor.org/stable/41413281 (accessed 13 April 2025).

vention or management scenario is a skill that requires both proper training and direct experience with these challenges.[20]

Hannelore Roemich identified that the main challenge for training in preventative conservation is to teach students the decision-making process and the application of technical tools to meet these complex demands for selecting sustainable choices in collection care. The importance of practical understanding in heritage science is evident in recent literature, which identifies the most absent skill among preventive conservation specialists as the ability to 'identify priorities and determine when to make compromises'.[21] The field work taught and undertaken at Hellens Manor over the last 10 years has focussed on building this skill, fulfilling the needs of modern heritage management and preventative conservation that recognised management must be practical and incorporate systems approaches.[22]

This model of teaching at Hellens is an example of how good preventative conservation practice can go hand-in-hand with increased accessibility to a collection. The longevity of Hellens field work has created long-term relationships which are in themselves practical solutions to the management of Hellens. This article has two objectives: firstly, it demonstrates by example how heritage science field work can be structured to combine pedagogical and real-world impacts; secondly, it shares a diversity of innovations that have emerged from the intellectual work of students during repeated field trips throughout the 12 years from 2012 to 2024. These innovations cover a wide range of activities, from new data visualisations, novel research methods and new uses of analytical equipment, to scientifically interesting case studies and the identification of different research gaps. Arguably the work at Hellens has fostered a sustainable community where a dynamic environment replete with conservation challenges has created a rich pedagogical setting where novel solutions have been developed, skills refined and knowledge actively generated.

The article is structured in four sections, which cover selected significant outcomes focussing on materials, the environment, imaging and the natural heritage aspects of the building. Each section is divided into three subsections, describing key projects, outlining the benefits and impacts from the outcomes of student work, and highlighting any innovations, particularly in heritage science. Lastly the article outlines how the novelties of these projects has engaged students directly in the field and provided unique opportunities and insights into the management of heritage science projects. This has arguably developed graduate understanding of how to undertake impactful science.

Methods: the heritage science field trip

1 The site and its conservation

Hellens Manor, located in Much Marcle, Herefordshire, UK, is an example of living heritage; a historic home, which is lived in and seasonally opened to the public, while hosting a series of cultural events. Hellens Manor is managed by the Pennington-Mellor Munthe Charitable Trust, which seeks to protect and maintain in perpetuity Hellens Manor and 'make the house available for educational and cultural activities to the local communities'. For example, tours run twice-weekly for visitors to view its 'wealth of period furnishings, artefacts, paintings and decorations'.[23]

The heritage of Hellens Manor exists to be enjoyed, its intangible heritage as important as the tangible collections. The fireplaces are lit, the historic furniture is used, the musical instruments are played, and the collection of art furnishes rooms that host public and private activities. As such, the conservation strategy for the house and its collections is defined

13 Peasland et al., 'Student Employability Enhancement through Fieldwork'.

14 Douglas J. McCauley, 'Digital Nature: Are Field Trips a Thing of the Past?', *Science* 358, no. 6361 (2017): 298–300.

15 Peasland et al., 'Student Employability Enhancement through Fieldwork'.

16 Tony Harland, 'Teaching to Enhance Research', *Higher Education Research & Development* 35, no. 3 (2016): 461–72.

17 Ian C. Fuller, 'What is the Value of Fieldwork? Answers from New Zealand Using Two Contrasting Undergraduate Physical Geography Field Trips', *New Zealand Geographer* 62, no. 3 (2006): 215–20.

18 Ellen Pearlstein, 'Teaching Sustainable Collection Care', *Journal of the American Institute for Conservation* 56, no. 2 (2017): 113–25, https://www.tandfonline.com/doi/full/10.1080/01971360.2016.1217726 (accessed 13 April 2025).

19 Joelle D. Wickens, 'Preventive Conservation: Continuously Defining Itself at the Crossroads of Theory and Practice', *Journal of the American Institute for Conservation* (July 2024), https://doi.org/10.1080/01971360.2024.2348924 (accessed 13 April 2025).

20 Cristiana Achille and Fausta Fiorillo, 'Teaching and Learning of Cultural Heritage: Engaging Education, Professional Training, and Experimental Activities', *Heritage* 5, no. 3 (2015): 2565–93, https://doi.org/10.3390/heritage5030134 (accessed 13 April 2025).

21 Hannelore Roemich, 'Teaching Preventive Conservation: Preparing Conservators for Understanding Sustainable Choices in Collection Care' (paper presented at the 42nd AIC Annual Meeting Conscientious Conservation: Sustainable Choices in Collection Care, San Francisco, 2014), https://ifa.nyu.edu/people/faculty/Roemich_PDFs/2010_Roemich_Weintraub_teaching_preventive_conservation.pdf (accessed 13 April 2025).

22 Mary Coughlin et al., 'Teaching Preventive Conservation: Interdisciplinary Origins and Evolution', *Journal of the American Institute for Conservation* (March 2025), https://www.tandfonline.com/doi/abs/10.1080/

by a high level of accessibility. Fires are lit under a Gainsborough painting, eighteenth-century chinaware is used on special occasions, and carpets are worn out and repaired. The uniqueness of Hellens Manor resides in its willingness to let life and heritage coexist; many Historic House Association sites aspire to this coexistence, but Hellens exemplifies it to a remarkable degree. This is the main lesson that all students who visit the house must learn: any proposed improvement in the conservation of the house needs to be carefully balanced with its values. In practice, this means that the most desirable interventions are the ones that do not sacrifice access to heritage. The difficulty in finding this compromise has fuelled the innovations made by students during the decade of experimentation described in this article.

01971360.2024.2437593 (accessed 13 April 2025).

23 Pennington Mellor Munthe Charity Trust, 'Hellens House & Gardens', http://www.hellensmanor.com/hellens-house—gardens.html (accessed 13 April 2025).

Hellens Manor is living proof that when heritage is enjoyed, it is also long lived. The house has origins in the thirteenth century, but is primarily comprised of Tudor, Jacobean and Georgian architecture.[24] The oldest remaining fabric, dating back to the thirteenth and fourteenth centuries, is a stone plinth in the northern part of the building. The outer envelope of the manor is built almost entirely in brick, save for occasional wooden window frames, a tiled roof and the Stone Hall, probably dating to the 1380s. Elsewhere the manor has experienced widespread modifications, additions and renovations throughout the centuries, their timing reflecting the waxing and waning economic power and fortunes of the various families who have lived there. The history of the building and its conservation is extensive and below is an outline of those elements focussed on in this article.

24 Historic England, 'HELLENS, Much Marcle—1099048', National Heritage List for England, https://historicengland.org.uk/listing/the-list/list-entry/1099048 (accessed 13 April 2025).

(1) The bricks reveal a long history of construction and modification. The tower is dated to 1450, a period which saw major expansion; the Tudor Kitchen was added between 1450 and 1500.[25] The first half of the seventeenth century saw a further expansion to the east, with a flurry of building works centred around a new stair hall more or less resulting in the present day appearance of the manor (Fig. 1(b)). The 1950s saw the most recent phase of expansion with a Picture Gallery built to join the Stone Hall and the Georgian Stables, closing the main courtyard.
(2) The house contains a variety of windows of historic importance. The wooden window frames, including the garden door leading out of the White Dining Room, were added in 1812. The courtyard created in the 1950s had been the site of a Second World War bomb impact which likely damaged the bricks and glass in the surrounding windows.
(3) The paintings at Hellens are distinguished for representing diverse collections, mainly from the Wharton Collection, spanning from the sixteenth to the nineteenth centuries. Noteworthy artworks include paintings by Van Dyck, Gainsborough and Goya, along with miniatures by Nicholas Hilliard and Samuel Cooper.[26] The collection of British miniature portraits stands as a unique global reference. Of particular interest is the painted ceiling, contributing to the house's historical narrative, crafted by a resident in the mid-twentieth century.
(4) The carriage shed, sited to the south-west of the main house, contains a historic carriage collection comprising a nineteenth-century wagonette sporting carriage, a 'Victoria' carriage from the 1870s, and a Victorian-era enclosed coach richly decorated with painted leather and a silk, wool and ivory interior. The carriage collection has been rarely used since the Second World War.
(5) Hellens has a collection of metal objects closely linked to the history of the house, encompassing a diverse range of artefacts that extends from a medieval armoury, British coronet, and heirlooms which in the house traditions are associated with Anne Boleyn.

