The Contribution of Natural History Museums to Science Education

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Executive Summary

This is a report of a project titled 'The Contribution of Natural History Museums to Science Education', funded by the Wellcome Trust and ESRC with a Phase 1 grant from the Science Learning+ initiative. The project explored how Natural History Museums (NHMs) and schools can complement one another to maximise learning among school-age learners, and researched the long-term benefits to learning and engagement with science that NHMs can provide. During the course of our work, our team, which consisted of museum professionals and academics in the UK and the US, worked in the UK and the US with practitioners in NHMs and with school teachers and students.

Our conclusions, as summarised in this Executive Summary, fall into two areas, one to do with the provision by museums of learning experiences for students, the other to do with how NHMs assess the effects of their provision. While our focus is on NHMs, a number of our conclusions apply more generally.

The provision by museums of learning experiences for students

1. An NHM visit should be a memorable event for students and help them see and engage with science in ways that the classroom environment cannot provide.
2. Programmes developed by or for NHMs ought to be embedded within STEM learning ecosystems so that parents, schools, NHMs and the general community are collaboratively involved in engaging students with science.
3. Successful collaboration between school teachers and museum educators relies on the two communities of practice clarifying boundaries, as well as defining strategies for encounters and crossing boundaries.
4. Learning outcomes for NHM activities should include content knowledge alongside social, emotional and developmental outcomes.
5. Students should be provided with suitable pre- and post-visit activities and these should give students opportunities to ask questions.
6. The most effective learning in NHMs takes place when students are physically engaged, and when learning experiences are enjoyable, meaningful and socially interactive.
7. Many teachers do not view museum activities as a sociocultural learning experience. In order for students to learn effectively on museum visits they should have the opportunity to explore exhibits interactively with others as well as on their own.
8. Learners benefit from being given opportunities to meet with scientists and other experts. Such encounters can have a positive influence on students' attitudes to learning science, enable students to become more informed about career choices and provide students with a better understanding of 'how science works'.

9. NHMs need to make use of new possibilities afforded by digital technologies, including online exhibits—possibly via the use of cybercabinets—and games, including interactive multi-user games.
10. Displays in museums can benefit from a degree of interactivity.
11. Museum experiences ought to develop students' scientific skills and understanding of science while also helping them to develop an enquiring and critical attitude towards science.
12. Given the extensive research indicating that cultural, educational and cognitive factors influence visitors' understanding of science, more attention should be given to students' prior knowledge and their resulting interpretive stance in the design of exhibits and related learning experiences.
13. NHM programmes ought to enable students to have autonomy in driving their own learning.
14. There is evidence that students' engagement with science could be improved if teachers encouraged students more often to think about science beyond the classroom and to think about how science is something they can engage with outside of school.

The assessment by NHMs of the effects of their provision

15. Given that museums invest significant resources in attempting to engage school students, the affective value of museum visits is an area that has received surprisingly limited attention.
16. It remains the case that the informal sector in general, and NHMs in particular, need to devise and employ better ways of measuring the long-term consequences of their provision.
17. Better approaches to evaluate the impact of the work of informal science education institutions on students' attitudes, engagement and learning would include baseline survey data and ensure that survey data are collected at intervals over the course of a number of years. In addition, survey data would be better used in conjunction with in-depth qualitative interviews before, during and after interventions/programmes.
18. There is considerable potential to devise protocols to match data obtained from museum evaluations with national or other databases. This should allow more rigorous evaluations of activities provided by informal science education institutions, including NHMs.
19. A curriculum mapping analysis of the educational resources provided by a number of NHMs in the UK and US indicates that these NHMs already provide an impressive range of such resources that serve the needs of the school science curriculum well.
20. School teachers are often very positive about what students gain from visiting NHMs though evidence for student learning is less robust.
21. NHMs are the repositories for the evidence that supports many scientific claims. However, in order to preserve collections and increase public access, NHMs are increasingly displaying replicas and digitising collections. Research is needed on the effects on the learner of this shift and into how to enable students to access and learn from the information about the natural world provided by online collections.

Introduction

At the start of this project, funded by the Wellcome Trust and ESRC with a Phase 1 grant from the Science Learning+ initiative, we set out to explore: (a) how Natural History Museums (NHMs) and schools can complement one another to maximise learning among school-age learners; and (b) the long-term benefits to learning and engagement with science that NHMs can provide. We deal in this report with these two broad issues within each of the seven objectives that our project has and that we use to structure this report. The project came about because although there is a widespread presumption that NHMs have a major role to play in science education, more research is required to understand what facilitates such learning. During the course of our work the team, which consisted of both museum professionals and academics, in the UK and the US, worked with practitioners in NHMs and school teachers in the UK and the US to address the questions that are embedded within our seven objectives.

We used a number of approaches in compiling this report, principally reviews of the literature, analysis of NHM websites and science curricula, collation of our existing professional knowledge, and interviews with 17 NHM practitioners and 15 school teachers and four students who were visiting UK and US NHMs. We draw on these interviews in the parts of our report that address objectives 5, 6 and 7 of our research.

As we had intended, our combined efforts have enabled us to: complete a critical literature review to: examine the contributions to learning and engagement that NHMs have been found to make; put forward suggestions for the development of improved instruments to determine the efficacy of learning experiences in NHMs; devise protocols to explore the possibility of data obtained from NHM evaluations being matched with national databases, to help improve our understanding of the consequences of museum experiences; map the areas of science curricula (using the latest version of the science National Curriculum in England and the Common Core Standards in the US) that NHMs might most valuably address; review current pedagogical approaches employed by schools and NHMs, with a view to developing and studying new practice models in Phase 2 of the Science Learning+ initiative.

Objective 1

Undertake a critical review of the published and grey literature to examine the contributions to learning and engagement that have been made by natural history museums

The purpose of this review is to identify and discuss the key issues that are related to and impact learning provided by natural history museums (NHMs). We concentrate on what may be termed 'student learning', that is, learning by those of school age. However, much of this learning does not take place while students are on school visits to NHMs or in schools being taught by experts from NHMs. It takes place as students visit or otherwise (e.g. digitally) access NHMs individually, with their familes or with friends. We therefore present findings from the general literature about learning in and through NHMs and other informal science education institutions when these have implications for the learning that takes place through NHMs.

We used a variety of methods to find our literature in addition to using literature that was already known to us. In order to be able to draw on work in related areas, such as science museums or other informal learning institutions, we used the following search terms: learning in natural history museums; learning in science museums; learning in aquaria; learning in informal science institutions; exhibits natural history museums; programmes natural history museums; education natural history museums / informal science institutions; students and natural history museums / informal science institutions and schools and natural history museums / informal science institutions. A comprehensive search using electronic databases was the first stage of our search. We used: Oxford Journals Collection, SpringerLink, JSTOR, Cambridge Journals Online, Sage Journals and Taylor and Francis Online. In addition, we used the search terms within Google to help access unpublished material. We make use of literature that draws upon a range of informal science education institutions and practices so that we are better able to make recommendations about what can help increase learning in natural history museums. NHMs are themselves research institutes and public-facing entities of science. As such, they are in the forefront of science and possess insights, narratives, materials and knowledge that can benefit science learning. While traditionally seen as sites of informal learning, they increasingly embody formal learning, to the extent that some even run higher education courses and award degrees.

Research in the UK, US and in other countries has found mounting evidence that students' knowledge and understanding of scientific concepts takes place in a variety of settings, both in and out of school and that such knowledge and understanding accumulate over time through being exposed to a wide range of public resources such as visits to museums and information in the media (e.g. Barron, 2006; Bathgate, Schunn, & Corenti, 2014; Bell, Lewenstein, Shouse, & Feder, 2009; Falk & Needham, 2013; Tal & Dierking, 2014; Committee on Successful Out-of-School STEM Learning, 2015). There is a widespread assumption that schools are where the majority of learning takes place; existing research indicates that other places of learning also play an important role (Downey, Von Hippel & Broh, 2004; OECD, 2012; Falk & Dierking, 2010; Falk & Needham, 2013). A range of settings outside of school (i.e. the informal sector, including NHMs) can provide informal science education. According to Crane, Nicholson, Chen and Bitgood (1994): "Informal science learning refers to activities that occur outside the school setting, are not developed primarily for school use, are not developed to be part of an ongoing school curriculum, and are characterised as voluntary as opposed to mandatory participation as part of a credited school experience" (p. 3). In reality, the formal-informal distinction may not be so clear cut; school trips occur outside the school setting but may not be voluntary. Experiences in informal science organisations can, for some young learners, represent a significant amount of their exposure to science and, for some, experiences at informal science institutions can be their first real experience of science learning (Bell, Lewenstein, Shouse, & Feder, 2009).

Research has also concluded that young learners' experiences at informal science institutions play an important role in the development of skills, dispositions, practices and knowledge that are vital in helping students to successfully learn about science (Dorph, Schunn, Crowley, & Shields, 2012).

Over the past few decades the state of science education has been evaluated with respect to the outcomes, overall goals and the way science learning occurs. A fundamental concern is how school science education can ensure that all students become scientifically literate to prepare them in their everyday lives as citizens and, in addition, how school science can ensure that enough students are able to pursue careers in STEM areas (Fensham, 1985; Millar, 1996). Research on western students' enrolment in post-compulsory science courses has been indicating for a number of years now that there has been a decline in the proportion of students who continue with STEM subjects (Ainley, Kos, & Nicholas, 2008; OECD, 2006; Osborne & Collins, 2000; Porter & Parvin, 2009). It has been argued that a key reason why interest and engagement in science has declined is because of the way science is taught in schools (e.g. Aikenhead, 2006). There have been a number of other reasons suggested as to why students are not engaged with school science; such reasons include cultural alienation, as students' parents' socioeconomic background, students' ethnicity and students' gender can all play negative roles (Archer et al., 2012). The European Commission (2007) has argued that the best way to promote science education is to introduce more inquiry-based teaching and to enable more collaboration to occur between the informal and formal science education sectors.

The Relevance of Science Education (ROSE) project (Sjøberg & Schreiner, 2005) used surveys to explore students' views of science from a range of countries. The findings indicated that science needed to be more engaging for students. The ROSE surveys also showed that there were differences in students' views about science depending on whether they were from developing or developed countries; students in developing countries expressed considerably more positive views about wanting to take up careers in science and about the role of science in society (Sjøberg & Schreiner, 2005). It is a key concern both in the UK and the US that something is done to make science more appealing, engaging and interesting to young people: "It is urgent that educational policy makers address the lack of engagement that so many students experience in school science and technology education" (Fensham, 2008, p. 20). Science education in informal settings is important largely because there is an argument that formal education is unable on its own to equip students with essential scientific knowledge and cannot engage students with science in isolation of what informal science education settings can provide. In formal science education, the goals of learning and outcomes have been discussed and redefined a number of times (DeBoer, 2000; Fensham, 1992; Reiss, 2007).

Increasingly, people are exposed to scientific knowledge in their daily lives in a range of settings. There will be much benefit in connecting the informal educational organisations (e.g. museums) and their expertise with formal educational providers in order to better promote science education and better engage young learners. The current challenge faced by science educators is that trying to establish an effective learning partnership between schools and informal science education organisations often remains a challenge and there is little available guidance on how organisations can build effective partnerships. Effective partnerships between schools and museums are becomin increasingly important given that the science education community has put forward evidence to indicate that there ought to be a real place for informal learning as it is able to give added value to science learning above what is offered by traditional formal schooling. Clear evidence for this comes, for example, from the US National Research Council (2009) report *Learning Science in Informal Environments*. This report indicates that community institutions (such as museums) that support science learning are able to support young people's learning of and interest in science better than schools can do in isolation from such organisations.

The differences between informal and formal learning institutions

There have been a number of researchers who have attempted to describe the differences between formal and informal learning; the way in which the two sectors have been described differs. Stocklmayer, Rennie, and Gilbert (2010) have set out the way different researchers have approached this and some of these approaches are presented in tables 1 and 2. The way in which Wellington (1990) categorised formal and informal learning focused on the differences between out-of-school and in school contexts. Stocklmayer, Rennie and Gilbert indicated that Martin's (2004) way of categorising the two sectors was slightly different to that of Wellington. While Martin divided formal and informal learning in similar ways as Wellington, Martin also differentiated between kinds of learning in culturally specific contexts. Stocklmayer, Rennie and Gilbert (2010) used Rennie's (2007) analysis on informal learning environments to arrive at the following conclusions about what constitutes informal learning contexts: (1) contexts students are not told that attendance is compulsory and where their involvement and attendance are entirely voluntary; (2) if there is a curriculum in place it is structured in a way that offers individual students choices about what they want to engage in; (3) contexts where the activities that have been developed for students are based on non-assessed and non-graded learning activities, where there is no evaluation or a non-competitive environment; and (4) contexts in which students are able to have social interaction with a diverse range of students from different age groups (as opposed to only mixing with peers of similar age with a teacher present which is often the case when students attend teacher-organised visits to NHMs). Following Rennie's definition, Stocklmayer, Rennie and Gilbert (2010) agree that within the formal education sector, learning is teacher-led and thus students' learning is typically extrinsically motivated as opposed to informal environments where learning is often intrinsically motivated and led by students themselves.

Having a student-centred approach to learning is generally beneficial but the informal sector needs to employ ways of measuring outputs (both cognitive and affective). Informal learning environments such as NHMs would benefit from partnering with schools and embedding some learning within the goals of the formal science curriculum. Ensuring attendance is compulsory would mean certain groups of students who are unlikely to attend out of choice would benefit from activities run in informal environments.

Table 1. Wellington's (1990) comparison of informal and formal learning

Informal learning	**Formal learning**
Voluntary	Compulsory
Haphazard, unstructured, unsequenced	Structured and sequenced
Non-assessed, non-certificated	Assessed, certificated
Open-ended	More closed
Learner-led, learner-centred	Teacher-led, teacher-centred
Outside of formal settings	Classroom and institution-based
Unplanned	Planned
Many unintended outcomes (outcomes more difficult to measure)	Fewer unintended outcomes
Social aspect central, e.g. social interactions between visitors	Social aspect less central
Low 'currency'	High 'currency'
Undirected, not legislated for	Legislated and directed (controlled)

Table 2. Martin's (2004) comparison of informal and formal learning in Westernised settings

Informal learning	**Learning in Westernised school settings**
Occurs in the course of mundane adult activities in which the young take part according to their abilities	Emphasises universalistic values, criteria and standards of performance
Occurs in families; expectations are in terms of who a person is not what was accomplished	What is being taught is more important than who is doing the teaching
Fosters traditionalism	May represent a culture that denigrates the indigenous culture
Emphasises emotional and intellectual domains	Emphasises language; language occurs out of context
Is strongly observational, participatory	Emphasises mastering symbol systems

Informal learning	Learning in Westernised school settings
Occurs where meaning is intrinsic to context	Introduces new subjects, unknown history, and physical universe not derived from senses

Stocklmayer, Rennie and Gilbert (2010) identified three models which explain the relationship between informal and formal education as put forward by various researchers and practitioners working within the area:

1. The first model sees the two sectors as unrelated and distinct with very different functions. While the informal sector uses science to provide entertainment and changes in line with market forces the formal sector is determined by governmental parameters which also dictate changes that take place in the curriculum.
2. The second model sees a limited interaction between the informal and formal sectors; while the formal sector is the lead sector in providing science education to students, it makes use of information and resources available in the informal sector to support student learning.
3. The third model sees the two sectors as working in close alignment so that the informal sector is closely integrated into the everyday working of the formal sector and therefore produces a third space for science education.

Stocklmayer, Rennie and Gilbert (2010) suggest that if organisations worked towards implementing either of models two or three into working practices this would help meet some of the problems faced in the formal sector in helping more students engage with science. Stocklmayer and colleagues also suggest that if organisations within the formal and informal sectors worked towards using either of these two models there would be a number of other challenges that professionals would need to be aware of and cater to, e.g. careful planning before taking students out of school, or changing structures within the school to allow activities from the informal sector to take place on site.