25 Malcom Munthe, *Hellens: The Story of a Herefordshire Manor* (London: Duckworth/Pennington Mellor Trust, 1991).

26 Munthe, *Hellens*, 17.

Fig. 1 (a) A student taking a measurement with a portable XRF in the Stone Hall; (b) the house and its gardens; (c) two students measuring the moisture content of a wooden panelling; and (d) a group of students discussing results with the house manager.

Hellens is a clear example of the conundrum that lies at the heart of conservation and heritage science. Hellens is heritage that is used and enjoyed but this use and enjoyment is likely to reduce the long-term lifetime of its heritage. However, it is only through this use that the heritage is valued and the desire to conserve and care for it and its contents is generated. As such, heritage management has to balance both use and enjoyment against those procedures estimated to best preserve the same heritage for future generations. Thus the aim of heritage management and conservation is not to extend lifetimes without justified cause—so not just locking objects or buildings away forever to minimise risk—but rather to align with the values of the owners, custodians and the public, weighing the needs and means of the present generation against those assumed in the future. A considerable amount of work in the heritage sector is about communicating value to decision-makers while understanding their values, and the setup inculcated in the Hellens field trips allows this practical skillset to be taught and understood by students firsthand.

2 The field work and its pedagogy

The Hellens' field trip is an annual educational activity engaging 5–20 students over a 1–2-week period (see structure in Table 1). The work conducted is student-led, with students defining their work while also accounting for a number of pragmatic factors. Firstly, the students must make sure their scientific project is relevant and useful for solving the problems of the historic house. This does not limit student activities nor the scope of their

Table 1 Structure of the educational activity, with activities before, during and after the fieldtrips.

	Time	Task	Learning objectives	Output
Pre-trip	1 week before	Studying past data and reports	Summarising past research and understanding the background of the site	
	1 day before	Presentation from last year's students Logistics	Understanding the practical limitations of field research, selecting and preparing equipment	A list of equipment
Trip	First day	Tour and meeting with house manager	Understanding the priorities of stakeholders	Oral communications of the priorities of management
	Days 2–9	Identification of research questions Division of roles Identification of main tasks Data collection Data interpretation	Working as a team Formulating a hypothesis Planning research under real-world constraints Time management Planning and deploying a monitoring campaign Finding value in complex data, discarding what doesn't count	Complex datasets
	Last day	Presentation to the house staff Deployment of sensors for next year's projects	Translate research into impact Consider the interests of the audience	A group presentation
Post-trip	1 day after	Presentation to peers and academics	Review	Students receive formative feedback
	Following months	Reporting	Technical communication, including how to write an Executive Summary and how to translate complex research into actionable advice	A group report Occasionally, a blog post

learning but rather it makes collaboration and compromise—skills needed for anyone working in practical science—part of their activities rather than separate from them. Student projects are also shaped by the equipment available, the specific materials involved in the problem and the amount of time available. Furthermore, the projects are shaped by the conclusions and outputs of previous trips. Altogether, these factors shape each project while creating a sense of ownership around the science and its practical applications.

The pedagogical approach to the field trips to Hellens Manor is shown in Fig. 2. Student projects begin with a broad scope. Prior to any data collection and practical work commencing, a review of existing data such as reports, datasets, presentations and any historical information occurs approximately 1 week before the trip in order to familiarise students with previous work and stimulate curiosity. Students are prompted to select areas of interest to best leverage their skills, interests and any expertise within time and research constraints. A check and inventory of any available analytical equipment is also conducted.

Once at Hellens students have some time to explore the historic house and attend a detailed historic tour with the property manager. This is followed by a conversation on the priorities and interests of those who care for the property, including any issues around management, conservation and interpretation. This initial phase determines the objectives for the week and is represented by the filter of constraints in Fig. 2. Subsequently, clear research questions are set with the aid and mediation of both lecturers and Hellens Manor's management team. Small-group work focusses on analysing and contextualising data from the previous year's projects, as well as planning experiments and interviews, collecting new data, conducting desk-based research, and interpreting the collected data. This approach has an important element of legitimate peripheral participation, i.e. the educational process where students gradually move from observing and participating in authentic tasks to more complex and independent contributions, integrating themselves into the community of practice through progressively responsible roles.[27]

The week fosters team building alongside independent work. The culmination of the field trip involves a formal presentation to manor staff, focussing recommendations. This is critical in the student understanding of effective projects as written plans for preservation and conservation may not be read or fully understood by stakeholders, the ability to succinctly convey and summarise management plans is a critical skill successful preservation advocates need.[28] On the last day, any new data collection and monitoring necessary for the following year is set up. A presentation to colleagues and the house staff follows, which is used to receive formative feedback on the report quality. This forms the project outcomes in Fig. 2 and these are used in future projects and by stakeholders. Finally, 1 year later, previous students typically present their progress to the new cohort of students. In such a process the outcomes are slowly disseminated, and feed back into the set up of further projects in the future while practically constraining and focussing further work. This cycle is still ongoing.

27 Cf. Lave and Wenger, *Situated Learning*, 29.

28 Coughlin et al., 'Teaching Preventive Conservation'.

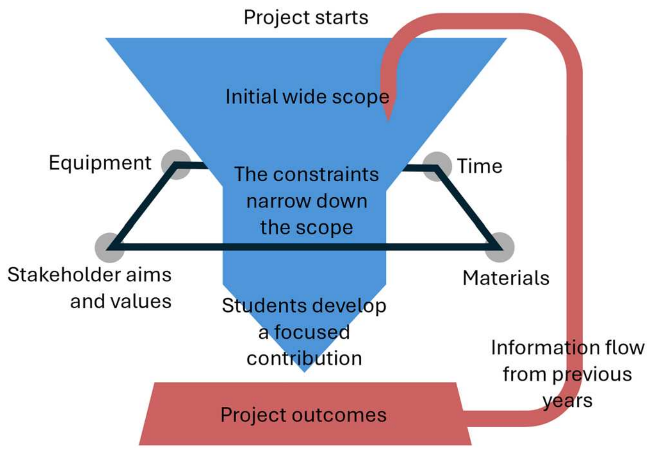

Fig. 2 The constraints of the field work experience: the available equipment and materials, time, and stakeholder aims and values act as a filter that narrows down the scope of the project. Students navigate this process interacting with experts. The outcomes of one year become part of the initial scope of the next projects.

3 Equipment, materials and methods

One of the learning objectives is for students to be able to select suitable equipment to take to Hellens and develop appropriate experimental methods. Because they need to understand that a significant volume of data does not automatically ensure high-quality answers, choosing the correct equipment and learning to construct feasible projects is a skill that allows students to think about different applications and outcomes achievable in scientific projects. As such, the approach taken in the field trips is to have more equipment than strictly necessary, presenting students with the challenge of selecting the tools necessary to help answer their research questions. To date this has therefore included equipment to monitor temperature, humidity, gaseous pollutants, particulate matter, salt crystallisation and other agents of deterioration, as well as tools for object examination such as a compound and 3D microscopes, ground-penetrating radar, optical profilometry, infrared spectrometry, and equipment to generate high-quality images, including thermal, infrared reflectography, multispectral and hyperspectral imaging, in addition to photographic cameras. A Zoom H4n field recorder, Soundman OKM II binaural microphones and a student-built hydrophone have also been used for ambient sound monitoring and recording.

Environment

In the pedagogical approach, students take on the role of environmental advisors, engaging as experts in dialogue with other experts: the house managers, conservators and other staff. They must not only understand the environment but also the practical constraints of managing it. For example, they must evaluate which environmental changes are feasible in practice and determine what compromises with other values, such as access, that the Hellens management team can negotiate.

1 Projects: the palace of humidity

The first project carried out in Hellens Manor in 2012 focussed on the indoor environment. The first cohort of students quickly concluded—after appropriate monitoring and a risk assessment—that relative humidity (RH) is a key agent of deterioration to consider at the manor. All the following projects have referred to or expanded on this initial work. Hellens Manor, like many historic houses of its age, is a porous environment that responds to the external climate. The house receives moisture from all conceivable sources, from the ground, through the old floors, from the air, through leaky fittings, from rain, through the roof and walls, and from its inhabitants, who breathe, cook and enjoy the house. It is, in short, in permanent flux, a wet house between the wet land and wet air. Moisture cannot be avoided and it is as integral to the fabric as is (and in) its bricks and mortar. Early investigations on the effectiveness of introducing scaled approaches to dehumidification showed marginal if any reductions in RH levels and indoor-to-outdoor moisture content ratios. Therefore, the task of the students was not to plan to achieve dryness, but to understand and manage wetness.