School-museum interactions

Partnerships and interactions between schools and museums present many challenges, as has been well documented (Anderson, Kisiel, & Storksdieck, 2006; Davidson, Passmore, & Anderson, 2010; Dewitt & Storksdieck, 2008; Griffin & Symington, 1997; Kang, Anderson, & Wu, 2009; Tal, Bamberger, & Morag, 2005; Phillips, Finkelstein, & Wever-Frerichs, 2007). Existing research has endeavoured to clarify the roles of schools and museums to help create successful partnerships and some of this research has focused on both the teacher and the museum perspective (DeWitt & Osborne, 2007; Gupta, Adams, Kisiel, & Dewitt, 2010; Kisiel, 2010; Tal & Steiner, 2006; Tran, 2007). Research has revealed that teachers' beliefs about what would be useful for their students' learning goals are often not fully realised in field trips to informal learning institutions. For example, Kisiel (2005) found that while 90% of teachers who took their students on a trip to an informal education institution indicated that they had hoped the trip would complement the school's curriculum goals, only 23% of them found that this was the case.

Only limited research has explored the expectations of museum educators. Existing research which has explored museum staff views has found that there is a misalignment in the expectations of school teachers and museum staff. So, for example, Tal and Steiner (2006) conducted observations and interviews of teachers on a field trip at a science museum; the teachers had not taken a lead or active role in directing students' learning; much of this had been left to the museum educators. The findings also indicated that museum educators had expected teachers to be more active in their students' learning. Tal and Steiner concluded from their research that the differences in expectations between teachers and museum educators can impact students' experience of museums and could serve to discourage museum educators. Interviews and observations were used as primary research tools by Tran (2007) who explored interactions between teachers and museum staff in order to learn more about the practices and perspectives of the museum staff. The findings indicated that the two key aims of the museum educators' efforts were to encourage students to return to the museum while also helping to foster and develop students' interest in science. For museum educators it was more important to provide a meaningful and memorable experience than to develop students' science content knowledge. In this particular study the differentiated and clear roles of museum educators and teachers worked well; museum educators expected to take the lead in educating students and presumed that teachers were responsible for controlling student behaviour and tracking time.

In some partnerships, students are educated within classroom settings rather than within museums themselves. A teacher-informal educator partnership was examined in order to understand the roles of both teachers and informal educators in the development and implementation of an elementary classroom science unit (Weiland & Akerson, 2013). Within this partnership each had a defined explicit role, so teachers led on classroom management while informal educators led on the content. The partnership was successful largely because of good communications between teachers and educators and because each of their roles had been established prior to the implementation of the unit.

Kisiel (2010) studied a school-aquarium partnership and showed that establishing effective partnerships takes good communication, change in organisational practices and time. In this partnership the school was given access to the aquarium for field trips alongside aquarium-led science lessons. Both teachers and informal science educators were interviewed; each voiced concerns about communication and it appeared that distinct differences in practices at each institution interfered with as well as influenced implementation of the programme. The programme ran for two years, and in time with good communication—discussing roles, strategies and objectives—an overlap of practices formed and adjustments were made by both partners to help with its successful implementation.

It has been theorised that the reason why miscommunication takes place between teachers and informal science educators such as those in museums is because they work in very different contexts without fully understanding the particular constraints and challenges within which each work (DeWitt & Osborne, 2007). DeWitt and Osborne (2007) suggest that museum educators need to better understand the conditions and context within which teachers work and create resources that complement the work teachers are already doing in classrooms. DeWitt and Osborne put forward a Framework for Museum Practice (FMP) which emphasises that the resources museum educators develop ought to be in alignment with the requirements of teachers while also making full use of educational resources found in museums. Of course, it is incumbent on schools, reciprocally, to understand the aims and practices of museums.

Kisiel (2014) collected data via interviews, focus groups and questionnaires to gain an insight into teachers and educators from informal science institutions (which included museums) about their expectations and the perceived challenges of activities taking place within their partnership. All of the participants were from one US region, South California. Kisiel found that issues around capacity, authority, complexity and communication were fundamental to influencing the experiences cited by both the teachers and the informal science educators. Kisiel found that both informal and formal educators had much overlap in ideas about what a successful field trip might look like. Kisiel also put forward a number of key recommendations based on the findings of the research. In order for partnerships to be successful and create practice-based connections partners need to focus from the start on developing shared goals. Developing a joint enterprise, with shared objectives and outcomes, is an important part of creating more meaningful connections between communities of practice.

Kisiel also pointed out that a challenge in realising these goals is that even within the same organisation there can be different and multiple ideas of what successful cognitive and affective outcomes look like. Kisiel found that different members of informal science education organisations varied in their ideas of what successful activities would involve. So, for example, while volunteers at a museum may feel a successful visit is measured by good student behaviour, informal science educators may suggest that the successful activity will introduce particular standards-based concepts (e.g. evolution), and both expectations differ from that of teachers who may view a successful visit as providing students with exposure to a new learning environment. Kisiel also suggested that a lack of communication which leads to confusion and differences in ideas may not be due to a lack of effort in trying to achieve a joint enterprise; rather, efforts to communicate may be undermined by other professional tasks which may limit opportunities to communicate. Finally, Kisiel indicated that another barrier to a successful partnership is that both teachers and informal science educators may not be sure about which activities are possible. For partnerships to be successful teachers need to cross boundaries into multiple communities in order to be able to incorporate resources from informal science organisations into their practice. Similarly, informal science educators need to navigate through school communities as well as their own organisation in order to foster effective connections with schools and/or teachers. This way of working was also suggested earlier by Wenger (1998). Wenger indicated that for one community (e.g. museums) to successfully interact with another community, it is necessary for communities to clarify boundaries as well as define strategies for encountering or crossing those boundaries. Wenger suggested that this way of working can lead to meaningful connections that involve changes in existing practices in organisations.

According to Braund and Reiss (2006) there are five ways in which out-of-classroom environments can contribute to students' science learning: improved development and integration of concepts; extended and authentic practical work; access to rare material and to big science; the development of more positive attitudes to school science which stimulate further learning; and positive social outcomes (collaborative work and taking responsibility for learning). They suggest that science educators need to focus on the type of activities that are available in school science. Despite laboratories being a good place to learn about science, they are unable to present science in a natural context and can be less appealing to students. They recommend that students be presented with opportunities for engaging with the natural environment (via fieldtrips) and have opportunities to attend zoos, science centres, museums and botanic gardens. They suggest that supporting students' science learning outside of the classroom, when combined with school laboratory and class-based discussions of what students have experienced, can help increase student engagement and learning of school science.

The role of informal science institutions in student science education

In the US, a range of organisations (e.g. Institute for Museum and Library services, 2005) have strongly recommended that informal science education institutions (such as museums) be used to support students' learning of science. There is an increasing recognition that formal partnerships between schools and informal learning settings is an effective way to help students with their science education but there is limited documentation of such collaborations and such documentation is often limited to simple reports of good practice without details on how the partnerships were implemented and what hurdles and challenges both the formal and informal learning organisations had to overcome (Bobick & Hornby, 2013; Pumpian, Fisher, & Wachowiak, 2006). A report by the Center for the Advancement of Informal Science Education (2010) which closely examined US partnerships between schools and informal science education settings indicated that despite the occurrence of partnerships between schools and informal science education institutions there was little evidence to show the impact of partnerships or the specifics behind the development and sustainability of such partnerships.

The UK science education community also feels the time has come to know more about what makes science education effective and the role school-museum partnerships can play. In a detailed study (the first of its kind), Falk, Needham, Dierking and Prendergast (2014) conducted an extensive review to explore how connected the science education community is in the UK. They administered a web survey, developed from a series of 51 semi-structured interviews, to key science educators from across the UK science community. Their findings indicate that despite certain parts of the science education community being highly to moderately interconnected and collaborative this was not the case with universities and schools. Falk and colleagues organised the science education resources into 17 distinct science education sectors. For the purposes of this review we will not expand on how organisations were grouped into each section but rather focus on Falk and colleagues' key findings which have implications for learning in NHMs. Their analysis indicated that in some science education organisations there is a high degree of interactivity between sectors but that in general collaboration was quite scarce. Although some organisations within some sectors have connections to other sectors, in general most of them lacked a wide range of long-term collaborations. Their findings also indicated that many science education organisations had an inflated sense of self worth which went hand in hand with such organisations only valuing external organisations that were in close alignment with their own particular priorities. The key culprits in working in an insular way, according to Falk and colleagues, were universities and schools. While schools benefit from informal science institutions, and all sectors contribute to the needs of schools, schools themselves return very little back. This was also true when looking at schools' collaboration with other schools—there was very little partnering between schools. In contrast, informal science institutions such as museums were very well interconnected and worked very collaboratively. Falk and colleagues concluded that in order to maximize the effectiveness of science education those involved within various communities would need to develop and build collaborative and synergistic relationships. They also found that there is much effort placed on developing resources for school-age students but very little for those under the age of five and adults. Other inequalities they found were to do with fewer resources being available for those in rural communities and those from lower socioeconomic backgrounds.

Existing research indicates that informal science education learning institutions such as museums have developed a range of methods to help with formal science learning (e.g. explainers, outreach programmes and web-based materials). While informal science education learning institutions could help with teacher professional development, without a formal partnership the onus lies on individual teachers to discover what resources are available and how to blend them into their own curriculum. In addition, where partnerships are being/or have been established, in order to engage schools and their students fully, NHMs need to take account of individual school culture (Anderson, Kisiel, & Storksdieck, 2006; DeWitt & Osborne, 2007; Mortensen & Smart, 2007; Tal & Morag, 2007).

A large number of informal science centres in a number of countries offer science education programmes, often in the form of field trips that are available to schools and can bridge the learning that takes place in informal and formal settings. Some informal institutions develop curricular resources available in print or online for schools. In addition, there is a tendency for some (not all) informal science education institutions to offer professional development programmes for teachers to help them know more about how to make the most effective use of their time on field trips. There is an increasing number of informal science education institutions that would like to (and do) play a more significant role in supporting high quality learning and engaging science in the classroom through the means of partnerships. In such organisations informal science educators expand (or create) teacher professional development programmes in order to create opportunities for teachers to engage in content learning, inquiry-based pedagogical strategies and learn more about classroom resources and pedagogies that are available. Both schools and informal science educators believe that good partnerships are the right step forward in expanding public engagement with science. Given this particular need and interest in developing effective partnerships to educate the public, the Informal Learning Collaborative (ILC) programme, a professional development programme for informal educators, has been created and is currently leading on teacher development programmes (Bevan et al., 2010). The key aim of the programme has been to build a community of informal educators. These educators are working closely with schools, with the inquiry resources of informal science institutions and the design of professional development programmes. The programme is based at the Exploratorium in San Francisco and since its establishment, the programme has worked with over 100 informal educators who represent around 60 institutions and communities in the US and the UK.

Lawrence and Tinkler (2015) used the Natural History Museum, London as a case study and established that science museums are no longer representing a static image of science or a fixed body of knowledge that is largely beyond doubt or dispute. In recent years, changes and developments in science museums have led to opportunities for students to gain more knowledge about the various processes of doing science; students are also able to engage directly with scientists and real scientific activities. NHMs are ideal candidates to help students learn more about science and to educate the public about important issues such as biodiversity, an area which requires special attention given that there is a lack of public awareness about how such issues impact the UK (Natural History Museum, London, 2015). To care more about biodiversity loss, the public needs to be: emotionally engaged; intellectually engaged; informed about threats and informed about what is being done. NHMs are well placed to help meet these goals (Natural History Museum, London, 2015). They have active research programmes that are committed to and geared towards helping students engage with real-world science; these programmes provide opportunities for students to know about the societal and scientific challenges of the present and future world.

The importance of STEM ecosystems

There has been some research which has pointed to the beneficial impact to students of project-based learning or community-based learning; this type of learning relies on the creation of a meaningful context linked with outcomes alongside connections with the wider community (Flanagan & Draper, 2006; Jenkins, 1999; Rennie, 2006). In project-based or community-based learning, students work with scientists or community members to gather data, so providing students with a more hands-on, inquiry-based approach to learning rather than simply undertaking investigations after having been told about scientific concepts by teachers. Many researchers within the field who propose such ways of learning place emphasis on the use of social interaction, real-life relevance, confidence-building and creative purposeful activity within a framework of inquiry-based learning in order for such initiatives to be successful. Such methods ensure that students' particular interests in learning are met as opposed to having to be told on what to focus their learning.

There is evidence to suggest that an inquiry-based approach set within a wider community setting has proved to be successful in students' learning (Donahue, Lewis, Price, & Schmidt, 1998). These types of settings cross boundaries that are not usually crossed in formal education and rely on building partnerships among parents, schools, scientists and the local community. There have been a number of evaluations of these sorts of initiatives which have indicated some positive findings. Moje, Collazo, Carillo and Marx (2001) found in their research that using a project-based learning approach enables students to have the opportunity to write, talk, read and investigate scientific ideas that appeal to them as individuals. Donahue, Lewis, Price and Schmidt (1998) found that students' scientific literacy increased as a result of such interventions. Similarly, Rennie and Howitt (2009) conducted an evaluation of a national project in which teachers partnered with scientists. As a result of the partnership students' knowledge of scientific concepts increased and students expressed an enjoyment for learning science. Similarly, Bouillion and Gomez (2001) found in their evaluation of community-based interventions that students had an increase in their learning of science concepts and scientific skills; students' interest in science was also enhanced.

In 2003, a Policy Statement about learning science in informal contexts was circulated by the Informal

Science Education ad hoc Committee of the Board of the US National Association for Research in Science Teaching (NARST). The statement indicated that learning rarely, if ever, occurs and develops from a single experience. Rather, learning in general, and science learning in particular, is cumulative, emerging over time through myriad human experiences, including but not limited to, experiences in museums and schools; while watching television, reading newspapers and books, conversing with friends and family; and increasingly frequently, through interactions with the Internet. The experiences children and adults have in these various situations dynamically interact to influence the ways individuals construct scientific knowledge, attitudes, behaviors, and understanding. In this view, learning is an organic, dynamic, never-ending, and holistic phenomenon of constructing personal meaning. This broad view of learning recognizes that much of what people come to know about the world, including the world of science content and process, derives from real-world experiences within a diversity of appropriate physical and social contexts, motivated by an intrinsic desire to learn (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003, p. 109).

Since the NARST statement, there has been a continued interest in trying to bridge informal and formal learning environments to increase students' engagement and interest in science. Very recently, in the US, a committee of experts from STEM organisations were put together to investigate how both the informal education sector and formal education could improve young peoples' learning in STEM. The findings were put into a comprehensive report (Olsen & Labov, 2014). We discuss these particular findings as they provide a comprehensive summary and guidance as to how various parties can work together to improve students' learning in STEM. The committee was supported by a number of research and teaching organisations. Specialists in education research, policy makers, professional development specialists and funders of STEM education alongside professionals from the communities explored how strategic connections among the diverse communities could help put into place a number of important factors: new avenues of teacher preparation and professional development; more comprehensive assessment of knowledge, skills, and attitudes about STEM; and integrated curriculum development.

The term ecosystem is used in the report (taken from Traphagen and Traill, 2014, whom they cite); a STEM learning ecosystem comprises a number of organisations (schools, afterschool and summer programmes, science centers and museums) alongside informal experiences at home. The report by Traphagen and Traill discusses six different strategies that could be adopted to help to build STEM learning ecosystems: build the capacities of educators in all sectors; equip educators from different sectors with tools and structures to enable sustained planning and collaboration; link in- and out-of-school STEM learning day by day; create learning progressions for young people that connect and deepen STEM experiences over time and focus curricula and instruction on inquiry, project-based learning, and real-world connections to increase relevance for young people and engage families and communities in understanding and supporting children's STEM success. None of the 15 ecosystems Traphagen and Traill looked at had engaged in all six of these strategies although there was some degree of overlap and collaboration between organisations.