To that end, the first group to study the house installed temperature (T) and humidity loggers in 11 rooms, which have been kept in operation ever since then. Each year the students have downloaded the data collected by their colleagues and replaced the loggers with freshly calibrated ones. The loggers measure every hour, which has resulted in close to a million datapoints. This dataset has been the basis of several group projects and the source of insights on all the conservation problems linked to humidity, such as mould, pests, corrosion, hydrolysis or dimensional change. These analyses are too numerous to be detailed in full and the article will continue by detailing some significant examples, where the work of students has been either innovative within heritage science or useful to the preventive conservation management of the house.

2 Advice: small changes that make a big difference

One of the most valuable observations enabled by the T and RH dataset has been an assessment of the benefits of heating. Central heating was introduced in 2014, 2 years after monitoring began. Table 2 illustrates how the conditions have changed before and after the introduction of the heating in a specific room which holds a collection of valuable miniature paintings. The quality of the environment is evaluated using the percentage of time where the values of T and RH are within the risk zones of different damage processes such as mould growth or metal corrosion. The table also includes the percentage of time where the environment becomes a hazard to the collection. This is identified as periods of time where the temperature change required to drive RH to the risk area is less than the difference between the internal and the external temperature. In other

Table 2 Change in environmental risks to the collection before and after Central Heating (CH). The table shows the % of days in a year where the conditions are favourable to certain degradation processes.

Mechanism	Outdoor frequency	Indoor frequency: Before CH Occur	Indoor frequency: Before CH At risk	Indoor frequency: After CH Occur	Indoor frequency: After CH At risk	Criteria
Mould growth	46%	0%	68%	0%	26%	After Viitanen et al.[a]
Mould germination	57%	1%	82%	0%	63%	After Sedlbauer[b]
Corrosion	96%	68%	54%	31%	58%	Essentially inhibited unless RH > 60%[c]
Warping/physical stress of ivory	89%	27%	0%	0%	0%	−2% to 1% dimensional changes from 50% RH reference if yield point = 0.005. After Mecklenburg[d] and Lafontaine and Wood[e]
Crizzling	0%	0%	0%	0%	0%	Conditions at which 64% of historic glass samples exhibited crizzling[f]

Notes: [a] Hannu Viitanen et al., 'Modeling Mould Growth and Decay Damages', in *Proceedings of Healthy Buildings* 3 (2000): 341–6.
[b]Klaus Sedlbauer, 'Prediction of Mould Growth by Hygrothermal Calculation', *Journal of Thermal Envelope and Building Science* 25, no. 4 (2002): 321–36.
[c]Stuart Lyon, *Guides to Good Practice in Corrosion Control No. 12: Atmospheric Corrosion* (Teddington, UK: National Physical Laboratory, 2020).
[d]Marion F. Mecklenburg, 'Determining the Acceptable Ranges of Relative Humidity and Temperature in Museums and Galleries, Part 1, Structural Response to Relative Humidity' (unpublished report Smithsonian Museum Conservation Institute, 2009), http://www.si.edu/mci/downloads/reports/Mecklenburg-Part1-RH.pdf (accessed 20 April 2025).
[e]Raymond H. Lafontaine and Patricia A. Wood, 'The Stabilization of Ivory against Relative Humidity Fluctuations', *Studies in Conservation* 27, no. 3 (1982): 109–17.
[f]Robert H. Brill, 'Crizzling—A Problem in Glass Conservation', in *Conservation in Archaeology and the Applied Arts, Stockholm Congress* (1975), 121–34, https://doi.org/10.1179/sic.1975.s1.021 (accessed 21 April 2025).

words, a collection is 'at risk' at times when an accidental increase of ventilation, such as opening a window, could easily worsen the quality of the environment in this case, by decreasing the temperature and consequently increasing the relative humidity. The benefits of heating are clear: all the metrics used for assessment show an improvement.

The empirical confirmation of the benefits of heating had other, more subtle effects as before Hellens Manor was considered a challenging environment to manage. However, the visualisation of the clear conservation outcomes changed this perception, showing that conservation is not incompatible with creating a comfortable environment for occupants. In this regard, the students' research empowered the managers of Hellens Manor to continue operating it as a living house as it demonstrated that their management values can be compatible with good preventive conservation.

Over the years various groups of students have complemented this main T and RH dataset with more localised measurements. For example, Fig. 3 shows a mapping of moisture conducted in the Stone Hall (see Fig. 1(a)), a room characterised by its high level of wall dampness. The map indicates areas with higher moisture and the location of several metal objects that are exhibited on the walls including a piece of armour, a helmet and a shield. This simple analysis allowed students to provide actionable advice. In such conditions, the space between an object and the wall is likely to become a microclimate where RH and T will differ from those in the rest of the room. Therefore it was suggested that the most sensitive objects are moved away from the walls by several centimetres. This non-intrusive strategy is ideal for this building and as a further result, simple wooden plank structures were installed to keep the sixteenth-century de *Munthe* tapestry and the *Landscape* tapestry away from direct contact with the walls. In 2023, a newly installed embroidery was also placed at a few centimetres from the wall following this advice.

3 Innovation: visualisation and simulation

One of the key challenges for the students was to develop strategies to overcome the difficulties of visualising the complex and multi-dimensional datasets of T and RH for every room. Hourly monitoring in 11 locations

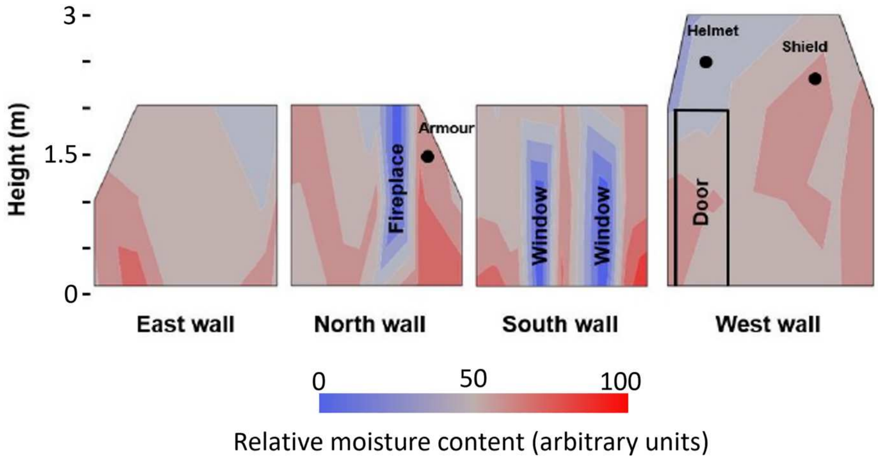

Fig. 3 Map of moisture content on the walls of the Stone Hall. The colour scale refers to the 1–100 arbitrary scale given by the moisture meter (Testo 610), which is not calibrated for stone and therefore should only be understood as a relative measure of wetness, proportional but not equal to water activity.

leads to more than 95,000 datapoints in a year and there is a problem in how they can be visualised in an intuitive way to support decision-making and informing the management at Hellens. In the process of answering this question, students created visualisations tailored to the needs of the managers. For example, an innovative approach in preventive conservation involved the creation of a heat map for T and RH (Fig. 4), rather than a simple scatter plot. The advantage of a heat map is that it shows the frequency of or how common different combinations of T and RH are. Figure 4 exemplifies 2D histograms of environmental conditions, showing two key aspects. Firstly, it illustrates the scatter of conditions by displaying the maximum and minimum values of T and RH for each season. Secondly, it also provides a quick overview of the most common combinations of conditions. For example, in summer, the figure shows two distinct yellow zones: one depicting cooler and more humid conditions, and the other indicating warmer and drier conditions. Figure 4 shows that both sets of conditions are common in this space and thus, these visualisations aid in understanding that the environment does not operate uniformly but may exhibit typical operational modes.

Despite the limited timeframe allocated for research during these field trips, the students have developed creative methods to use predictive models to interpret the indoor environment. In 2018, students created a mass balance prediction model of the interior moisture conditions, which involved consideration of moisture infiltration from external sources as well as internal moisture emissions, such as those from groundwater or ambient moisture. As this model was highly simplified, its effectiveness was found to be inadequate for the complex environmental conditions of Hellens Manor. However, it demonstrated notable success in more controlled environments, such as boxes and display cases. Building upon this finding, this model was elaborated into a predictive tool for environments within display cases and storage boxes.[29]

Materials

Students engage in material analysis where the evidence they collect has the potential to reshape the history and values of the building. They must critically assess the significance of selected materials, while also understanding how management perceives and values that history. The

29 Josep Grau-Bove et al., 'Modelling and Performance Evaluation of Storage Enclosures', in *Transcending Boundaries: Integrated Approaches to Conservation*, ICOM-CC 19th Triennial Conference Preprints, ed. Janet Bridgland (Paris: International Council of Museums International Council of

Museums, 2021), https://www.icom-cc-publications-online.org/4394/Modelling-and-performance-evaluation-of-storage-enclosures (accessed 13 April 2025).

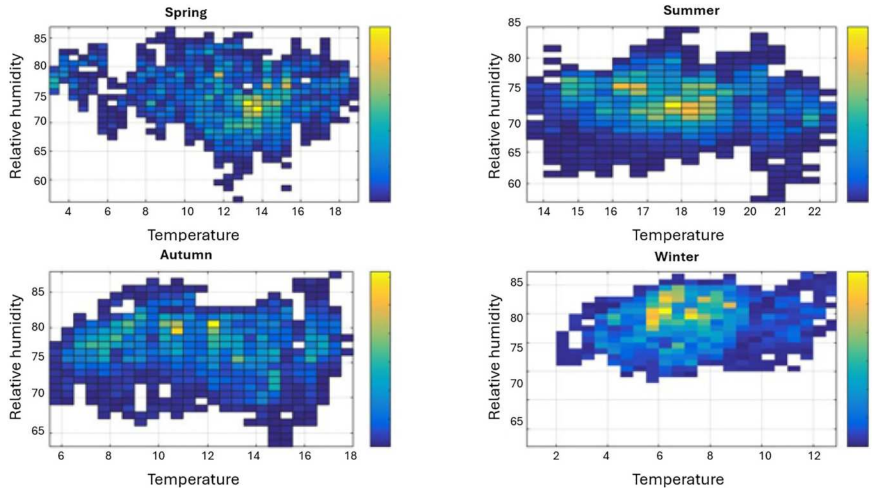

Fig. 4 2D histograms of moisture and temperature. The colour scale indicates the number of hours in which a combination of T and RH is measured, from very common (yellow) to rare (blue).

pedagogical advantages are in this interaction which requires students to balance their findings with the broader narrative that the house management seeks to preserve and promotes.

1 Projects: a unique assembly

Centuries of different ownership have enriched Hellens Manor with a remarkable heterogeneity, not least evident in its building fabric. A prime example is the assembly of two materials in its structure: bricks and glass. The diversity of bricks date from various construction phases from the sixteenth century to more contemporary conservation efforts, and a similar variety is found among the windows panes, which include examples of medieval craftsmanship and all subsequent production periods thereafter. The variety of both materials derives from the need for continuous replacement due to breakage, loss or alteration.

Many techniques have been used for characterising building materials and their properties in situ, such as salt identification, microscopy, roughness, surface hardness analysis and X-ray fluorescence spectroscopy (XRF). Salt identification provided significant information regarding the source of moisture ingress found in the walls. For example, heavy salt deposition was observed on the walls inside the Stone Hall and nitrates and sulfates were identified in the salt samples, suggesting that ground water was the dominant moisture source.[30] In response, ground drainage channels were determined to be an effective intervention to reduce damp in the walls.[31] Roughness analysis using a contour gauge and optical profilometer (Innowep TraceIT.)[32] and hardness analysis (Equotip Piccolo)[33] revealed the degradation states of the surfaces which could be correlated with the environmental factors. One of the most innovative techniques used was the application of a portable XRF (Thermo Scientific Niton XL2)[34] to reveal the construction history of the building by elemental compositional analysis.

2 Innovation: using elemental composition to tell a story

XRF is a non-destructive technique that analyses the elemental composition of materials. Although it has been frequently applied to moveable heritage in museums, its application to built heritage is still limited. Students took on the challenge and made a pioneering attempt to use the

30 Andreas Arnold and Konrad Zehnder, 'Monitoring Wall Paintings Affected by Soluble Salts', in *Proceedings of a Symposium Organized by the Courtauld Institute of Art and the Getty Conservation Institute, London* (Los Angeles: Getty Conservation Institute, 1987), 103–35; Samira A. Ben Mussa et al., 'Determination of Available Nitrate, Phosphate and Sulfate in Soil Samples', *International Journal of PharmTech Research* 1 (2009): 598–604.

31 Jonathan Taylor, 'Rainwater', *Historic Churches* (2013), https://www.buildingconservation.com/articles/

technique to uncover the diversity of the building fabric through the use of XRF coupled with statistical analysis. By identifying the elements commonly presented in bricks, such as silica, aluminium and iron, this approach helped the students to gain a deeper understanding of the construction history of the building envelope.

The XRF analysis identified that some chemical elements such as silica and aluminium were present in great quantities in all the bricks as they are the main composites of clay. Most of the bricks also contained potassium.[35] In addition, analysis identified that all the bricks contained iron, which probably originated from the firing conditions of the bricks and haematite, the mineral form of iron oxide, which gives the bricks their red colour.[36]

As shown in Fig. 5, bricks at different locations, even when aesthetically similar, often showed a distinctive chemical composition. For example, the bricks from the same phase of construction in the late fifteenth–early sixteenth century: the Tower, the Stone Hall and the Tudor Kitchen (not shown in the image) were not categorised in the same group by elemental composition. Bricks used for bricked-in and repair interventions, such as the bricked-in windows or the modern repairs, showed varied chemical compositions, suggesting that it is likely that a mixed assortment of bricks already on-site were re-used.

3 Advice: glass composition and Hetty's ghost

The same XRF technique has been used to obtain other elemental evidence that has significantly influenced the narrative surrounding the house. Specifically, students determined the likely date of a piece of glass containing an historic inscription. The information they uncovered supports the current interpretation provided by the tour guides as within the seventeenth-century part of the building there is a particularly noteworthy window that contains several inscriptions. It is located in 'Hetty's room', named after the once long-term occupant of the room, Hetty Walwyn. Hetty was the daughter of John Walwyn, and at the age of 15 reportedly eloped with a local man named John Pierce.[37] She was shortly abandoned and returned home a few years later and as a punishment, she was forced to live the remaining 30 years of her life in the room until 1728. During this time, she is thought to have inscribed the following line into two of the window panes: 'It is a part of virtue to abstain from what we love if it should prove our bane'. The curiosity of this story and the visual memento of Hetty's time at Hellens is a key feature of the house, and undoubtedly adds to the intrigue of the property.

In response to this story, analysis was undertaken using the glass dating method developed by David Dungworth,[38] which categorises glass based on its elemental composition. These categories are associated with approximate production periods with, for instance, HLLA Glass dating between 1567 and 1700, Kelp Glass between 1700 and 1835, and Soda Glass between 1835 and 1930. By analysing data from 500 glass pieces within the house, students created maps of relevant chemical elements to identify windows still containing historic glass. As illustrated in Fig. 6, one crucial element for this identification is strontium as it distinguishes glass pre- and post-seventeenth century. With the presence of this element, students demonstrated that the window pane containing Hetty's inscription existed during the time of her alleged imprisonment.

Imaging

Students also engage in imaging paintings, a specific form of material analysis, where the main challenge is managing what can be achieved within a limited time and in situ. Imaging offers powerful data, which stu-

rainwater/rainwater.htm (accessed 13 April 2025).

32 Innowep GmbH, 'TraceIT', https://innowep.com/traceit (accessed 20 April 2025).

33 Screening Eagle Technologies, 'Equotip Piccolo 2—Bambino 2', https://www.screeningeagle.com/en/products/equotip-piccolo-2-bambino-2 (accessed 20 April 2025).

34 Thermo Fisher Scientific, 'XRF Analyzers | X-Ray Fluorescence Analyzers', https://www.thermofisher.com/uk/en/home/industrial/spectroscopy-elemental-isotope-analysis/oes-xrd-xrf-analysis/x-ray-fluorescence/instruments.html (accessed 20 April 2025).