Traphagen and Traill found that student teachers were used as educators across several sectors within some ecosystems therefore encouraging student teachers to engage in collaboration early on in their careers is important. In addition, the development of curricula to be used in afterschool programmes for teachers to work with young people meant that teachers changed their teaching practice in their classrooms. Furthermore, STEM organisations and out-of-school programmes instigated public awareness campaigns about the importance of STEM while also engaging families and communities. Traphagen and Traill put forward three categories of actions which could advance these ecosystems: practice; policy; and research and evaluation. With respect to 'practice' they suggest scaling work so that more can be learnt about what is effective and ineffective. In addition, there ought to be a community of practice between the various sectors in the ecosystems invested in STEM learning while also ensuring that more is learnt about how ecosystems can meet the goals of the curriculum. With respect to research and evaluation there needs to be a focus on assessing learning outcomes across settings, finding more ways of connecting research and practice across different organisations and taking part in dissemination activities across sectors. For the third area, policy, there ought to be an agenda that pinpoints strategic levers at different levels to improve ecosystem-building efforts.

The discussions enabled the committee to develop a framework for STEM integration in K-12 education. The purpose of the framework was to develop an alignment of goals with a particular emphasis on: the overall goals of the programme; what the nature of an integrated approach is; the type of support that needs to be in place for success; the ways in which teachers design their classrooms; and how teachers ought to work with people inside and outside of schools. In addition to the framework, the Committee on Integrated STEM Education developed four categories with a total of nine recommendations to help realize the goals implicit in its framework. The four categories developed were: research; outcomes; design and implementation; and assessment.

Research

1. Research ought to be used when there is: a detailed account of an intervention; alignment of study design and outcome measures with the goals of an intervention; and control groups are a part of the process.
2. A common framework ought to be used for both the research strategy and the intervention by the various sectors involved in integrating STEM education, e.g. educators, programme developers, researchers.

Outcomes

3. There needs to be a clear outline about what impact the intervention will have on student interest, identity, achievement and persistence. Avoid the 'integrated STEM is good for everything' strategy.
4. There ought to be a detailed examination of the long-term impact of interventions on students' interest and how this relates to students from different backgrounds

Design and Implementation

5. There needs to be a clear outline about the support needed to implement the intervention, overall goals and the outcome measures.
6. The teaching and learning goals need to be identified and clear from the start.
7. When developing programs there needs to be a focus on the cognitive and learning literature to understand and help develop learning goals and learning progressions.

Assessment
8. Programs need to develop new assessment tools to enable programs to be assessed effectively.
9. The various sectors involved in programs need to incorporate continuous improvement as a part of the program.

Survey research conducted on 1000 afterschool programme staff by the Afterschool Alliance indicated that it was important for afterschool programmes to propose STEM programmeming as part of a larger widespread effort (Afterschool Alliance, 2011a). However, in contrast to these findings, another survey found that 80% of US households have not enrolled their children in afterschool STEM programmes (Change the Equation, 2013), suggesting either that many families are choosing not to take advantage of afterschool programmes or that such programmes are not always available, despite the fact that there is much enthusiasm to increase student numbers by the afterschool programme community. There have been evaluations conducted on STEM research in the US which suggest some positive results about learning outcomes. Research conducted by the Afterschool Alliance on afterschool STEM learning indicated that the programmes they investigated were able to deliver various goals and outcomes identified in the integrated STEM report (National Academy of Engineering and National Research Council, 2014).

The role of families

There has been some research that has examined the role of families in students' science learning and engagement and the importance of families in students' science engagement has been established (e.g. Archer et al., 2012). This has implications for learning in NHMs, particularly when looking at the role of families within a formalised STEM ecosystem. There is some existing research that has examined the role of parents in children's learning at exhibits. In one recent study, for example, Tare, French, Frazier, Diamond and Evans (2011) studied twelve families (with data collected on parents and children) at an exhibit called Explore Evolution, which focused on the evolution of seven organisms. The families were at the exhibit for, on average, 44 minutes. Tare and colleagues specifically examined the role of parents in their children's learning. The conversations between parents and children were coded for: evolutionary conversations; non-explanatory conversations; and explanatory conversations. In around one in ten conversations, parents used evolutionary terms and evolutionary concepts. In 65% of conversations, substantive explanatory conversation occurred while non-explanatory conversation occurred in only 21% of conversations. In 13% of conversations, parents made substantial use of exhibit text; in these instances parents reframed the exhibit text and read it to their children. In addition, children also used evolutionary terms when parents were using such terms. These findings suggest that parents play an important role in the development of children's engagement and learning in science. It would be worth having further museum exhibits designed specifically for parents, particularly as existing research suggests that the development of informal learning activities aimed at parents and/or guardians can help with science engagement (Jones, Taylor, & Forrester, 2010).

How to measure outcomes in informal science education learning institutions

In their research report Bell, Lewenstein, Shouse and Feder (2009) indicated that being able to measure learning outcomes at informal science education institutions and being able to determine how effective learning is important, but that, to date, defining a good outcome has often been controversial. Bell and colleagues point out that achievement measures used in school settings have been used as tools to measure outcomes at informal science education institutions. However, Bell and colleagues argue that it is not appropriate to use traditional academic achievement outcomes because of key limitations. Although there are advantages to using academic outcomes, such as the fact that they are readily available and help facilitate coordination between informal environments and schools, they also have certain disadvantages, in particular because they are unable to reflect the defining characteristics of informal environments. Informal settings can provide a range of capabilities that are not possible with academic achievement outcomes; the curriculum of informal settings is very different to that of schools and the learning is focused on voluntary experiences, which means that academic outcomes can play only a very limited role in this respect. Finally, the exhibits are designed for a range of ages and abilities, and for specific learning and experiential goals within their defined spaces; capturing this experience with academic outcomes is difficult. Bell and colleagues have suggested that rather than use academic outcomes or subjective learning goals, educators and researchers ought to use a variety of specialised science learning goals.

Bell and colleagues put forward a 'strands of science learning' framework; the framework recommends the development of science-specific competencies that are supported by informal environments. This framework builds on an earlier framework which was specifically developed in the US context for K-8 science learning (National Research Council, 2007). This four-strand framework from the National Research Council is in close alignment with Bell and colleagues' framework. However, Bell and colleagues suggested two additional strands on the grounds that these are of particular value in informal learning environments. Here we list the six strands for students as suggested by Bell and colleagues (p. 4):

> Strand 1: Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world (this strand is of particular relevance to informal learning environments).
>
> Strand 2: Come to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science.
>
> Strand 3: Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.
>
> Strand 4: Reflect on science as a way of knowing; on processes, concepts and institutions of science; and on their own process of learning about phenomena.
>
> Strand 5: Participate in scientific activities and learning practices with others, using scientific language and tools.
>
> Strand 6: Think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science (this strand is of particular relevance to informal learning environments).

Bell and colleagues conclude (and we concur) that among the informal science learning community (and we think also among the broader science education community) there is a diverse range of views about how to measure learning outcomes appropriately, including which outcomes are the most important ones to measure. Nevertheless, there is some consensus among science educators about the nature of informal science learning outcomes. First, there ought to be a focus on outcomes that are not confined to ones that are limited and narrowly defined; rather, some outcomes need to be complex, so as to recognise that learners are diverse and have different needs. Such a focus will enable more flexible personal learning trajectories to take place within school settings. Secondly, research ought to focus both on outcomes that are intended and ones that are unintended. Often, learning outcomes are based on the goals and objectives of a programme set externally (to the learner) by a teacher or informal science educator. However, as is the case in informal science learning settings, learning can be guided by what intrinsically motivates student. What they focus on during a trip, for example, to an NHM, may therefore not be closely related to the planned learning objectives. Accordingly, when measuring learning outcomes, researchers need to focus on all types of learning that have taken place during a field activity. A third and important point about measuring outcomes is that it may not be the case that learning outcomes are immediately evident. In many studies the outcomes used to measure the impact of informal science learning experiences have focused on short-term outcomes; there needs to be a greater focus on long-term impacts and, in addition, how these long-term impacts on learning differ from short-term ones. Bell and colleagues also suggest that students' learning outcomes ought to focus not only on the way an individual learns but on how whole groups learn collectively; so, for example, one might have peer groups collectively develop strategies for learning together and sharing information.

What about actual assessments?

Bell, Lewenstein, Shouse and Feder (2009) also address the key issue about the form which assessments should take. They suggest that assessments of learning at informal science education environments ought to measure a range of outcomes: cognitive, behavioral, social, intellectual, attitudinal and participatory capabilities. They also suggest that assessments should encompass student learning experiences that make these environments attractive and engaging while also having construct and ecological validity. To date, much of the research suggests that there is often an over-emphasis on academic outcomes which may not be valid, or any rate very accurate, when trying to uncover the type of learning that has taken place. Assessments ought therefore to be aligned with the type of learning that has taken place, for example, having a focus on features of the activities in which students have engaged. In order to make accurate inferences about what has been learnt, and before inferences can be made about the effectiveness of learning in an informal science education environment, those researching such effectiveness ought to ensure that there is an alignment between the learning activities and the assessment and consider whether the assessments are based on the same norms as those that promote engagement in the learning activities.

Factors that contribute to successful engagement and learning at exhibits

Although some of the objectives in informal science education institutions complement those of schools, there are many objectives where there is no overlap. However, little research has been conducted about what particular factors contribute to successful engagement and learning around exhibits, whether for visitors in general or students specifically. Very recently, there has been some quantitative evidence put forward to help pinpoint the sorts of factors which contribute to visitor engagement and learning around interactive surfaces (Block et al., 2015).

There are a number of reasons why there has been little quantitative research conducted on factors that relate to effective visitor engagement; some of these issues are related to being able to define with precision what a group is. This is particularly problematic in museums as groups dynamically form, overlap, transform and disperse as the result of a naturalistic flow of visitors. Block et al. (2015) were able to decide on how to categorise visitors through an automatic grouping algorithm that partitions a constant flow of visitors into groups based on visitor's shared time spent around the table. The algorithm was developed based on observations of visitor engagement over a two-year period at two exhibits. From their research they concluded that the following factors impacted how visitors engaged with exhibits: age composition; occurrence of certain social behaviours, such as turn taking; and group size. It was not necessarily the case that groups spend more time at the exhibits than single visitors, although people in groups of two spent longer on exhibits than those who were alone or in groups of three.

Furthermore, Block and colleagues found that larger groups (four and above) were rare; they concluded it would be best to design exhibits tailored towards pairs of visitors. Block and colleagues also found that it was better if exhibit designs catered to single users as well as those in groups as around 30% of their visitors interacted with exhibits on their own. With respect to children, they found they were more likely to engage with the scientific content of the exhibits and spend more time there if there were adults who accompanied them. Block and colleagues recommended that in order to maximise effectiveness of adult-children groups, there ought to be information available by exhibit displays so that adults can help as facilitators to guide children. Block and colleagues also indicated that overlap between different groups of visitors was common; some groups would join an exhibit part way through as they walked into an exhibit already being experienced by another group. Block and colleagues indicate that a way of overcoming this is for exhibits to provide meaningful entry-points into the exhibit regardless of the stage at which people join an exhibit.

There are many research findings that detail the value that the public assigns to informal learning environments; a myriad of research indicates that visitors to museums (and other informal learning environments) greatly appreciate both the entertainment and social aspects of their visits alongside the opportunity for learning. Intrinsic reasons (such as enjoyment) are one of the key reasons why people visit informal learning environments. So, for example, research indicates that the challenges put forward by interactive exhibits lead to visitors feeling positively engaged (Sadler, 2006) and that even after the visit has ended people continue to express interest and excitement about what they have learnt (Stocklmayer & Gilbert, 2002), particularly when they have increased their skills and knowledge (Falk, Scott, Dierking, Rennie, & Jones, 2004). Existing research suggests that enjoyment can be embedded within learning, so that ensuring an appropriate connect with learning that feeds on students' intrinsic motivation would be valuable in increasing students' science learning. So, for example, Rennie and McClafferty (1996) found that when school students were given the opportunity for investigation this was an important pre-cursor to effective learning; other research points to the benefit of investigations in helping to build students' confidence (Perry, 1989). The use of narrative has been found to be a key element in raising engagement and interest in scientific concepts in zoos and NHMs (Tunnicliffe, 1996; Tunnicliffe, Lucas, & Osborne, 1997). In various studies Tunnicliffe has documented that visitors to NHMs used narrative as a way of gaining knowledge, interest and engagement with others when discussing specimens; similar findings were reported in her work at zoos when visitors used narrative to discuss animal behaviour. The intrinsic reasons for visiting informal learning environments, alongside the intellectual merits of engaging in such activities, were in recent years summarised by Bell, Lewenstein, Shouse and Feder (2009): "There is evidence of learner excitement and strong positive emotional responses … There is also clear evidence for learning science content … participants can reflect on the enterprise of science and on their own thinking about science … there is evidence of learners' attempts to personalise and integrate science learning experiences with their values and identity" (pp. 161-162).

The role of informal science institutions in creating affective learning

Given that museums invest significant resources in attempting to engage school students, the affective value of museum visits is an area that has received surprisingly limited attention. The science education literature uses the term 'affective learning' to refer to both the changes in visitors' attitudes and the emotions that are created by the learning that takes place at informal science education institutions (Roberts, 1993). Salmi (2003) found that Heureka, a Finnish science centre, was able to create effective learning for students by partnering up with schools. Students' intrinsic motivation was increased simply by creating opportunities for them to engage in the open-learning environments of the science centre. Salmi also surveyed 1019 undergraduate students at the University of Helsinki; the analysis showed that informal science education institutions had a strong impact on the academic career choices of students. In a study that explored the role of informal science education institutions on positive affect, it was concluded from a series of 75 interviews with museum professionals that many of these professionals had talked about important museum learning experiences, some of which took place in childhood. Of the 75 interviews, Spock (2000) indicated that museum learning experiences were life-changing incidents for 30-35 of the museum professionals.

A study undertaken in the 1980s found that young children cited affective outcomes as reasons for visiting a zoo (Birney, 1988). In another study that explored affective outcomes in students and teachers, Hooper-Greenhill et al. (2005) found that both students and teachers indicated positive emotional responses having participated at museum visits. Winterbotham (2005) conducted a survey on 450 teachers that explored teachers' perceptions of what they expected their students to gain from museum visits. The findings indicated that teachers expected their students to develop skills and positive attitudes towards the particular subject they went to study. Teachers also indicated that their students showed enhanced positive attitudes towards their particular subject when they had the opportunity to take part in interactive exhibits and hold museum artefacts. Furthermore, students' positive attitudes towards the particular science subject increased because of the museum visit.

There have been a number of appraisals of afterschool programmes; many of these have explored the effects on two types of outcomes: science-related attitudes and school performance. Research has demonstrated that there is considerable educational value of afterschool programmes at museums; these programmes have been found to increase students' performance in school science. Evaluations of afterschool programmes at museums also indicate that students' attitudes towards science careers, their interest and their self-confidence are greatly increased as a result of such visits. So, for example, the Miami Science Museum's youth programmes mainly directs its attention to enabling young people from low socio-economic backgrounds to have the opportunity to improve their interpersonal, confidence and communication skills while also providing them with opportunities to gain work experience, mentoring and training. The approach used by the museum has had (as demonstrated by case studies) an extremely positive impact on increasing young people's grades at the end of compulsory education as well as enhancing young people's employment opportunities. Similarly, the Evolutions Afterschool Programme at the Yale Peabody Museum of Natural History has seen consistently positive impacts on its participants and their interest in (and attitudes toward) science. Altmann, Tamez and Bartels (2001) argued that students' increased school success and enhanced intrinsic motivation in the San Francisco Exploratorium's programs is reliant on the program giving students autonomy and fostering an atmosphere of responsibility and respect. Gibson and Chase (2002) explored what led to positive outcomes in a short summer program; they concluded that to ensure success, students need an environment which enables them to express their opinions, talk about science and ask questions and all this can only be possible in safe, supportive environments.

It is not necessarily the case that museums can only impact positively on students outside of school time and in isolation from schools. Research has found that when museums and other informal learning organisations work with schools using particular interventions during school time there can be long-term benefits for students. For example, Laursen, Liston, Thiry and Graf (2007) found that even in a short science intervention, teachers indicated that students' engagement and interest had increased for both high and low ability students. In addition, the programme was able to challenge and change students' stereotypical perceptions of science and scientists. The programme also had an improved impact on students' scientific and critical thinking skills. The intervention also had a positive impact on teachers' increased understanding alongside learning about new ways to teach science within the classroom. The research indicated that particular elements of the programme underpinned all these positive changes; these elements were: specialist knowledge; having authentic science experiences; an inquiry approach; a break from routine; and teachers' active participation in the programme.