35 Marino Maggetti, 'Phase Analysis and Its Significance for Technology and Origin', in *Archaeological Ceramics*, ed. Jacqueline S. Olin and Alan D. Franklin (Washington, DC: Smithsonian Institution Press, 1982), 122–30.

36 Sarah Pavia and Jason Bolton, *Stone, Brick and Mortar: Historical Use, Decay and Conservation of Building Materials in Ireland* (Co. Wicklow, Ireland: Wordwell, 2000).

37 Munthe, *Hellens*, 37.

38 David Dungworth, 'Historic Window Glass: The Use of Chemical Analysis to Date Manufacture', *Journal of Architectural Conservation* 18, no. 1 (2012): 7–25.

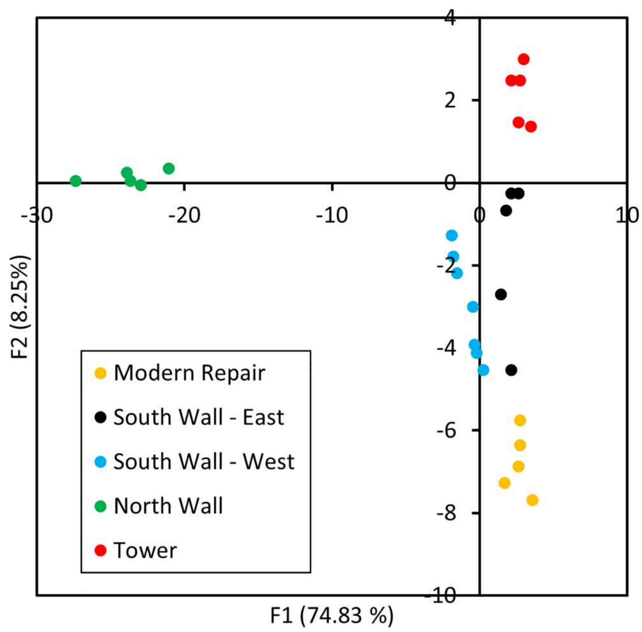

Fig. 5 Results of a principal component analysis (PCA) made with the elemental composition of several bricks measured with XRF. The two axes correspond to the factors (F1 and F2) which explain most of the variability. This plot shows that bricks from different locations form clear, separate clusters, indicating different origins or manufacturing processes.

dents must avoid over-interpreting to satisfy stakeholder curiosity. The pedagogical approach taken in the field trips challenges students to become responsible emerging experts, ensuring their conclusions are grounded in evidence and proportional to what can be meaningfully interpreted.

1 Projects: the mobile imaging lab

Over the years, a diversity of imaging techniques have been used to investigate paintings in the collection. These have included Infrared Reflectography (IRR), Multispectral Imaging (MSI), Near Infrared Spectroscopy (NIR) and Hyperspectral Imaging (HSI), all of which have been used to study eight different pictures. This section summarises the analysis of three paintings, as seen in Fig. 7.

One study was the ceiling painting in the dining room attributed to a family member in the twentieth century. This depicted faces rumoured to be cherubs, although this remained unconfirmed. An old photograph showed the ceiling before it was partly repainted, but it was not known if further modifications had been done in the intervening years. IRR images revealed the paint layers beneath the faces, showing that these figures were angels with wings but lacking bodies (Fig. 7(c)).

A second painting is *The Laughing Girl*, attributed to Joshua Reynolds, where imaging techniques provided a wealth of valuable information. MSI images were able to capture the painting beneath a thick bituminous varnish layer. HSI also allowed the identification of various pigments in the palate of colours used that are consistent with those used by eighteenth-century artists. Reynolds created around five different versions of the subject in two different compositions, often referred to as ‘Type A’ and ‘Type B’. Type A depicts the girl wearing a cream-coloured dress with her hair split with a central parting held back by a band. The main version of

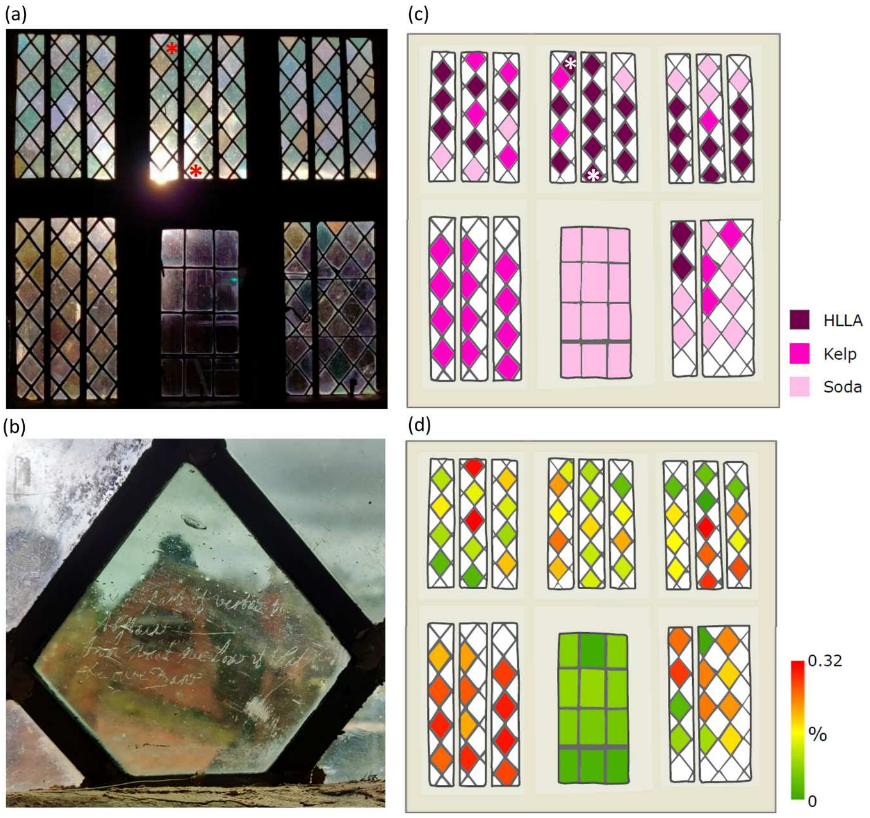

Fig. 6 (a) The window at Hetty's room, with two glass pieces with inscriptions marked with asterisks; (b) a detail of the inscription made by Hetty in the lower glass piece; (c) the likely classification of the glass according to the Dungoworth system; and (d) the Strontium content, as an example of how the elemental composition differs within the window.

this painting is under the care of English Heritage at Kenwood House. The version held in Hellens is a Type B composition in which the girl has dark curly hair, a white blouse and a red shirt. Four different versions of this version of the painting are recorded in the authoritative catalogue of Reynolds work, alongside numerous contemporaneous copies.[39]

Finally, work on *The Resurrection*, an oil painting on canvas attributed to Jacob Robusti Tintoretto, demonstrates how these imaging techniques provided evidence concerning its alterations. IRR images were used to document the *pentimenti*, which are observable traces of earlier compositions beneath subsequent layers of paint. An example of this can be seen in Fig. 7(h), which illustrates Tintoretto's adjustment of Jesus Christ's arm positions (see arrow). Additionally, by using this imaging technique, students were able to analyse the paint composition to try and identify if any areas had been repainted in any previous restorations. No areas with visible additions of non-original pigments were detected.

2 Innovation: in-situ imaging

Conducting imaging on-site within a limited timeframe presents challenges and requires students to use creative problem-solving to ensure they obtain high-quality evidence in the field. Among the encountered challenges was the need to darken the rooms to capture high quality images within the historic house. To ensure that all windows were completely covered involved improvisation, using blankets or even jackets to block out light sources. Another significant concern was safeguarding the historic

39 David Mannings and Martin Postle, *Sir Joshua Reynolds: A Complete Catalogue of His Paintings* (New Haven: Paul Mellon Centre for Studies in British Art, 2000).