Research in the 1990s indicated that not all museum trips contributed to student learning; a number of review articles have discussed these findings (e.g. Falk & Dierking, 1992; Bitgood, Serrell, & Thompson, 1994; Ramey-Gassert & Walberg, 1994). The only drawback of these earlier studies is that assessment of children's museum learning only used short-term assessments; the maximum length of time between the museum visits and recall of experiences was a few days. In addition, these studies only looked at a narrow range of facts and concepts. There is evidence to suggest that the learning that takes place at museums only becomes apparent at a later date which can stem from anywhere between weeks to a few years after visits to museums (Dierking, Falk, & Abrams, 1996; Falk & Holland, 1994; Falk, Luke, & Abrams, 1996; McManus, 1993).

Falk and Dierking (1992) interviewed 120 adults and children about their memories of school field trips undertaken during the early years of their school education. They interviewed 34 nine to ten year olds, 48 thirteen to fourteen year olds and 46 adults. Falk and Dierking concluded that trips to museums in early childhood are important experiences in people's lives. Almost all of the adults and children interviewed could recount at least one thing they learned during a school museum trip while most interviewees could recount three or more things (non-conceptual) about their trip (e.g., purchasing souvenirs). Falk and Dierking reported that there were strong interrelationships between cognition and affect, cognition and the physical context and cognition and social context. Their analysis found that most of the memories of museum trips were rooted within descriptions of the physical and social setting and usually often in relation to accounts of feelings and/or attitudes; therefore, the physical, personal and social contexts were inseparably bound together. From their research they concluded that people learn about science in museum visits by adding it to the knowledge base and experiences they already have and that this process of learning and adapting one's knowledge takes place within a physical context (e.g. a museum) and is mediated through the actions of educators (school teachers and/or museum personnel). The learning that took place was helpful in learning about new concepts; so, some people generalised what they had learnt to additional situations. They also found that there was evidence that learning was always connected to feelings and emotions. Overall, they found that of the 123 people who were able to recall a field trip, almost all of them (98%) could remember at least one explicit event on the trip. A large proportion of people could also remember three or more explicit events on the field trip.

It is evident that in order to raise students' interest in learning science, more needs to be done to increase their intrinsic motivation for learning science. Evidence suggests (as discussed above) that both long-term and short-term science interventions conducted within or by those from the informal science education sector can have a sustained positive impact on students' enthusiasm for science. Interactive exhibits found in NHMs can develop students' skills as well as create an interest in science and this can be done in ways which complement learning in school, particularly given that the knowledge and skills gained from the informal science education sector cannot be replicated within the classroom. More needs to be learnt about how museum experiences impact on students' knowledge and understanding of and engagement with science. There has been some evidence to suggest (as discussed above) that exhibits which are tailored towards communicating scientific concepts are effective at eliciting the development of new understandings of scientific concepts, but some of these studies do not focus on the impact on attitudes alongside the impact of learning.

The Organisation for Economic Cooperation and Development (OECD) concluded from its analysis of the Programme for International Student Assessment (PISA) data (OECD, 2007) that students' engagement with science could be improved if educators encouraged students to think about science beyond the classroom and encouraged them to think about how science was something they could engage with outside of school. Woods-Mcooney et al. (2011) found that for Indigenous and non-Indogenous Australians the "variations in students' interest, enjoyment, personal and general valuing, self-efficacy, and self-concept in science were most strongly associated with the extent to which students engaged in science activities outside of school" (p. 233).

In addition, the answers to questions measuring out-of-school science activities were the ones that most strongly explained the variation in the answers to the questions that measured students' cognitive and emotional engagement in science. This was quite an important finding, especially as traditional measures used to explore differences between students (in particular, socio-economic ones) had a smaller role in explaining differences between students. Formal time spent in classrooms on science lessons and student-reported characteristics of classroom science activities also had a smaller effect on students' engagement with science and scientific literacy than did their out-of-school science activities.

There is a strong belief among the science education community that museums can have a major impact on pupils' attitudes to learning science (Braund, 2004a, 2004b). In the 'Student Review of the Science Curriculum', Murray and Reiss (2005) found that museums had a positive impact on students' attitudes to science. In their study, 16 to 19 year-old students were asked to complete an online survey about their experiences of learning school science. The questions asked about learning science inside and outside of school. The findings indicated that students found science field trips more enjoyable as a way of learning than any of the other options listed. The next two most enjoyable ways of teaching and learning science were looking at videos and taking part in science experiments in class. Although these particular two questions were concerned with learning in the classroom, the findings have implications for museum educators. If young learners find science videos and taking part in hands-on activities to be enjoyable, having exhibits that enable young people to learn in this way at museums may also prove effective.

In the Student Review of the Science Curriculum, students were also asked to rate which of the teaching and learning methods listed in the survey were the most useful and effective in helping them understand school science. Their top three selections were: having a discussion/debate in class; taking notes from the teacher; and doing a science experiment in class. Collins and Lee (2006) maintain that these survey findings have important implications for museums. They suggested that museums ought to emphasise discussions and debates as a way of engaging students with learning in museum visits. In the Student Review of the Science Curriculum, just over two-thirds (69%) of students indicated that the school science curriculum ought to include controversial issues such as genetic engineering or cloning. In addition, just over half the sample (57%) indicated that the science curriculum should also include topics on ethical and philosophical issues. NHMs have wide-reaching links in the scientific community to help set up exhibits that are able to address these issues; in addition, they are well placed to set up interactive exhibits to enable students to have opportunities to take part in hands-on learning.

Collins and Lee (2006) conducted a qualitative study with 38 secondary science teachers and four NHMs across England and explored the role of NHMs in supporting science teaching and learning. The museums worked collaboratively with the schools to support school science learning for 11–18 year olds. The teachers were all asked: How can NHMs effectively support science teaching and learning? In addition, data were collected from surveys and focus groups at the museums. The analysis revealed that the provision by museums of access to resources not available to schools and museums creating opportunities for students to meet 'real scientists' were important ways in which

NHMs could support science teachers. Furthermore, the findings indicated that museums' potential to inspire students by making them more inquisitive about the natural world is another way in which they could support the work conducted by teachers. It also emerged that creating opportunities for students to engage with scientists was useful for the new Key Stage 4 curriculum changes (for 14–16 year-olds) as well as being important for informing young people about career choices. The partnership discussed ways in which they, the partners, were able to put these ideas into practice and created strategies to help meet their goals. Teachers had to indicate when it was preferable for activities to take place for each Key Stage. There were a number of curriculum areas identified that would especially benefit from resources and expertise available from the NHMs; these areas were: evolution; earth science; classification/taxonomy; ideas and evidence; and 'how science works'. The analysis of the data collected was also able to inform the kind of support NHMs can offer to secondary schools' teaching and learning in science. The authors suggested at the time (2006) that given the educational climate, in particular the various changes to the science curriculum, there would need to be an ongoing consultation with science teachers. Many of their concluding remarks about the curriculum in relation to the learning that takes place in museums are still pertinent.

Research exploring students' interest in science and implications for NHMs

There has been much focus on exploring what the word 'interest' actually means to students. A distinction is often made between two types of interest: situational interest and individual interest (Ainley, Hidi & Berndoff, 2002; Hidi & Renninger, 2006; Silvia, 2006). Individual interest focuses on people's individual preferences for particular activities or topics and develops gradually over time and is long-lasting. Given that it focuses on people's preferences, usually people also tend to have positive affect that accompanies individual interest and it is associated with learning. Any given individual interest may eventually become a part of people's individual values. Situational interest is associated with a short-term change in interest which occur as a result of a change in the environment and can be associated with positive and negative affect although won't necessarily have an impact on people's personal values. Situational interest can lead to changes in knowledge and values if an individual is repeatedly exposed to the same stimulus. Although there are other ways of defining and distinguishing between different types of interest (and motivation is another way of measuring interest) which may be equally important in assessing students' engagement with science, e.g. Eccles (1994), we have emphasised these terms largely because they may enable a way of talking about and assessing the differences in types of learning that take place in museums, other out-of-school activities and the classroom.

Swarat, Ortony and Revelle (2012) examined the effect of three learning environment elements on students' interest in science; the focus was on the content *topic* to be learned, the *activity* through which the particular content was learned and the *goal* of learning the particular content. Swarat, Ortony, and Revelle recognise that there are other factors that could have an impact on student interest but focused on those particular three elements (topic, activity and goal) because taken together they constitute the key parts of science lessons. In total they recruited 533 US school students—187 students from the sixth grade (i.e sixth year of schooling) and 346 from the seventh grade. These students completed a survey at the start of the school year. The findings indicated that most of the explained variance in student interest was accounted for by activity type (the way in which learning took place) while content topics and learning goals contributed only a small proportion or nothing at all. Activities that were hands-on in nature and those that involved the use of scientific instruments or technology received the most reported interest from students while activities that were less hands-on or entirely cognitive in nature received the least amount of interest.

Evolution and the contributions to learning and engagement made by NHMs: A case study

Iconic exhibits of impressive fossilised specimens attract hundreds of thousands of visitors to NHMs across the world (Asma, 2001). Remarkably, there has been very little published empirical research on the characteristics of successful paleontological exhibits as learning experiences. Awe-inspiring authentic objects, such as the fossils that form the backbone of such collections, invite the public to experience the story of nature (Conn, 1998). Such objects derive their power from their authenticity; they are "invested with knowledge" (Conn, p. 9). Unlike human-made artefacts, however, objects of nature do not easily speak for themselves (Evans, Mull & Poling, 2002). Their meaning is revealed by the interpretive context in which they are placed, usually reflecting the perspective of the curator; however, visitors also bring their own interpretive stance (Friedman, 2005). Ideally, successful exhibits should integrate these dual perspectives (Roberts, 1997; Gurian, 1999).

In a survey of a representative sample of almost 400 visitors to US museums, Storksdieck and Stein (2006) found that, in comparison to the general public, museum visitors were somewhat more likely to endorse an accurate definition of evolution (56% of visitors vs 48% among the general public) and to report familiarity with the topic (90% vs 83%). When asked whether evolution was an accurate account of human origins, museum visitors were much more likely to endorse this statement (49% vs 27%) and to agree that science museums should present an exhibit on evolution (59% vs 27%). In a comparative study of museum visitors in Australia, Britain, Canada and the United States, Abraham-Silver & Kisiel (2008) found that there was international confusion regarding the mechanisms of evolution, in particular natural selection, with 75% of visitors exhibiting misunderstanding of the topic. This misunderstanding was unrelated to the educational level of the visitors or to their acceptance of evolutionary origins (see also Macfadden et al., 2007; Spiegel et al., 2006). Even biology teachers or students who have taken relevant courses and who might be expected to have a firm grasp of the topic have difficulty understanding evolutionary mechanisms as well as difficulty accepting the idea. For example, Nehm, Kim and Sheppard (2010) compared matched samples of U.S. biology- and non-biology teachers and found comparably high levels of misunderstanding of natural selection; further, about 50% of both samples endorsed the inclusion of creationist ideas (God created all species individually) in school curricula. These kinds of misunderstandings have been found in diverse student populations from graduate (Gregory & Ellis, 2009) to medical students (Bishop & Anderson, 1990) to child dinosaur experts (Evans, 2000). The percentage of the US population that rejects the idea of evolutionary origins, especially of human evolution, has remained steady at just about 46% over the past thirty years. Although they are correlated, both religious belief, negatively, and educational attainment, positively, are independent predictors of the acceptance of evolutionary origins (*USA Today*/Gallup Poll, 2012). Of course, many contemporary religions do not reject evolutionary ideas (Martin, 2010), but those religions whose teachings indicate a belief in the inerrancy of the Bible are more likely to do so and they predominate in the US. However, these beliefs are spreading to countries across the world (Reiss, 2008).

Clearly, a large segment of the public either does not understand or does not accept evolutionary theory, indicating that neither the formal nor the informal educational communities have been markedly successful at conveying these ideas. As the caretakers of the evidence for evolution it falls to museums of natural history to present this evidence in a way that acknowledges the interpretive difficulties of the average visitor. This is particularly true for paleontological presentations emphasising anatomical relationships, which comprise the majority of the exhibits, though some more recent exhibitions have made efforts to engage the public with a more visitor-centred approach.

While there have been few formal research studies documenting the success of the paleontological approach, Diamond and Scotchmoor (2006) found that the main foci of major evolution exhibits in museums around the world aligned with the prevailing US national science education standards of that period: geological time, fossil assemblages, systematics, evolutionary mechanisms, the historical approach (p. 24). Thus this classification (with some additions) is used here.

Life through time exhibits, such as Evolving Planet at The Field Museum in Chicago, offer visitors a clear pathway through geologic time ("… awe-inspiring journey through 4 billion years of life on Earth" http://www.fieldmuseum.org/), exposure to extinct species, and some sense of the relationships between species change and environmental change, which maps easily onto the science standards. Even though most children and adults have great difficulty grasping geological time (MacFadden et al., 2007), such time-based exhibits do provide an easy-to-follow, linear narrative that allows visitors to encounter macroevolutionary change against the backdrop of an ever-changing planet. If, however, such an exhibit displays the geological succession of single exemplars of extinct fossils from one taxon (horses, for example) it is likely to elicit a teleological bias, that individual adaptive changes lead to progressive changes in successive generations, over time. *Assemblages of fossils* in outdoor sites such as Dinosaur National Monument in Colorado (Diamond & Scotchmoor, 2006) provide an opportunity to observe fossils in situ and observe natural variation in a population, which does counter the idea of progression and individual change. Moreover, such sites often provide an opportunity to see the scientists at work. This approach is thus more likely to engage younger visitors interested in fossils and the process of fossilisation, which, in contrast to dinosaur expertise, is a positive predictor of evolution understanding (Evans, 2000). Although these sites are often in remote areas, many NHMs now deliver such an experience in-house, by providing visitors with opportunities to observe paleontological lab-work in progress (e.g., the Carnegie Museum of Natural History), or even to participate in 'fossil digs'.

The curatorial organisation of the evidence for evolution according to evolutionary theories of biological diversity and evolutionary relationships (systematics) may make more sense to the budding biologist than to other visitors. If, like the American Museum of Natural History (Diamond & Scotchmoor, 2006), museums that take this approach have an abundance of fossils illustrating the entire fossil record, then this approach has the virtue of avoiding the presentation of a single fossilised representative of a particular species, which is as likely to mislead as inform. However, members of the public are more likely to concentrate on mammal and hominin exhibits and hurry past invertebrate collections, as seen in a 1938 timing and tracking study at the Peabody Museum (Logan & Pickering 2014, Figure 5), thus evading the intent of the curatorial staff and incompletely experiencing the whole story of evolution.

Given that most NHMs are repositories for the fossil evidence for evolution, exhibits highlighting fossils are most likely to focus on the evolutionary history and origins of the specimens rather than the *mechanisms of evolutio*n. But some of the larger museums in the US, London, Paris, Melbourne and Moscow have devoted entire galleries to evolutionary mechanisms, incorporating them into broader evolutionary themes (Diamond & Scotchmoor, 2006). This means that evidential basis for these presentations have to shift from the more iconic and easily visible fossils, to the less easily visualised molecular evidence, in particular DNA. Although an understanding of genetic evidence is part of the science standards for older students, it is not easily grasped by a younger audience and exhibits highlighting such evidence are less likely to captivate visitors. Moreover, even museum visitors who accept the idea of evolutionary origins often fail to understand natural selection (Evans et al., 2010; Macfadden et al., 2007); thus more esoteric mechanisms, such as genetic drift and sexual selection, are even less likely to be accessible to this audience. Perhaps one of the more popular exhibits embracing the *historical approach* was mounted by the American Museum of Natural History on 'Darwin' (Diamond & Scotchmoor, 2006). This particular exhibit portrayed Darwin's life work, including his study, his writings, and his struggles as he began to clearly articulate his theories. Notably, the exhibit included a series of short videos with contemporary scholars describing the scientific approach, and how religion and science can be reconciled, exemplified by Pope John Paul II. This is one of the few exhibits that clearly addresses the controversies that directly concern members of the public.

One potential downside of the paleontological approach is that it may reinforce the idea that evolution happened in the distant past with little relevance to the visitor's everyday life. Exhibits with the potential of countering this viewpoint have taken a variety of approaches: hominin and behavioural evolution, narrative, including argumentation, issues of particular interest to the visitor, such as health, and digital representations.

Those museums that have access to fossil *hominin* specimens (and even those that do not) mount informative exhibits on human evolution (Scott, 2005). Despite the attraction of such exhibits, the late appearance of modern humans in the fossil record can give the impression that evolution is directional and progressive with *Homo sapiens* as the endpoint, especially to visitors with preconceived beliefs. Moreover, the relationship between humans and other primates is particularly problematic for visitors with strong creationist beliefs (Tare et al., 2011). Thus, merely including human evolution in exhibits is not sufficient; it is necessary to carefully organise the evidence and demonstrate that *Homo sapiens* is one species among many (Scott & Giusti, 2006). In Evolving Planet, the hominin story is intentionally placed at the midpoint of the final gallery—rather than at its end—for this very reason (R. Kissel, personal communication).

Several exhibits have used *narrative* to centre the visitor in the exhibit experience and this can take a variety of forms. Explore Evolution (Nebraska Museum of Natural History and six other Midwest museums) provided a contemporary touch by highlighting the 'story' of the ongoing research of the scientists investigating the evolution of a variety of organisms from a virus to a whale (Diamond et al., 2012). Moreover, it successfully bridged the gap between the more typical paleontological exhibits and those focusing on the molecular level by presenting both the genetic and fossil evidence for each organism. Pre-post studies of the visitor experience indicated that this approach successfully conveyed basic evolutionary science concepts (Spiegel et al., 2012). Charlie & Kiwi's Evolutionary Adventure (New York Hall of Science) used a story about 'Charlie' to focus on the evolution of birds from dinosaurs. The latter exhibition was designed for 7–10 year olds, traveled to a variety of informal learning institutions, and included a children's book. Children who visited the exhibit were more likely than their peers who visited a different exhibition to grasp the basics of natural selection (Evans, Weiss, Lane & Palmquist, in press). The 'Great Debate' Programme at the Natural History Museum in London was carefully designed to directly involve students in the 1860 Oxford Evolution debate. Students adopted the roles of the main participants in the debate and on a field trip to the museum they were introduced to the evidence by carefully trained facilitators. In comparison with their peers, students who attended the museum programme increased their understanding of evolutionary concepts (Tenenbaum, To, Wormald, & Pegram, 2015).

Exhibitions that focus on *health issues* from an evolutionary perspective have the goal of tying evolution to visitors' everyday interests. For example, the Yale Peabody museum developed programmes on Lyme disease (endemic in that area) and West Nile disease (Pickering, Fawcett, & Munstermann, 2012), which were very popular among visiting students. Pre-post evaluation of student understanding indicated that the exhibit/programmes were successful in conveying evolutionary concepts to the majority of students. Similarly, an exhibit titled Evolution Health Connection took as its main focus the science of evolutionary medicine. This exhibit portrayed the ongoing evolutionary processes in human populations and the influence of evolutionary principles on human health and disease. Adult and teen visitors enjoyed the experience and, in comparison with their peers, who visited a control exhibit, they were much more likely to grasp the idea that evolutionary processes contributed to modern health problems (Weiss, Evans, & Palmquist, in preparation).

Digital representations of evolution are increasingly becoming standard components in evolution exhibits, as they can more easily be used to represent the process of evolution and they facilitate visitor interactions; however, their effectiveness has not often been evaluated. Digital representations of the tree of life can be particularly successful, as visitors often fail to interpret the more standard two-dimensional format, even when they are augmented with fossil replicas (Giusti, 2006; Novick et al., 2014).

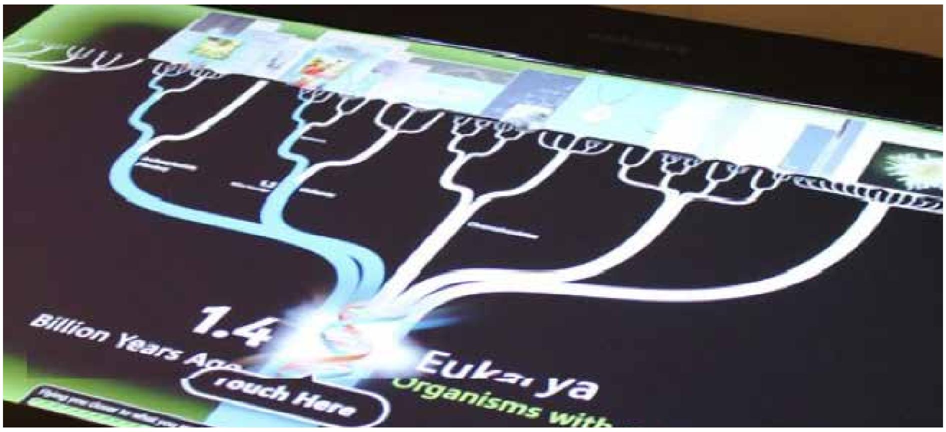
Interactive exhibits provided by NHMs to explain difficult concepts

A recent report urged the need for practitioners and researchers to find ways of using game-based technologies and informal experiences into formal classroom settings to help students find science to be more meaningful and relevant to their daily lives (Feinstein, Allen, & Jenkins 2013). Visitor experiences in NHMs and other informal science institutions have been found to be impacted by both open-ended exploration play and interactive exhibits (Allen, 2004; Allen & Gutwill, 2004; Crowley et al., 2001; Humphrey & Gutwill, 2005; Oppenheimer, 1976). Interactive exhibits usually allow visitors an opportunity to explore and/or manipulate physical artefacts, phenomena or specimens. Digital media have increasingly become popular as a way of enhancing visitor experiences by creating new types of hands-on experiences (e.g. via the use of videos, photos, texts, puzzles, games and augmented reality). In recent times some museums have begun to offer experiences that have extended the use of hands-on manipulation to include visitors being able to explore visualisations of large scientific datasets (e.g. Block et al., 2012; Louw & Crowley, 2013; Ma, Liao, Ma, & Frazier, 2012; Roberts, Lyons, Cafaro, & Eydt, 2014). Exhibits that offer these types of manipulation have several advantages. They have the benefit of offering hands-on experiences that use digital and computational tools while also allowing visitors to learn scientific concepts (Louw & Crowley, 2013; Ma, Liao, Ma, & Frazier, 2012).

Evolution is an example of a difficult concept that many NHMs try to convey to their visitors. There is increasing evidence to suggest that an effective way of increasing learning about evolution is exhibitions that have multiple components (Spiegel et al., 2012; Tare, French, Frazier, Diamond, & Evans, 2011), particularly if they are rooted within meaningful narrative (Evans, 2013). Video films have been used by NHMs to help educate visitors about evolution (e.g. Prum, 2008), although the problem with this is that videos are normally not interactive, so visitors are unable to ask questions. Research involving digital interactive displays indicates that when visitors have personal control over their exhibit experiences, they are more engaged with the learning. Non-interactive exhibits such as evolutionary (or phylogenetic) tree diagrams—which have been used to communicate the relatedness of organisms and the evolution of traits and structures over time—have been found to be difficult to understand (Meir, Perry, Herron, & Kingsolver, 2007; Novick & Catley, 2013; Phillips, Novick, Catley, & Funk, 2012; MacDonald & Wiley, 2012), which is particularly the case if the concepts presented by the phylogenetic tree diagrams are in conflict with people's own beliefs about evolution (Novick, Catley, & Funk, 2011). An effective way to help visitors learn is by having exhibits that enable social and physical engagement (Crowley et al., 2001; Eberbach & Crowley, 2005; Falk & Dierking, 2000).

Recently there has been an interest in learning more about how social and physical engagement shapes visitors' learning at computer-based exhibits, particularly those involving the visualisation of large scientific datasets (Davis et al., 2015; Horn et al., in press). For example, Davis et al. (2015) conducted an analysis of the different kinds of dyad interactions that are elicited by interactive tabletop exhibits. The exhibit that was the focus of their research, DeepTree, is an example of a type of interactive exhibit that is not yet common in NHMs. DeepTree, supported by the integration of phylogenetic and species data from five publicly available data sources, allows visitors to explore a phylogenetic tree of life that contains over 70,000 species. The exhibit has a deep zoom interaction technique that enables users to learn about the origin and unity of life, and the diversity of species on the planet. While exploring DeepTree, users encounter a range of evolutionary landmarks such as the emergence of nucleated cells, and of jaws (Figure 1).

Figure 1. DeepTree phylogenetic tree of life



In a study of the effectiveness of the DeepTree exhibit, the DeepTree research team recruited 248, 8–15 year-olds, in dyads, from two NHMs (Horn et al., in press). The dyads were randomly assigned to one of four conditions. In the first two conditions, the dyads interacted with different versions of DeepTree for ten minutes; in the third condition, dyads watched a ten-minute video on the same evolutionary topics. The final condition was a baseline control. The dyads were video-recorded so that researchers could collect measures of oral engagement, which were used in conjunction with computer logs of touch interaction collected in the interactive exhibit. The follow-up interviews assessed understanding of both macro- and micro-level evolutionary concepts. In comparison with the baseline condition, dyads in both of the DeepTree conditions were signficantly more likely to endorse the idea that all species on Earth were related through common ancestry, use evolutionary terms and concepts in their explanations, and correctly interpret a phylogenetic tree diagram. Moreover, the learning conditions that seemed optimal occurred when youth dyads both activated the relevant interactive exhibit functions and conversed about the specific experience. Statistical analyses controlled for the participant's age, family background and prior knowledge. These results provide strong evidence that interactive table-top exhibits can provide effective learning experiences, even if the interaction is relatively brief.

Interactive environments such as DeepTree can help enhance museum experiences and learning, especially given that research shows that the quality of visitor social interaction underpins enhanced learning in free-choice environments (Ash, 2004; Crowley et al., 2001; Eberbach & Crowley, 2005; Falk & Dierking, 2000; Falk & Storksdieck, 2005). Multi-touch tabletops like DeepTree are increasingly being seen as a particularly effective way of helping people learn about all forms of science (e.g. Price & Pontual Falcão, 2011). Price and Pontual Falcão (2011) concluded that young learners' attention switches between exploring technical aspects of the system and learning concepts, while also being able to entertain themselves. They also indicated that the process around having shared interfaces between learners enhances collective knowledge construction and argumentation. Research on such digital exhibits has found that interference leads to students changing their course of action and/or integrating the choices of others and/or ignoring/undoing the actions of others (Price & Pontual Falcão, 2011; Davis et al., 2015).

The design of DeepTree was influenced by similar digital multi-touch displays which focus on helping visitors learn about biological concepts and evolution. So, for example, the two learning environments Phylo-Genie (Schneider et al., 2012) and G-nome Surfer (Shaer et al., 2011) introduce students to evolution, genomics and tree-thinking (Baum, Smith, & Donovan, 2005), with the use of a combination of tangible and multi-touch tabletop technology. Build-a-Tree is another example of a project that has explored the use of tabletop technology in an NHM (Horn et al., 2012); this is a phylogenetic tree-thinking game based on multi-touch tabletop technology. Visitor interaction with Build-a-Tree was analysed and this demonstrated that the use of social interaction through game play contributed to visitors reporting that they had had an engaging and enjoyable learning experience. Other similar positive findings have been found with a range of digital tabletop interaction displays, e.g. Futura, a tabletop game on issues of environmental sustainability (Antle, Tanenbaum, Seaborn, Bevans, & Wang, 2011).

The role of NHMs in increasing visitors' knowledge of climate change: A case study

Over the last few decades museums have increasingly sought to be relevant and benefit society in ways beyond traditional collecting, preserving and educating activities (Silverman, 2010). NHMs around the world have started to do significant work on climate change (Cameron, 2011). Alongside other informal science institutions, such as zoos, aquaria and science centres, NHMs now see environmental issues, climate change and sustainable development as essential mission-related topics. Furthermore, many NHMs play major roles in fundamental research on the impact of climate change on Earth's biodiversity, and their collections are an irreplaceable resource to support such research. Some institutions also take public stances on climate change and examine their own activities in terms of their sustainability. Many act as civic spaces to foster community dialogue about the issues. And, most commonly, museums are developing educational programmes and exhibits that aim to change visitor knowledge, attitudes and behaviours. Responding to climate change and other environmental issues has become a common topic for discussion within the profession and specialist groups such as the Museums and Climate Change Network, launched in 2013, (http://www.amnh.org/our-research/anthropology/projects/museums-and-climate-change-network) have formed.

There is a wealth of literature on public understanding of and attitudes towards climate change that informs museum practice in this area. In 2008 the Association of Science-Technology Centers (which includes many NHMs as members) partnered with the Yale Project on Climate Change Communication to survey museum visitors to understand what they knew about the climate system and the causes, impacts and potential solutions to global warming (Yale Project on Climate Change Communication, 2011). Perhaps not surprisingly, frequent visitors to informal science institutions have a better understanding of these issues than non-visitors, are more likely to consider climate change as real, and are supportive of personal and political actions to mitigate the threat. However, even within this segment of the public relatively few had an in-depth understanding of climate change. The study did find that respondents think informal science institutions are trusted sources of information, and that the majority of visitors are interested in learning more about climate change. An extensive survey (Cameron, 2012) was conducted in Australia and the U.S. to probe the roles of NHMs and other types of informal science institutions in public understanding of these issues. It revealed that the public believes museums are places to obtain impartial information and found that many visitors thought museums should be actively engaged in public discourse around these topics, particularly in facilitating discussion and being part of networks of organisations concerned with climate change.

The great majority of the literature on NHMs and climate change centres on what museums are (or should) be doing in this arena. A special issue of the *Journal of Museum Education* (Anderson & Williams, 2013), which examined the best ways that museums can empower visitors to create a positive future, included several papers on climate change. A special issue of *Museum and Society* (2011) looked at how museums can communicate and foster an understanding of climate science. There are numerous studies that examine the effectiveness of individual climate change and environmental programmes, and are conducted for programme improvement rather than generalisable knowledge. Examples include the summative evaluation of the American Museum of Natural History's major traveling exhibit Climate Change (People, Places & Design Research, 2009) and summative evaluation of POLAR-PALOOZA, a programme that was implemented across the U.S. (Selinda Research Associates, 2010). There are many more examples that can be found online at informalscience.org. However, like much of the work in assessing impact of informal science programmes, such studies are focused on short-term affective and cognitive outcomes rather than long-term impacts.

There has been significant work in zoos and aquaria to evaluate their potential to change visitors' environmental conservation behaviours, while acknowledging the challenges of measuring outcomes, particularly over the long-term. This is summarised in Fraser and Sickler (2009). One of the few in-depth studies was carried out in a botanic garden (Sellman & Bogner 2012, 2013) to investigate whether participation in a one-day environmental education intervention could persistently enhance students' knowledge and conceptions of climate change, as well as changing environmental attitudes positively. The results were encouraging with cognitive achievement and positive environmental attitudes persistent over several weeks, as well as shifting students' conceptions towards a more scientific view of the issues.

Newer museum-based projects are being set up to address this gap in the research literature. However they have yet to report any outcomes. Examples include the National Network for Ocean and Climate Change Interpretation (NNOCCI) which involves informal science institutions, climate researchers and learning researchers, and aims to train front-line informal science institution educators and volunteers to communicate about climate change using techniques that are informed by research in the cognitive and social sciences (Spitzer 2014). Another example is the Climate and Urban Systems Partnership (Snyder et al., 2014), which is a partnership of NHMs and science centres in four cities that aims to foster city-scale learning initiatives on the subject of climate change. Again this project is rooted in the learning sciences and educational research.