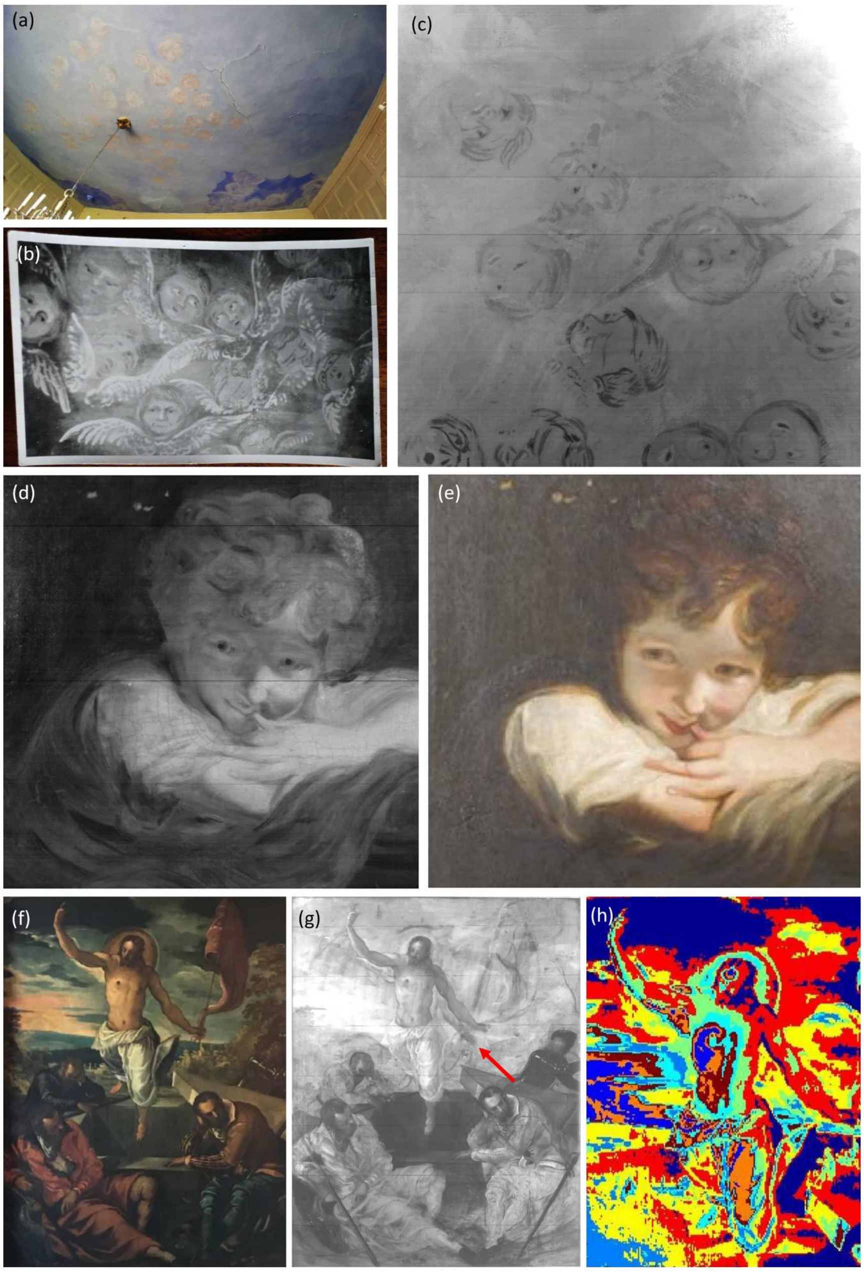

Fig. 7 (a) A visible image of the ceiling painting; (b) a historic image showcasing a section of the ceiling painting, showing angels adorned with wings; (c) an infrared reflectography image revealing details of the ceiling painting; (d) an infrared reflectography image of *The Laughing Girl* painting, displaying extended details in the hair and body that are otherwise not immediately apparent; (e) a visible image of *The Laughing Girl*; (f) a visible image of *The Resurrection*, an oil on canvas attributed to Tintoretto; (g) an infrared reflectography image of *The Resurrection* where some *pentimenti*, such as the correction made to the arm of Jesus Christ, are clearly observable; and (h) a spectral map of *The Resurrection* from the hyperspectral imaging dataset, showing the distribution of pigments used in the painting. Each colour within the image corresponds to a similar chemical signature, for instance, the use of some pigments in both the clothing and Jesus Christ's skin.

floors from equipment scratches. To address this, students employed lesser-value carpets to cover the wooden floors and attached tennis balls to the tips of the tripods. Moreover, due to the limited data processing capabilities on site, students had to meticulously plan both the quantity of images captured and the specific areas of interest. This approach was crucial to prevent the accumulation of excessive data that could hinder their analysis.

It is well known that constraints, when appropriately moderated, foster creativity in many educational and business contexts.[40] Conducting complex imaging in such a short period of time and on location is certainly an example of this, but it should be noted that this exercise has an additional dimension. At the start of the activity, the students have an excess of options with hundreds of paintings to choose from and a number of complicated techniques available to use. The first task was to design-in constraints by developing specific research questions. The richness of such an activity lies in how students set about generating constraints that later imposed the need for creativity in execution.

40 Oguz A. Acar, Murat Tarakci, and Daan Van Knippenberg, 'Creativity and Innovation under Constraints: A Cross-Disciplinary Integrative Review', *Journal of Management* 45, no. 1 (2019): 96–121.

3 Advice: a richer story

One of the main benefits of the students' research has been to contribute to the stories told at Hellens Manor. Through the imaging of the paintings, the historical narrative of the house has been enriched, adding, for example, to the information provided during guided tours. Consequently, tour guides have refined their storytelling, integrating new elements into the narrative of the house. In some cases, the research has supported interpretation, such as in the case of the painted ceiling, which confirmed the presence of angel wings underneath the paint. In others, a dash of science has made it into the tours. Nowadays, a visitor can hear about the *pentimenti* of Tintoretto paintings, which enhances their understanding of art history, as these *pentimenti* become partially visible to the naked eye once pointed out.

A natural reserve

Pedagogy in this context also involves assessing natural heritage as well as cultural heritage values, as nature and culture may often support each other's conservation but, at times, can be in conflict such as with bat colonies at Hellens. In this case students need to contribute to a rebalancing of values, especially when these values are not universally agreed upon by the management, and their research can enable new management conversations. This highlights how a strong understanding of values is a critical precondition for any scientific interpretation and presentation of results.

1 Projects: competing for resources

A pest can be defined as a living organism which competes with humans for resources.[41] In a historic house like Hellens Manor, pests can be any animal or living organism that has the potential to harm the site or the collections within it. The biodiversity in Hellens is varied and includes an array of living organisms that have access to or reside in different areas within the property and grounds. This includes donkeys, dogs, birds and a colony of bats roosting in the roof-space of the carriage shed in the grounds. Furthermore, there are several insect populations identified by the students within the building, including several common species found in museums and historic houses in the UK: case bearing clothes moth *Tinea pellionella*, various species of carpet beetle larvae *Anthrenus spp*, masonry bees (*Osmia spp*) and woodboring beetles such as furniture beetles or woodworm *Anobium punctatum* and death watch beetles *Xestobium rufivillosum*.

41 David Pinniger, *Integrated Pest Management for Cultural Heritage* (London: Archetype Publications, 2015).

Pest management in Hellens Manor presents a further challenge by the fact that the site has two listed nature reserves on its grounds. First is the colony of bats. Bats are protected species in the British Isles and the colony above the carriage shed is registered. Moreover, the land surrounding the property covers c.150 acres of ancient woodland and wildflower meadows,[42] and is listed as a site of special scientific interest (SSSI), protected by the Woodland Trust.[43] As a response to the current climate emergency and the loss of biodiversity, management at Hellens have started to make plans to regenerate the grounds in consultation with conservationists and National Trust experts aiming to improve the biodiversity in the area.

Early on in the cycle of field trips students installed the first pest traps in Hellens, identified species and correlated their presence with environmental conditions. This work has later evolved and in the hands of the house managers it has become a more comprehensive Integrated Pest Management plan. IPM findings have had some very direct impacts, as described below.

42 'House and Garden', Hellens Manor, https://hellensmanor.com/house-and-garden/ (accessed 20 April 2025).

43 Woodland Trust, 'SSSI Definition: What Is It and What Does It Mean for Conservation and Development?', webpage, 2019, https://www.woodlandtrust.org.uk/blog/2019/03/sssi-definition/ (accessed 29 March 2023).