The role of the digital world in NHMs

Digital media are providing museum educators and exhibit developers with a new suite of tools for accomplishing their communication goals (e.g. Loveland et al., 2015). Indeed, teachers and their students are increasingly relying on educational materials produced by NHMs and other informal science learning institutions. In recent times mobile technology and the internet are providing new ways of helping students engage with and learn science. So, for example, Scanlon, Jones and Waycott (2005) found that there were positive outcomes when secondary school students were encouraged to use mobile technologies to access science; students were able to have a sense of ownership over their work as they were able to keep their data and learning materials on their own computer. Putting processes in place to enable public access to online digital natural history collections is a valuable approach that many NHMs are developing; this is an important way of trying to engage the public with NHMs, given that we are living in a world which is increasingly digital, while for the vast majority of the younger generations using the internet to access information is a part of everyday life.

To date, the way individuals access natural history collections online has largely centred around using an online search interface that is connected to a collection database. This requires users to enter a keyword into the system which then produces related records. The disadvantage of using an online database and search is that it does not enable individuals to explore physical collections, to see what items look like in reality and to hear museum staff talk about the significance of objects. The advantage of online collections is that they provide a way of reaching members of the public who may not ordinarily come into a museum due to personal reasons or geographical location. With online collections, students and the general public do not necessarily need to take an entire day out to see collections; the public can return multiple times to see collections which fit into their busy lives. Unfortunately, many of these databases originated within scientific research projects, making many online interfaces difficult to manoeuvre for non-scientists or well-informed amateurs. More research is required into how to create strategies to enable the public in general and students in particular to use resources efficiently so that NHMs are better able to engage them. NHMs have an increasing presence on the web and are aware that in order for their information to be valuable the public needs to be able to find, access and use their resources (e.g. Woods, 2007). Online platforms (which are referred to by some as cybercabinets) are facilitating innovative ways for users to increase their knowledge and relate to scientific concepts.

Research by Sargent (2014) led to guidelines being put forward about how NHMs could help engage the public using online methods. Sargent used a range of research methods in formulating the recommendations: existing literature was used; three case study interviews of personnel were taken; a survey was conducted; and six model sites were analysed with a heuristic evaluation tool. This research recommended that the most efficient way to build cybercabinets are those that utilise eight key factors: be useful; be beautiful; keep it personal; provide serendipity; share; encourage participation; provide access to experts; and collaborate. The recommendations were aimed at NHM professionals interested in building cybercabinets. Here we go through the eight key recommendations, which apply to students as well as to other members of the public:

1. Be Useful: Cybercabinets need to incorporate flexibility across presentation platforms, findability, accessibility, intuitive navigation and simplicity of layout.
2. Be Beautiful: Survey respondents were discouraged by text-heavy sites and chose sites to browse when they looked interesting and fun.

3. Keep It Personal: In order to increase user engagement, there has to be a mechanism in place where users can personalise their interaction with a digital collections site.
4. Provide Serendipity: Users should be able unexpectedly to discover something the user only knows they want after they find it.
5. Share: Sharing digital collections between sites to build up a sense of community with online users was extremely effective.
6. Encourage Participation.
7. Provide Access to Experts: Enabling online users to have access to experts encourages users to return to online museum resources (cf. MacArthur, 2007; Howes, 2007).
8. Collaborate: Multi-institutional collaborations are created when cybercabinets capitalise on online networking, as has been found by others (e.g. Weinberger, 2012).

Using IT to enhance visitor experience

Recent NHM research from Hanko, Lee and Okeke (2014) focused on a visitor study in The Field Museum, Chicago that explored what visitors expected to do in NHMs and then explored what visitors wanted to do with digital technology in NHMs. Grant funding enabled The Field Museum to invest in digital technology and this centred around five initiatives: technology infrastructure; digital imaging of collection objects; planning for the Museum's new Digital Learning Lab; digital technologies for exhibits; and the development of new offerings for the museum's far-flung online and mobile audiences. The research found that there were two key ways in which technology can help visitors (at The Field Museum) meet their expectations of museum experiences. First, technology needs to help visitors get closer to the artefacts held by museums; secondly, museum technology needs to help facilitate shared experiences and knowledge growth within groups of visitors. Although in theory this is possible, the qualitative research by Hanko, Lee and Okeke (2014) indicated that digital technology can hinder experiences and learning. Ttechnology has to be managed to ensure that it doesn't create a divide between the museum content and the visitors or create a divide between visitors. Although technology can help visitors experience authentic connections, the qualitative research indicated that when technology is not used appropriately it can negatively impact visitor experience. The quantitative element of the research indicated that by and large, visitors are excited by the suggestion of having access to new digital tools in their Field Museum experience. Around three-quarters of visitors within the research study indicated that new technologies could help enhance the experience in NHMs. In addition two-thirds of respondents indicated that they were positive about museums incorporating technology into exhibitions and expressed preferences as to the types of digital technology that might be used such as apps that can be used on their own or museum-provided handheld devices and digital touchscreens featuring multimedia content. The research also explored the levels of interest in technology and found that this was largely independent of demographic factors such as age, education and income. This finding stands in contradiction to general assumptions that older visitors are less likely to be interested in digital media than younger visitors.

Lemke, Lecusay, Cole and Michalchik (2015) conducted an extensive literature review alongside assembling expert meetings in order to discuss the challenges in assessing learning in media-rich and informal environments while also making recommendations within these areas. The key finding from Lemke and colleagues' work is that content knowledge alongside social, emotional and developmental outcomes ought to be learning outcomes within informal learning activities and that learning ought to be undertaken at individual, group and project levels, with outcomes at any given level being influenced by those at other levels. Lemke and colleagues concluded that many of the learning outcomes reported by researchers were often not aimed for at the start of the projects. They maintain that effective documentation and assessment of informal learning activities should take into account the social and cultural context of the communities and institutions that support and constrain the activities being assessed. They also suggest that in order for an assessment to be useful, informal learning activities must be specific to the goals of each project, while also keeping in mind the community the project serves and providing an insight into why there has or has not been some success in achieving the learning outcomes. A part of effective assessment and documentation is that these should consider whether the project is sustainable long term, whether it can be adapted to other contexts and if it is sustainable under a range of different conditions.

Lemke and colleagues also suggest that assessment ought not simply to be a one-off practice but a series of events embedded within a longitudinal design. Having assessment take place longitudinally recognises that over time individuals become better at any given activity; using such methods enables assessors to know what learning outcomes are achievable in certain time frames. The authors also suggest that assessment should provide information that has practical value in helping to pinpoint particular strengths and weaknesses in people's learning and attainment of given objectives. Routine assessment can help plan future improvements. Lemke and colleagues also indicate that assessments based only on the initial goals of a project may not capture learning outcomes that were not foreseen at the start of the project.

The findings from the survey of visitors at the Field Museum reported by Hanko, Lee and Okeke (2014) help to quantify the views of visitors about the technology that museums employ. The research found that there were a fair number of visitors who, because they deeply value being able to see physical, authentic, natural objects at museums, express discontent at having technology replace physical objects. However, the research also indicated that a large proportion of visitors felt that technology played an important and positive role in enabling them to have real meaningful experiences with museum objects which would otherwise not be possible. At the same time, the research supported the established notion that visitors have emotional and social motivations for visiting the museum; a number of visitors indicated that the visit presented an opportunity for them to reconnect with the natural world, sharing the experience with people they were close to as well as refreshing them. Almost half of the visitors reported that their ideal visit to The Field Museum gave them an opportunity to escape from modern life.

Hanko, Lee and Okeke (2014) reported an important yet obvious point that regardless of whether or not visitors were keen on seeing technology used in museums, a large proportion of visitors used their own technologies within the museum; visitors were using tablets, cameras and smart phones in order to capture memories of their experience. In addition, a large proportion of visitors were also using technology to enhance their experience of the museum; so, for example, around a quarter of visitors used personal devices to looking up a topic of interest while at the museum. A larger number of visitors (38%) researched a topic after they had left the museum and gone home. Hanko, Lee and Okeke. suggest that museums can capitalize on these impulses and provide fresh, perhaps surprising ways for visitors to achieve their goals.

New directions: educational apps

Over the past few years there has been a heightened interest in the use of apps to help with students' science learning. A number of reasons can be put forward as to why there is now a focus on this relatively unexplored area. First, devices that use touch-screens are very accessible to even pre-school children and toddlers. In addition, there has been a surge in the number of schools that use electronic tablets in everyday learning within classrooms.

Furthermore, these devices have become increasingly common as tools within family homes. The current generation of young learners are spending a lot of their time on digital media. Given that less than 20% of a child's waking time is spent in school (LIFE Center: Learning in Informal and Formal Environments, 2005), it is quite possible that apps will increasingly be used by parents to supplement their children's learning. The surge in the use of digital media makes this an important area for NHMs to expand into, to create exhibits that are interactive and accessible to a larger range of people than was previously possible. Our literature review so far has included research evidence which indicates that the most effective learning takes place when students are physically engaged, and when learning experiences are fun, meaningful and socially interactive. Apps can facilitate such factors.

Informal science education and professional development for teacher

Teachers and schools value visits to museums as they present opportunities for students to learn about scientific concepts and take part in science in ways that are not possible in the classroom. Despite teachers' positive views about museums, more can be done by them to get the most out of museum experiences. As far back as the 1980s there was a recognition by the academic community that in order to make museum trips successful, teachers need to have the capability in organising, sequencing, focusing and evaluating the event for the needs of their students, while also ensuring that the trip itself leads to particular planned learning goals (Muse, Chiarelott, & Davidman, 1982). Research suggests that many teachers do not plan their visit, nor do they define learning goals for museum visits or view museum activities as a sociocultural learning experience (Cox-Petersen, Marsh, Kisiel, & Melber, 2003; Griffin, 2004; Griffin & Symington, 1997; Kisiel, 2003; Price & Hein, 1991). In order for students to learn effectively on museum visits they should have the opportunity to explore exhibits interactively with others as well as on their own. As this review has indicated, social interaction has been found to be important in creating a more meaningful learning experience. Students should have the opportunity to discuss what they are learning with their peers, museum educators and their teachers; they should also be encouraged to make links with knowledge they already have about scientific issues. In order to do this well students need to spend some time on learning goals both before and after the visit. Although teachers spend time making some preparations for class management (e.g. giving students instructions on appropriate food and clothing), they typically spend little time on more meaningful issues such as preparing students about learning goals (Griffin & Symington, 1997).

There is some existing research which reports that some teachers do engage in meaningful activities that focus on museum learning, but these examples, at least when reported in the literature, have been where academic researchers have worked closely with museum staff or school teachers (Anderson, Lucas, Ginns, & Dierking, 2000; Gilbert & Priest, 1997; Henriksen & Jorde, 2001). There are a range of reasons why teachers do not spend time planning for museum visits. Griffin (2004) reports that logistical issues, time constraints, various student needs and pressure for accountability are the key professional factors that limit teachers' ability and willingness to provide proper preparation and post-visit activities.

Research that has explored the role of teachers and interactions between museum educators, students and teachers indicates that often the group is led by the museum educator, who provides information about exhibits and that as groups move from one exhibit to the next there is little social interaction between the various members of the group (Cox-Petersen, Marsh, Kisiel, & Melber, 2003). Even when a teacher is leading the visit by using task sheets, social interactions between teachers, students and chaperones are not common (Griffin & Symington, 1997; Kisiel, 2003). Griffin (2004) proposes that one way of enriching museum visits is for teachers themselves to receive professional development in what they should be doing in museum settings. It is important that teachers play a central role in museum experiences (Falk & Dierking, 2000; Hein, 1998). Tal, Bamberger and Morag (2005) collected data from teachers at four NHMs in Israel. The aim was to uncover what kind of planning teachers did when they took their students on field trips to museums. Tal, Bamberger and Morag observed around 40 class visits to the museums and from those visits 30 teachers agreed to take part in semi-structured interviews for the study. The teachers were asked questions about the planning process to the museum visits, what activities took place in school and what arrangements teachers had made with the museum staff prior to the museum trip. There were further questions about the actual visit plan and activities and a question about follow-up activity at school after the museum trip.

In their analysis the researchers found that most of the teachers were unable to indicate why they had chosen to take students on a field trip to the museum; partly this was due to the teachers themselves not planning the trip or choosing the learning activities. They also found that some teachers do not view the field trip as a well-planned educational experience but rather as a fun event. In their study only a very few teachers had actually spent time on planning the trip and relating it to the class curriculum. Only a few teachers had planned the museum trip because it linked with what they were teaching in class and had created pre-visit activities for their students.

Informal science institutions can play an important role in science teachers' professional development. One US survey study found that a large proportion of informal science institutions played a key role in the professional development of K–12 teachers (CILS, 2005). Around 59% of all informal science institutions and 81% of science centres provided science professional development. In addition, another piece of research found that K-12 science teachers (again in the US) reported that the professional development they received from informal science institutions was of greater value and quality than the professional development they received from other sources (Dorph et al., 2007; Dorph, Shields, Tiffany-Morales, Hartry, & McCaffrey, 2011). Collectively, the scale of this work is quite significant (CILS, 2005). In the US, informal science education institutions have been involved in developing school curriculum materials for many years, and some of these institutions provide online materials to support teachers. Examples of such curriculum projects include: Engineering is Elementary, developed by Boston's Museum of Science (Engineering is Elementary, 2015) and Great Explorations in Math and Science, developed by Berkley's Lawrence Hall of Science (Great Explorations in Math and Science, 2015).

Conclusions and recommendations

This review has enabled us to reveal how NHMs can support and be part of students' learning and engagement in science. Our review also covers the role of the digital world and provides evidence for how the digital world can help to engage students with science by enabling them to take ownership of their work and accessing NHM resources online. We also note that there is a preference by some learners to see authentic physical objects so there needs to be a balance between exposure to authentic tangible objects and the digital world. The review indicates that NHMs can provide students with new knowledge and perspectives in well-designed exhibits. Existing research suggests that the most effective way of using NHM resources to enrich science teaching and learning is for NHMs to collaborate with the formal sector and, if at all possible, embedding such resources within a science learning ecosystem. The most fruitful way of ensuring change is by implementing long-term programmes. Any programme ought to have an element of evaluation (cf. Fu et al., 2015) which collects data / conducts learning assessments at more than one time (rather than just straight after the end of a project). Any such assessment ought to measure both cognitive and affective gains, in part because students' intrinsic motivation (e.g. expressions of interest, enjoyment, enthusiasm) is strongly related to science engagement in the classroom.

From our review of the literature on learning in NHMs, drawing in places on the more general literature about informal science education institutions, we can put forward a list of recommendations. These are particularly targeted at school-age learners.

- An NHM visit should be a memorable event for students and help them see science in ways that the classroom environment cannot provide.
- Programmes developed by or for NHMs ought to be embedded within STEM learning ecosystems so that parents, schools, NHMs and the general community are collaboratively involved in engaging students with science.
- Learning outcomes for NHM activities should include content knowledge alongside social, emotional and developmental outcomes.
- Students should be provided with pre- and post-visit activities and these should give students opportunities to ask questions.
- Science shows should be enjoyable and involve practical demonstrations.
- Learners benefit from being given opportunities to meet with scientists. Such encounters can have a positive influence on students' attitudes to learning science, enable students to become more informed about career choices and provide students with a better understanding of 'how science works'.

- NHMs need to make use of new possibilities afforded by digital technologies, including online exhibits—possibly via the use of cybercabinets—and games, including interactive multi-user games.
- Displays in museums can benefit from a degree of interactivity.
- Museum experiences ought to develop students' scientific skills and understanding of science while also helping them to develop an enquiring and critical attitude towards science.
- Given the extensive research indicating that cultural, educational and cognitive factors influence visitors' understanding of science, more attention should be given to students' prior knowledge and their resulting interpretive stance in the design of exhibits and related learning experiences.
- Programmes ought to enable students to have autonomy in driving their own learning.

It remains the case that the informal sector in general, and NHMs in particular, need to devise and employ better ways of measuring the long-term consequences of their provision.