2 Innovation: bats and heritage

In 2019 the carriage shed was identified as a space which could be made more accessible to visitors during tours. However, any changes must also respect the legal protections afforded to the bat colony in the shed's roof space. The bat colony's influence on the condition of the carriages is significant with visible deposits of bat urine and guano on top of the carriages. The highest concentration of deposits was on an enclosed coach roof. Bat urine is not inert when in contact with a range of materials and will absorb into porous surfaces such as pitted iron work, fabric and woodwork,[44] which are all present in the carriage collection. Urea, a component of urine, crystallises when the RH is ≤68% but the crystals absorb water from the surroundings and deliquesce ≥72% RH. James Hales proposed that this could cause weakening and cracking of porous materials in a similar way to freeze–thaw cycles.[45] Figure 8 shows RH in the carriage shed cycling through crystallisation–deliquescence over multiple days of the year and demonstrates how the risk is higher in May and August. This is the first time the authors are aware of the criteria from Hales' research being used in a preventive conservation context, which if correct represents the rapid translation of research into practical advice. To mitigate further deposition while preserving bat access, it was recommended to divide the shed volume into two zones by installing a protective barrier between the upper roof space occupied by bats and the lower area where the carriages are stored.

In addition to the innovative use of Hales' research another novel approach was the use of sound monitoring and recording, which was applied within the house and grounds using portable equipment. This provided data to map the acoustic ecology of the site to highlight elevated biodiversity in areas such as ponds, fields and nearby woodland.

44 James Hales, 'Bats in Churches: Objective Assessment of Associated Damage Mechanisms', *Archaeology International* 17 (2014): 94–108.

45 Hales, 'Bats in Churches', 98.

3 Advice: saving the book collection

Paper collections, as with any organic materials, are affected by mould growth and pests. Mould species produce enzymes such as cellulases which digest the cellulose present in paper, causing discolouration or foxing.[46] Mould species can also digest parchment, wool leather, wood and manufactured polymers, among others. In addition, mould mycelia penetrate the substrates of organic materials causing loss of coherence and affecting physical properties of materials.[47]

During several field trips students created a customised Risk Factor Analysis (RFA) framework to assess the risk of future pest infestations occurring in 12 rooms within Hellens Manor. The RFA was developed to acknowledge that Hellens is a living home and not a museum and that it would be beneficial for such assessments to be relatively quick to undertake. Six risk-factor parameters were defined: environmental conditions (T and RH); the presence of organic materials in the room; the use of the

46 Anikó Várnai et al., 'Carbohydrate-Binding Modules of Fungal Cellulases: Occurrence in Nature, Function, and Relevance in Industrial Biomass Conversion', in *Advances in Applied Microbiology*, ed. Sima Sariaslani and Geoffrey M. Gadd, 103–65 (Elsevier Science & Technology, 2014), doi:10.1016/B978-0-12-800260-5.00004-8.

47 Beata Gutarowska and Agatha Czyżowska, 'The Ability of Filamentous Fungi to Produce Acids on Indoor Building Materials', *Annals of Microbiology*

59, no. 4 (2009): 807–13, doi:10.1007/BF03179227.

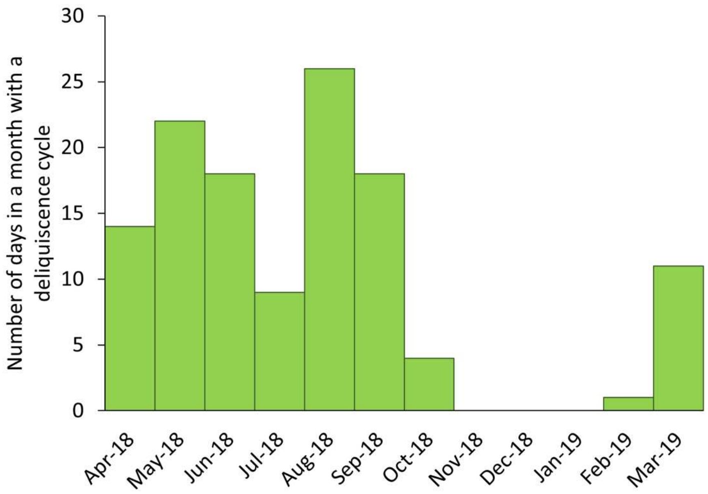

Fig. 8 Number of urea crystallisation cycles during the year. A cycle is any instance where the ambient RH crosses the crystallisation and liquification thresholds.

room; the room's envelope; the level of dust; and any evidence of previous pest infestations. Each parameter was assigned a value from an ordinal scale (1, 2 or 3), in which 1 indicated minimal, and 3 indicated major, risk of pest presence. Similar to Robert Waller's risk categorising system,[48] each factor was considered a risk in itself and classified according to its frequency and severity. For example, T and RH was considered a risk factor 1 when RH was below 65% and T below 15°C for over 4 months and risk factor 3 when RH was above 65% for at least half of the time over 6 months and T below 15°C for under 2 months of the year. The value given to each risk factor reflected how it contributed to the overall risk of pest infestation, following Waller's framework.

The overall RFA score was calculated for each room by averaging the parameter values assigned to that room (Fig. 9). Students found that an effective pest management strategy should be area-specific and address the parameters which pose the highest risk. Methods for mitigating against these high-risk parameters—where a total RFA was 3—include the ventilation of rooms, regular vacuuming and dusting, limiting the rooms where food is consumed, and installing brushes on external doors. Students outlined mitigation strategies ranging from cost-free to more expensive and from being feasible to immediately implement to those offered as more long-term solutions. Some mitigation strategies were readily applied, for example changing the location of a bookshelf to an area offering less favourable conditions for pest infestation.

48 Robert Waller, 'Conservation Risk Assessment: A Strategy for Managing Resources for Preventive Conservation', *Studies in Conservation* 39, sup. 2 (1994): 12–6, doi:10.1179/sic.1994.39.Supplement-2.12.

Conclusions

The experience of the last decade of research-led teaching in Hellens Manor shows that innovation and learning in heritage science can go hand-in-hand. To summarise, some of the innovations presented in this article are:

1. a simple and effective way to visualise improvements in T and RH conditions;
2. a predictive model of indoor environments, which has later been used successfully to study boxes and enclosures;
3. the first use of portable XRF known to the authors to map the composition of historical bricks; and

	Upstairs corridor	Library	Long Gallery	Hetty's Room	Stone Hall	Display case	Bloody Marys Room	Dining Room	Cordova room	East Hall	Music Room	Tudor Kitchen
T & RH			2	1	2	2	2	2	2	3	2	
Dust	1	2	2	2	3		1	1	2	2	3	3
Materials	1	2	1	2.5	1	2.5	3	3	3	3	3	3
Envelope	1	1	1	1	2	1	2	3	3	3	3	2
Use of Room	1	1	2	2	1	2	2	2	2	2	2	3
Evidence of Pests	1	1	2	2	2	2	3	2	3	3	3	3

	Upstairs corridor	Library	Long Gallery	Hetty's Room	Stone Hall	Display case	Bloody Marys Room	Dining Room	Cordova room	East Hall	Music Room	Tudor Kitchen
Total Risk Factor	1	1	1	2	2	2	2	2	3	3	3	3

Fig. 9 Example of a risk factor analysis framework created by students to suit the needs and values of Hellens Manor. This framework helped identify rooms at a higher risk of pest infestation.

4. the first use of the thresholds for urea crystallisation as a metric to quantify the risks to collections next to bat colonies.

In addition, the article also demonstrates some notable results from the application of some well-known techniques. This includes mapping the history of glass with the Dunworth classification method, conducting imaging that produced conclusive results within significant practical constraints, using existing criteria of environmental risk to summarise the consequences of the installation of a heating system, and developing a customised risk factor analysis for pests.

There have also been several pedagogical advantages of this approach to teaching, which helps:

1. develop students as responsible emerging experts who can balance environmental changes with practical management constraints while abiding with stakeholder values;
2. foster critical thinking, enabling students to assess how material evidence can reshape a site's history while understanding the management's interpretation of that history;
3. encourage students to make evidence-based, responsible statements about data, avoiding over-interpretation and managing stakeholder expectations; and
4. teach students how to navigate conflicting heritage values, reinforcing the importance of understanding and presenting values as a foundation for scientific interpretation.

This kind of field work positions students as emerging experts, working with other experts. Most experiments were carried out with minimal prior expertise, using a 'learning by doing' approach under academic supervision. As discussed earlier, the field trip pedagogy centres on narrowing possibilities through expert guidance and practical constraints. Students begin with broad access to Hellens' heritage collections and a range of equipment, reflecting the real-world complexity of heritage science, where multiple paths can lead to valid outcomes. They must determine what is useful, feasible and significant. Once defined, these boundaries drive creative problem-solving.

Most importantly, the scientific advancements over the past decade demonstrate the substantial value received by collections that open their doors to students. Well-planned and increased accessibility enriches these collections in many ways, including the contribution of new knowledge. Hellens Manor has benefitted from a forward-thinking management, which has put the house at the centre of its intellectual and artistic activities. The management at Hellens takes the view that everything is finite but that extended care can protect and prolong the cultural value of things over time. Arguably, this may result in things having a shorter existence in the world, but they are better able to communicate the realities of the past, the joys and trials of existence, the challenges, the risks, the comforts and everything in between that goes up to present a living experience of history.

By using contained, problem-based learning approaches, students can strike a balance between mastering the practical aspects of heritage science problem-solving and engaging in innovative projects. The authors hope they have demonstrated how Hellens serves as an example of how such work not only teaches emerging heritage scientists to conduct effective research but also allows the creation of valuable, applicable results that contribute meaningfully to the field.

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Resumen
"La casa más estudiada del mundo: doce años de docencia de investigación en Hellens Manor, Inglaterra"
Este artículo muestra cómo las salidas de campo, impulsadas por una enseñanza centrada en la investigación, pueden llevar a innovación en las ciencias del patrimonio y su conservación. Basándose en una década de viajes de campo a Hellens Manor, en Herefordshire (Reino Unido), el estudio destaca varias innovaciones científicas realizadas por estudiantes durante estas visitas en ámbitos tan diversos como la visualización y predicción de las condiciones de temperatura y humedad relativa, el uso de espectroscopia de fluorescencia de rayos X portátil para cartografiar la composición histórica de los ladrillos y la aplicación de umbrales de cristalización de la urea para cuantificar los riesgos para las colecciones cercanas a colonias de murciélagos. Además, el artículo muestra aplicaciones notables de técnicas establecidas, como la cartografía de la composición del vidrio y la obtención de imágenes in situ. La pedagogía de las excursiones a Hellens Manor emplea un proceso en dos fases: en primer lugar, se definen cuestiones de investigación específicas que son viables y científicamente interesantes, con potencial para informar la gestión del patrimonio y, en segundo lugar, se fomenta la creatividad en la resolución de problemas dentro de las limitaciones prácticas de la excursión. Este modelo educativo puede proporcionar experiencia práctica en la toma de decisiones reales, laguna ya identificada en la literatura. Los resultados muestran las ventajas de dar prioridad al acceso a las colecciones, edificios y sitios del patrimonio con fines educativos, de manera que en última instancia se promueva su conservación además de fomentar las relaciones de colaboración entre educadores y administradores de sitios del patrimonio. En definitiva, el éxito de este tipo de enseñanza basada en la investigación depende de la alineación entre la pasión por la ciencia y las necesidades y los valores del patrimonio.

:الملخص
المنزل الأكثر دراسة في العالم: اثني عشر عامًا من التعليم القائم على البحث في هيلينز هاوس، إنجلترا
يستعرض هذا المقال كيف يمكن للرحلات الميدانية، المدفوعة بالتعليم القائم على البحث، أن تؤدي إلى الابتكار في علوم التراث وصيانة الآثار. من خلال الاستفادة من عقد من الرحلات الميدانية إلى منزل هيلينز في هيريفوردشير في المملكة المتحدة، يسلط البحث الضوء على عدة ابتكارات علمية حققها الطلاب خلال هذه الزيارات في مجالات متنوعة مثل تصور وتنبؤ ظروف درجة الحرارة والرطوبة النسبية، واستخدام التحليل الطيفي بالأشعة السينية المحمولة لرسم تركيبة الطوب التاريخي، وتطبيق عتبات تبلور اليوريا لتحديد المخاطر التي تهدد المجموعات التراثية بالقرب من مستعمرات الخفافيش. بالإضافة إلى ذلك، يعرض المقال تطبيقات ملحوظة للتقنيات المعتمدة مثل رسم تركيبة الزجاج وإجراء التصوير الميداني في الموقع.
يستخدم منهج التعليم في الرحلة الميدانية في منزل هيلينز عملية من مرحلتين: أولاً، تحديد أسئلة بحثية محددة تكون قابلة للتحقيق وشيقة علمياً، ولها القدرة على إبلاغ إدارة التراث، وثانياً، تعزيز الإبداع في حل المشكلات ضمن القيود العملية للرحلة. يمكن لهذا النموذج التعليمي أن يوفر خبرة عملية في مهارات اتخاذ القرارات في العالم الحقيقي، وهي فجوة تم تحديدها سابقاً في الأدبيات. تظهر النتائج فوائد إعطاء الأولوية للوصول إلى المجموعات التراثية والمباني والمواقع لأغراض تعليمية بطريقة تفيد في النهاية صيانتها، إلى جانب تعزيز العلاقات التعاونية بين المعلمين ومديري مواقع التراث. في النهاية، يعتمد نجاح هذا التعليم القائم على البحث على توافق شغف العلم مع احتياجات وقيم التراث.

Resumo
"A casa mais pesquisada no mundo: doze anos de ensino orientado para a pesquisa na Hellens Manor, Inglaterra"
Este artigo mostra como as viagens de campo, conduzidas pelo ensino orientado para a pesquisa, podem guiar a inovação em ciência do patrimônio e conservação. Baseando-se em uma década de viagens de campo a Hellens Manor em Herefordshire, Reino Unido, o estudo evidencia várias inovações científicas feitas por estudantes durante estas visitas em áreas tão diversas como a visualização e previsão de condições de temperatura e umidade

relativa, o uso de espectroscopia de fluorescência de raio X portátil para mapear a composição de tijolo histórico e, a aplicação de patamares de cristalização da ureia para quantificar riscos para coleções próximas a colônias de morcegos. Além disso, o artigo apresenta aplicações notáveis de técnicas comprovadas, como mapeamento da composição do vidro e condução de imageamento in-situ. A pedagogia da viagem de campo a Hellens Manor emprega um processo em duas fases—em primeiro lugar definindo questões específicas de pesquisa que são tanto viáveis quanto cientificamente interessantes, com potencial para informar a gestão do patrimônio e, em segundo lugar, fomentar a criatividade na solução de problemas dentro das restrições práticas de viagem. Este modelo educacional pode proporcionar experiência prática na habilidade da tomada de decisões do mundo real, que é uma lacuna identificada previamente na literatura. Os resultados demonstram os benefícios de priorizar acessibilidade às coleções, edificações e locais de patrimônio para propósitos educacionais de uma maneira que, em última análise, beneficia sua conservação em conjunto ao incentivo de parcerias colaborativas entre educadores e gestores de sítios de patrimônio. Finalmente, o sucesso de tal ensino orientado para a pesquisa depende em alinhar a paixão pela ciência com a necessidade e valores do patrimônio.

摘要

“世界上研究最深入的房子在英国海伦庄园进行十二年基于研究的教学”

本文探讨了如何通过研究导向教学驱动的实地考察，促进文化遗产科学和保护领域的创新。通过对英国赫里福德郡海伦庄园十年来的实地考察，该研究着重介绍了学生在考察期间取得的多项科技创新，涉及包括温度和相对湿度状态的可视化和预测、使用便携式 X 射线荧光光谱（XRF）绘制历史砖石成分图，以及应用尿素结晶阈值来量化蝙蝠栖息地附近藏品的风险等多个领域。此外，文章还介绍了一些既有技术的显著应用，如绘制玻璃成分图和进行现场成像。海伦庄园实地考察的教学方法分为两个阶段，首先是确定既可行又具有科学意义的具体研究问题，它具有为遗产管理提供参考的潜质；其次是在考察的实际限制条件下培养解决问题的创造力。这种教育模式可以提供真实世界的决策经验，而这在现有文献中是一个空白。研究结果表明，将文物藏品、建筑和遗址优先开放于教学活动，不仅有助于其保护，同时还能促进教育工作者与文物遗址管理者之间的合作关系。归根结底，这种研究导向教学的成功依赖于对科学的热情与对文化遗产的需求和价值观的相结合。

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