Objective 2

Develop improved instruments that are common across school, NHMs and other out-of-school settings to determine the efficacy of learning experiences

The above literature review enabled us to form ideas about how the community of NHM practitioners and researchers might develop more valid instruments to determine the efficacy of learning experiences. We provide analyses of existing instruments that have been used to evaluate learning in NHMs and other informal science education settings. We then use this information to propose more valid instruments which incorporate validated psychological constructs. We begin by evaluating instruments used in informal science education settings and then evaluate instruments that have not necessarily been used in informal science education settings but have great potential if such settings drew on them.

Instruments used in informal science education setting

Science Curiosity Scale (Harty & Beall, 1984)

The science curiosity scale has undergone a range of testing for its reliability and validity. This survey is one geared towards students' views about science and has been used in a range of studies, some of which have explored gender differences in views of science.

The instrument

The instrument contains 30 questions about general science, covering areas such as the intrinsic value of science (e.g. 'I enjoy collecting leaves or other things from the outdoors'), taking part in extra-curricular science activities (e.g. 'I like to visit zoos to watch how animals act') and an interest in gaining more scientific knowledge (e.g. 'I like to watch the TV news reports about the space shuttle'). The survey also contains 13 questions about physics: one open-ended question (e.g. 'Briefly describe what you think physics is') and 12 closed questions. The questions covered a range of physics-specific attitudes and interests, e.g. students' extrinsic motivation for wanting to continue with physics, including 'I need to take physics to get the job I want'.

Our evaluation of the instrument

With respect to the general science questions, some of the items would be good to use for a baseline study, e.g. 'It is boring to visit with scientists in their labs' and 'I would like to visit a museum to see dinosaur bones'. Obtaining such data as a baseline would enable a research study looking into the effects of a science programme or intervention to make comparisons about changes in students' perceptions of informal science education learning over a number of years. Some of the questions on extrinsic motivation are particularly valuable and it would be useful to see if taking part in learning within informal science education settings has a positive impact on students wanting to continue within a range of sciences (physics, biology, chemistry, earth science).

Guided school visits to Natural History Museums in Israel: teachers' roles (Tal & Morag, 2004)

The study explored the roles and perceptions of teachers who visited a total of four natural history museums with their students. Teachers participated in semi-structured interviews after the visit, with the questions addressing issues such as the planning process, activities in school, arrangements made with the museum staff prior to the visit, the visit plan and activities and follow-up activity at school. In addition, observation data were collected while teachers were on the museum visit.

Our evaluation of the instrument

This is a useful instrument which focuses on teachers' preparation of field visits, which helps elicit information on pre-, post- and actual visit information. The instrument itself has little on explicit links between teachers' perceptions of the visit and its usefulness to the curriculum. This instrument nonetheless provides a good starting point to expand on in order to focus on issues around teacher preparedness.

The Sant Ocean Hall Visitor Study (Yalowitz et al., 2009)

The National Museum of Natural History opened the Sant Ocean Hall and within the Sant Ocean Hall The Smithsonian Institute opened a large exhibition on the current understanding of the ocean and the way oceans connect with people. The Sant Ocean Hall has around 674 marine specimens and models which include high-definition video experiences and exhibits. Yalowitz et al (2009) conducted an evaluation in order to learn more about how visitors to the Sant Ocean Hall reacted to, learnt from and behaved in response to the various learning opportunities that were available to them. They based their study on 553 visitors and collected data via a range of methods: visitor exit interviews, timing and tracking and focused studies for specific exhibits and experiences.

The instrument

The focused studies element was used to help gain an understanding of visitors' behaviours and interactions at any given exhibit or part of the experience within Sant Ocean Hall. Initially, visitors' behaviours and comments were recorded; this was followed by an interview with one adult member of the group about their understanding, use and reaction to the exhibit/expereince and its content. The exit interviews assessed visitors' perceptions and understanding of the exhibits; the interviews were geared towards finding out about both knowledge gained and experiences of the exhibits such as: satisfaction with Sant Ocean Hall, what they most enjoyed, what improvements could be made and what visitors' general understandings were of oceans and knowledge learnt. Example questions include: 'what did you enjoy most about Ocean Hall and why', 'how could Ocean Hall be improved upon?' and 'in the hall do you specifically remember or seeing or hearing anything about how the ocean and its life forms have changed and evolved over time?' The timing and tracking instrument consisted of an observation sheet with a floor plan map of 14 key areas (e.g. living on an ocean planet exhibit) and researchers marked on a four-point scale how dense the crowds were alongside the type of interactions that were taking place at the exhibits.

Our evaluation of the instrument

The instrument has specific questions on both the personal satisfaction and enjoyment visitors had as well as specific questions which explore what has been learnt and the quality of the exhibits. It is evident that many of the questions and the instrument used to gather data can be adapted to other NHM exhibits. Although the study did not specifically focus on the school-age population, the instrument used would be appropriate for such an age group.

Exploring a school-aquarium collaboration: an intersection of communities of practice (Kisiel, 2010)

This study explored the development and on-going activities of a partnership between one school and an aquarium; the study focused on documenting the way the collaborative nature of the relationship between the school and the aquarium developed. The study used open-ended interviews with teachers, administrators, aquarium instructors and programme coordinators over two years. One positive element about the research design of this study was that if teachers were unable to take part in interviews with researchers they had the option to participate by completing written surveys. The instruments for teachers and aquarium instructors explored science planning, lesson success, other components of the collaboration, impacts and suggestions for improvement.

Our evaluation of the instrument

The instrument did not ask teachers or aquarium educators about how challenging it was to implement the partnership; the evaluation would have also benefitted from asking students about their opinions about the program and assessing changes in their perceptions of and attitudes towards science. The aquarium educators were asked ten questions on science lessons (e.g. 'How were your experiences with these classroom programmes this year different from last?') and six questions on other aspects of the partnership (e.g. 'If there was one piece you could focus on to improve any part of this partnership, what should that be?'). The list of questions asked were detailed and through. Although this evaluation was for an aquarium programme, both the instruments and the results are useful for use in NHM settings. The evaluation instrument did not ask questions about diversity: whether educators felt that the programme was equally useful for all student groups, whether they felt some student groups would have benefitted from some alterations in the program and what types of changes would benefit particular student groups.

The instrument asked teachers three questions on science planning (e.g. 'Did working with the aquarium instructors affect your decisions regarding what science was taught, when science was taught, or how science was taught? Explain'), eight questions on aquarium-led outreach lessons (e.g. 'Do you feel these classroom sessions benefited the students who participated? If so, how did the student benefit? How do you know?') and nine questions on other aspects of the partnership (e.g. 'If another school was deciding to enter into such a partnership, what suggestions might you make?'). The instrument could be improved by asking teachers' points of view about student diversity in learning.

Finegold et al. (2011)

Finegold et al. (2011) have developed an evaluation instrument to investigate how young people can increase their interest in engineering. The survey element of their evaluation instrument consists of six questions which cover three key areas: inspiration; knowledge acquisition; and future behavioural change. This short survey is used alongside another evaluation instrument they have developed to measure behavioural change after interventions.

Evaluation

The three areas that the survey captures are appropriate core areas that surveys ought to include to measure the impact of programmes run by informal science education institutions. This survey would make a good baseline instrument to use in a longitudinal study. However, the survey could benefit from being longer. As an instrument to use in a longitudinal evaluation it could be extended by explicitly asking students whether their opinions/attitudes changed; in addition, using the same survey before and after an evaluation would enable researchers to make statistical comparisons. The inclusion of a baseline instrument that helps measure changes in responses after interventions would be valuable. Another way of evaluating the effectiveness of events (which this instrument is geared towards) is to see if the interventions/programmes influence students' opinion of the relevance of engineering in their everyday lives. Undertaking teacher interviews that explore changes in students' perceptions of science after programme events can enable researchers to explore whether students' attitudes/perceptions towards science/physics in class have improved.

Wellcome Trust Science Learning Survey (Falk et al., 2014)

Falk et al. (2014) developed survey instruments in order to obtain information about how interconnected and collaborative within individual sectors organisations were as well as exploring how interconnected and collaborative organisations were between sectors. Their research sampled key science educators from the science community. The survey was administered via the web and its development was based on the analysis of an initial set of 51 semi-structured interviews. Their survey contains 28 questions which reflect the UK cultural and educational context; a shorter version of this survey was also developed for the science education sectors (e.g. libraries, nature centres and parks), where there was a low response rate.

The instrument

The instrument is geared towards organisations and asks a range of background information about them. The survey then asks a series of questions about the individual who is completing the survey, such as with whom they collaborate with and how they collaborate with other organisations. The survey also asks individuals to think about the types of organisations that are important for science learning in the UK, their evaluation of internal and external support, the outcomes they are achieving for their audiences and the purpose of informal science learning activities.

Our evaluation of the instrument

The instrument comprehensively covers a range of important issues that organisations in the science informal sector play a role in. The survey is quite lengthy and, as Falk and colleagues note, they had initially a very small return rate. This survey could be adapted either by shortening it further or by conducting telephone / face-to-face interviews where the researcher asks interviewees the questions and completes the survey, rather than using postal paper returns.

Instruments used in science education settings

Critical Thinking in Everyday Life (Mincemoyer & Perkins, 2001)

The National On-line Youth Life Skills Evaluation System has developed evaluation instruments to use with students, mainly to help design and determine the impact of educational programmes. The Youth Life Skills Evaluation System was developed by Penn State University and Purdue University. The instruments measure particular skills set for each life skill (e.g. critical thinking). These instruments have largely been used by US establishments and have been used to try and establish a national system, which means that there is a possibility that data can be aggregated at the county, state and national levels which will enable organisations (who use these instruments) to show the impact of their youth development programmes to other stakeholders. The part of the instrument we focus on is critical thinking; this is an important skill to have for science learning as it enables students to engage with the scientific world around them.

The instrument

This survey contains items that assess students' critical thinking skills; students are given a list of statements and they are asked to think about certain things in their daily lives. The following areas are assessed: reasoning; enquiry; analysis/information processing; flexibility; and evaluation. In designing a student survey to explore students engagement in science it would be good to include some items from this instrument such as: 'I develop my ideas by gathering information', 'I can easily express my thoughts on a problem', 'I usually have more than one source of information before making a decision' and 'I compare ideas when thinking about a topic'. These selected items are useful critical thinking skills to have when engaging with scientific issues.

Our evaluation of the instrument

The instrument is a good instrument to use when assessing critical thinking skills. For the purposes of a science education evaluation it would not be desirable to use the whole instrument given its length and the fact that there are other aspects of students' attitudes and skills about which researchers would want to gather information. It is recommended that whenever a small number of items from a larger scale or instrument are selected for use the items are piloted to check for their internal reliability in providing an overall measure.

Classroom Activities and Outcomes Survey (Terenzini et al., 2001)

This instrument was developed for engineering undergraduate students and its purpose is to measure students' perceptions of the amount of progress they have made in science while taking part in a science course.

The instrument

This survey contains 25 items.

Our evaluation of the instrument

Although this instrument was developed for undergraduate students on engineering courses (so the language for some items may not be accessible to students in compulsory education and it is for a specific topic), nevertheless it provides a good basis for thinking about how to develop an instrument that assesses students' perceptions of changes in their own learning. In this instrument students were asked to use a Likert scale to answer a series of questions put to them so as to determine how much progress they had made. Some of these items would be useful in their present format, e.g. 'Clearly describe a problem orally' and 'Clearly describe a problem in writing'. Other items would still be useful but need rewording so that students in compulsory education can understand them, e.g. 'Weigh the pros and cons of possible solutions to a problem and apply an abstract or concept or idea to a real problem or situation'.

Changes in Attitudes about the Relevance of Science (CARS) (Siegel & Ranney, 2003)

This instrument measures changes in students' science-related attitudes; it also measures the effect of similar curricula on the attitudes of different classes.

The instrument

This survey contains 59 items and there are three different versions of this instrument available with eight common items.

Our evaluation of the instrument

The instrument has many items which won't be of relevance to a survey exploring the impact of informal science education learning on students' engagement and attitudes to science. The items which are of interest are those that measure changes in science-related attitudes. For this purpose, key items could be selected that assess changes in attitudes and included within an overall student survey.

The survey as a whole appears adequately to cover some science-related attitudes, e.g. use of science in everyday life. However, it falls short of measuring important attitudinal changes, such as perceptions of lessons and teachers, and the instrument does not measure other psychological measures, such as self-concept or self-efficacy. The instrument touches upon extrinsic motivation in science but appears not to have the types of explicit items that have been used in other surveys.

Relevance of Science Education (ROSE) Student Questionnaire (Schreiner & Sjoberg, 2004)

The ROSE study is a well-known project that assesses students' interest in, attitude towards and experiences in science and technology. The survey also assesses students' opinions about environmental challenges and career aspirations.

The instrument

This survey contains 245 items and many of these attitudinal items could be of relevance (when assessing students' attitudes). The survey also contains a number of open-ended questions.

Our evaluation of the instrument

The instrument has detailed questions on out-of-school experiences which would be useful to help design both quantitative and qualitative instruments. In total, there are 61 items which measure out-of-school experiences; many of them would be ideal to use to obtain baseline data and then determine after a number of years whether there have been any changes.

It is clear that many of these items are measuring experiences that are not necessarily taking place as a part of school-led/instigated programme, making them ideal items to explore whether learning that takes place via informal science institutions has an impact on students' daily lives at home. Such items include: 'Tried to find the star constellations in the sky', 'Watched nature programmes', 'Planted seeds and watched them grow', 'Sorted garbage for recycling', 'Used a science kit', 'Changed or fixed electric bulbs or fuses' and 'Searched the internet for information'. There are also a number of useful items which explore the impact of science classes on students' everyday lives, e.g. 'School science has opened my eyes to new and exciting jobs', 'The things that I learn in science at school will be helpful in my everyday life', 'School science has increased my curiosity about things we cannot explain' and 'School science has taught me how to take better care of my health'. The survey also has important items which measure students' opinions about science and technology, e.g. 'Science and technology are important for society'. Finally. The survey contains a number of items that measure scientific literacy.

Programme for International Student Assessment (OECD, 2006)

The OECD's PISA provides a very well-known study which assesses students' perceptions of science, their future plans, scientific literacy and science skills they have learned at school.

The instrument

This survey covers around 46 areas which are subdivided into a number of individual questions. Most of the items are Likert-type questions with some open-ended questions. Some of the PISA items (in the science versions of the survey) ask about non-science related issues.

Our evaluation of the instrument

A particular strength of the PISA survey is the care and rigour with which it was developed. The instrument has some interesting and thorough items on the type of out-of-school lessons that students attend, e.g. ones on enrichment in science and other subjects. The particular items we would be interested in are those that focus around scientific literacy, which are similar in nature to those in the ROSE study.

Is science me? (Aschbacher & Roth, 2010)

This instrument was created by researchers who were using an ethnically and economically diverse sample of 33 high school students to investigate why within a group of students who were keen to continue with science, engineering or medicine, some changed their minds and some continued with the trajectory.

The instrument

This survey contains a large number of items: 132 Likert scale type items and 44 multiple-choice items. In the original study it took about 60 minutes to administer the survey.

Our evaluation of the instrument

This instrument measures a range of attitudes and perceptions which includes many areas which may not be of use in such great depth for the purposes of putting together an instrument that to explore the impact of informal science education learning, e.g. students' perceptions of family support in science or the perceptions of science by students' peers they are romantically interested in. All in all there are some interesting items that could be taken from this to measure whether students think science is for them but these items only represent a small proportion of what is contained in the survey. Some of the items which may be of use include: 'People who share my ethnic background have trouble getting jobs in science in this country', 'People who are the same gender as I am have trouble getting jobs in science in this country', and those to do with how interested students are in taking science-related jobs (scientist, nurse, doctor, physical therapist, dentist, technician, engineer, programmer etc) and how much teachers/adults at school encourage students to take science classes / continue with science post-16 / take science at undergraduate level.

Improved instruments

One suggestion for improved instrument(s) would be to use both quantitative and qualitative approaches in conjunction with one another. In recent years there has been an increasing use of mixed methods research in the social sciences which has taken the place of using qualitative or quantitative methods in isolation from one another. There is a realisation that there is a need for enhanced incorporation of both quantitative and qualitative approaches for richer research. Large-scale quantitative research with little or no use of qualitative approaches will not be able fully to uncover the importance of informal science education's impact at an individual level. While large scale quantitative research studies will help increase understanding about informal learning in general, such studies used in isolation from qualitative research will have limited value to practitioners in their distinctive contexts. In order to add breadth to a study on informal science education, we advocate the use of one-off focus groups and longitudinal surveys and interviews. While recognising that there are a huge number of instruments already in existence that are used for the evaluation of informal and formal science education, we have suggested a number that could be used as starting points for the development of new instruments to enable richer evaluation.

Any instrument that is put together either by drawing on established constructs from other surveys or when a researcher creates their own items ought to go through a series of steps to check for the reliability and validity of the survey as a whole and the individual items. This requires appropriate development and piloting of the instrument. Once data have been gathered, conducting a reliability analysis on the construct scale scores (created from individual items) is essential. The decision to group certain items together may be supported by pre-determined theoretical knowledge (particularly in the case of having taken items from validated constructs). Alongside this, checking for item distributions and internal correlations would help researchers form an idea about how well individual items related to one another (within a construct).

The reliability of each construct can be measured using Cronbach's alpha coefficient. In quantitative research, internal consistency of a construct/scale via reliability analyses is established based on the correlations between different question items on the same scale. This helps to establish whether the individual items that make up the overall scale are measuring the same construct. When using Cronbach's alpha any figure between 0 and 1 can be produced. A measure above 0.6 shows acceptable reliability for the overall scale. In any instance where the measure is less than 0.6, this indicates that the scale is probably tapping into more than one distinct construct or that there is no relationship at all between the items. In order to substantiate the findings of the reliability analyses as to whether the items that formed each of the constructs measured the same dimensions a principal components factor analysis or a confirmatory factor analysis helps to test these relationships further.

Inter-correlations between the various constructs of an instrument would enable researchers to see if the theoretical dimensions of the instrument are tapping into different aspects of attitudes. Low-medium inter-correlation values between constructs would indicate that the underlying dimensions are acceptable in their discriminant validity and so are designed to measure theoretically different concepts, while correlations between constructs which are high would suggest that the overall instrument has poor discriminant validity.

When putting together an instrument to evaluate the impact of informal science education institutions on students' attitudes, engagement and learning it is important to remember that it is unlikely that a single or series of events would for most students suddenly help them decide to continue with the sciences, or that science is for them or that science immediately becomes an interesting subject and it is particularly important to remember that given that research also indicates that most students don't make career choices early on (although very early on students do decide whether or not they like science). A more probing evaluation would include baseline survey data (prior to the start of a programme or evaluation) and ensure that survey data are collected at intervals over the course of a number of years. In addition, survey data would be better used in conjunction with in-depth qualitative interviews before, during and after interventions/programmes.

Objective 3

Devise protocols to explore the possibility of data obtained from museum evaluations being matched with national databases

The situation in England

Education administrative and survey data in England are collected by government departments and other organisations for a range of reasons. The government in England collects extensive details on every single student when they enter the school system and updates this with educational attainment data (as well as personal data such as individual socio-economic status and neighbourhood characteristics) as students' progress through their school career; this database is known as the National Pupil Database (NPD) and the information is available at individual student level.

There are a number of other databases available that are collected on a cross section of students, and researchers could also try to utilise information available from them to make better use of Natural History Museum (NHM) data. Further on in this document we discuss the potential for enriching analysis by combining the NPD with such databases such as the Next Steps and other cohort study data held by University College London Institute of Education (e.g. as done for other purposes by Mujtaba & Reiss, 2014).

At a very basic level what researchers need if they are to match NHM data to a national database is simply the names of the schools attended by students who have visited an NHM and completed a survey (e.g. evaluating an exhibit). The researchers can then match on school level aggregated information from a national database (e.g. the NPD; the student level information would be aggregated to school level) and conduct analyses to test various hypothesis. For more detailed analyses, individual student names with their dates of birth and gender would enable a fairly accurate match to individual student NPD records to be made, enabling more sophisticated analyses to be undertaken than would otherwise be possible. So, for example, if one wanted to compare the effect of a group of students from school x taking part in a museum programme on science interest compared to students in control school y who did not take part in such a programme, only having the school name would allow one to undertake analysis and make some generalisations about the impact of the programme without knowing for sure whether the findings were influenced by the type of student that attended these schools or whether the programme was more beneficial for students with certain characteristics. Having individual student names would enable researchers to control for the influence of gender, ethnicity and socio-economic status in any statistical comparisons; the analysis could conclude that the effects observed were due to the programme and that certain types of students benefitted more from the programme, e.g. girls' interest in science increased more than boys'.

The National Pupil Database

The National Pupil Database contains detailed information about students in schools and colleges in England and these data are collected throughout compulsory education and post-compulsory education at colleges or in school sixth forms. The NPD can also be linked to the further and higher education (post-18) sectors, using data from the individualised learner record (ILR) and Higher Education Statistics Agency (HESA) student record. The NPD therefore has huge potential in enabling extensive analysis of data collected by informal science institutions including NHMs. Used in this way, data collected by informal science institutions can be used to deepen the level of analysis, produce statistics and provide information, advice or guidance.

The data held in the NPD include test and examination results, prior attainment and progression at different key stages for students in the state sector, attainment data for students in state and non-state special schools, sixth form and further education colleges and information on students in independent schools, where available. The NPD also includes information about students' characteristics, such as gender, ethnicity, first language, eligibility for free school meals, special educational needs (SEN), absence and exclusions from school and neighbourhood characteristics (e.g. crime rates).

Next Steps

The Next Steps study has collected data on and is following the lives of around 16,000 people born in 1989–90 in England. The study began in 2004 (when it was called LSYPE), when the cohort members were aged 13–14. Following the initial survey at age 13-14, the cohort members were visited every year until 2010, when they were aged 19–20. There was then a gap in data collection; further data were collected in 2015 when the cohort was aged approximately 25.

This longitudinal study has collected information about participants' education and employment, economic circumstances, family life, physical and emotional health and wellbeing, social participation and attitudes (see Strand, 2007). The attitude dimension asks some questions on science-specific issues, e.g. self-concept and aspirations to continue with the sciences post-16. As with the NPD, the data are available at individual level. The data have been matched to the NPD and there is a strong possibility that with the right permissions the data could be matched to individuals for whom there are museum data available.

Cohort studies

The Millennium Cohort Study follows similar principles to the Next Steps study. In the Millennium Cohort Study there are around 19,000 children born in the UK in 2000–01. This longitudinal study been tracking these 'Millennium' children through their childhood years and plans to follow them into adulthood. The type of data collected include: parenting; childcare; school choice; child behaviour and cognitive development; child and parental health; parents' employment and education; income and poverty; housing, neighbourhood and residential mobility; and social capital and ethnicity.

We have looked at the possibility of exploring data from other England-wide social science surveys (e.g. the British Social Attitudes survey; the Annual Population Survey; The Family Resources Survey, The National Child Development Survey and the 1970 British Cohort Study) and have concluded that the most appropriate data to use are those in the NPD (given that all England students take part in this). The Next Steps and Millennium Cohort Study are also possibilities given that they cover individuals who are still in the school system or who have recently left. However, given that these studies only collect data on a cross section of society it is likely that only a very small percentage of the students who participated in these studies will have data held on them by NHMs. Therefore any data used from either of these studies would simply be to help undertake case study analysis rather than quantitative analysis. So, for example, if one finds there are 15 students for whom Next Steps data are available, matched to NPD and museum data, one would be able to explore qualitatively if there is an association between experiences at the museum and later aspirations and educational/employment outcomes.

The situation in the US

In the United States, the situation differs considerably from that in England. Of primary importance is the lack of a national pupil database in the US. As a result, longitudinal tracking of students—and their involvement with informal education—is consistently lacking. At the local level, however, there are examples of connections between NHMs and formal school data. For example, the *Pathways to Science* programme at Yale University is a coordinated, data-driven STEM outreach initiative. Developed with a commitment from New Haven Public Schools, the programme encourages middle and high school students to participate in science-based activities at Yale. The nearly 1,000 students involved in the programme are invited throughout the year to special events, academic lectures, demonstrations, hands-on activities, summer programmes, and even research opportunities, choosing from more than 50 different programmes annually that capture their interest. The combined hours that students spend within these STEM programmes exceeds 48,000. The Yale Peabody Museum of Natural History plays a significant role within the programme, especially with its free Evolutions Afterschool Programme—a standout programme within Pathways that exposes more than 100 high school students to in-depth scientific content and college preparation.

A critical aspect of *Pathways to Science* is its collaboration with and commitment from New Haven Public Schools. *Pathways* coordinators have access to student records to develop a longitudinal database that not only tracks their path through school, but also their attendance at *Pathways* programmes. Student performance can therefore be generally tracked against any participation in *Pathways* programmeming.

Jon Miller's 'Longitudinal Survey of American Youth' (http://lsay.org/index.html) database may be useful. A new cohort of grade 7 students will be followed from 2015, mirroring research conducted with a 1987 sample of grade 7 and 10 students where the development of career plans, students' interest and skill acquisition in mathematics and science are tracked. The original 1987 study led to an increase in the knowledge base about the origins and composition of the scientific workforce in the United States. At present it is unclear just how many students will be included in the 2015 study. However, this study will in time provide useful data about how learning relates to the acquisition of STEM skills and the opportunity to create linked research work with the informal science learning education sector.

An indication of the potential value of such approaches in the US is provided by Suter (2014). The work by Suter is based on the original 1987 cohort. His secondary analysis of of student attendance at science museums indicated that student achievement in science and mathematics improved with science museum attendance. There are a number of important science education variables available in the dataset that could be used to conduct secondary analysis on how learning in science is impacted by engagement in science education informal activities. Such analyses could also be compared to data obtained from more recent cohorts of students, thereby enabling users to track changes in the US in the role of informal science learning and the impact on learning and engagement.

Objective 4

Map the areas of science curricula (using the latest version of the science National Curriculum in England and the Common Core Standards in the US)

Curricula and standards in England and the United States

In England, the Department for Education provides a National Curriculum (Department for Education, 2013) with statutory programmes of study and attainment targets for science for students at Key Stage 1 (Years 1–2, ages 5–7), Key Stage 2 (Years 3–6, ages 7–11), Key Stage 3 (Years 7–9, ages 11–14), and Key Stage 4 (Years 10–11, ages 14–16). Key Stages 1 and 2 occur in primary (elementary) schools; Key Stages 3 and 4 occur in secondary schools (middle/high schools). Students can then complete non-compulsory upper-secondary education (Years 12–13, ages 16–18) at secondary schools or colleges to gain qualifications necessary for university (college) entry.

The National Curriculum aims to ensure that students develop scientific knowledge and conceptual understanding, together with understanding of the nature, processes, and methods of science and different scientific enquires, and that students understand the uses and implications of science (Department for Education, 2013). Students should be taught knowledge and concepts (involved within areas such as the structure and function of living organisms, chemical reactions and changes, forces and motion) and be able to work scientifically. The curriculum area of 'working scientifically' covers scientific attitudes (such as considering reproducibility), experimental skills and investigations (such as asking questions to develop enquiries and making predictions), analysis and evaluation (such as interpreting results and identifying further questions), and measurement (Department for Education, 2013).

In the US, states or districts provide varying programs of study and attainment targets for science. A potential national framework has been proposed (National Research Council, 2012) covering three dimensions: scientific and engineering practices (such as asking questions, developing models, analysing and interpreting data), cross-cutting concepts (such as patterns, cause and effect, systems, structure and function), and disciplinary core ideas (knowledge and concepts within topics or areas such as the growth and development of living organisms, Earth's system, and matter and its interactions). This framework has been operationalised into the Next Generation Science Standards (Achieve, 2013). The standards cover guidance for students in kindergarten (ages 5–6), elementary school (Grades 1–5, ages 6–11), middle school (Grades 6–8, ages 11–14), and high school (Grades 9–12, ages 14–18). Students may then continue their education at college (university).

Similar to the area of 'working scientifically' in England, 'scientific and engineering practices' in the United States (Achieve, 2013; National Research Council, 2012) aim to cover the areas of: asking questions (for science) and defining problems (for engineering); developing and using models; planning and carrying out investigations; analysing and interpreting data; using mathematics and computational thinking; constructing explanations (for science) and designing solutions (for engineering); engaging in argument from evidence; and obtaining, evaluating, and communicating information. Related areas, such as modelling (via systems and system models) and measurement (via scale, proportion, and quantity), are also reiterated through the cross-cutting concepts (Achieve, 2013; National Research Council, 2012).

Natural history and curriculum content

Natural history, considered broadly, may encompass various curriculum areas, principally within the domains of biology, chemistry and earth science. 'Working scientifically' may also be relevant to natural history; for example, the accumulation of fossil evidence and the associated changes of theories over time can provide an applied example of scientific practices and development. Accordingly, a number of potential areas of natural history knowledge and concepts can be identified through a review of the National Curriculum (Department for Education, 2013) and the Next Generation Science Standards (Achieve, 2013) content.

Students in England at Key Stage 1 are required to learn about: plants (including identification and structural features); animals including humans (including identifying structures and features/functions of body parts); and living things and their habitats (including animals being suited to their habitats; simple food chains).

Students at Key Stage 2 learn about: plants (including identification and classification); animals including humans (including classification and identifying structures and features/functions of body parts/skeletons; different functions of teeth; food chains); living things and their habitats (including classification systems and keys; environmental change; life cycles of different living things); rocks (including comparing and classifying rocks with different properties; the formation of fossils); and evolution and inheritance (at Year 6: including changes over time; fossil information; variation from reproduction; adaptation).

Such content is expected to vary according to student age: for example, biological classification at Year 1 is only covered through students identifying and naming various common fish, amphibians, reptiles, birds, and mammals, their various body parts, and which are carnivores, herbivores, or omnivores; biological classification systems and keys are then introduced at Year 4 and developed at Year 6. During Key Stage 2, the curriculum additionally suggests (in non-statutory guidance) that students may in the process learn about the work and significance of scientists such as Carl Linnaeus (classification), Mary Anning (palaeontology), and Charles Darwin and Alfred Wallace (evolution).

Students at Key Stage 3 (Years 7–9) learn about: the structure and function of living organisms (including cells and organisation; the skeletal and muscular systems; reproduction); interactions and interdependencies (relationships in an ecosystem, including interdependence and food webs); genetics and evolution (including heredity; a simple model of chromosomes, genes, and DNA; variation/differences between species/individuals; adaptation; natural selection); and the Earth and atmosphere (including the composition and structure of the Earth; rock cycles; carbon cycles). Students at Key Stage 4 (Years 10–11) learn about: ecosystems (including levels of organisation; cycles of material; interdependence and adaptation); evolution, inheritance, and variation (including genomes; genetic variation in populations of a species; the process of natural selection leading to evolution). Students also learn about more specialised cell biology, coordination and control (such as nervous systems), photosynthesis, and other areas that may be less directly applicable to natural history.

Similarly, considering potential natural history knowledge and concepts only (and not areas of working scientifically), students in the United States at elementary school may learn about various Disciplinary Core Ideas within the Next Generation Science Standards, covering: molecules to organisms (including structure and function via different internal and external body parts; growth and development of organisms via reproduction and their life cycles; specialisation of body parts for different information processing); heredity and the inheritance and variation of traits (via offspring being similar but not exactly like their parents; individuals of the same kind of plant or animal being similar but also varying; the influence of the environment); ecosystems and their interactions, energy, and dynamics (including interdependent relationships via plants depending on light, water and animals; any food tracing back to plants; social interactions and group behaviour; cycles of matter and energy transfer via air, soil, plants and animals); biological evolution via unity and diversity (evidence of common ancestry and diversity via fossils; natural selection; adaptation; biodiversity and humans); Earth's place in the universe (the history of planet Earth); and Earth's systems (including Earth's materials and systems).

Students at middle school (Grades 6–8) may learn about: molecules to organisms (including structure and function via cells; growth and development of organisms via reproduction; organisation for matter and energy flow in organisms via photosynthesis); ecosystems and their interactions, energy and dynamics (including interdependent relationships; cycles of matter and energy transfer via food webs; dynamics and resilience; biodiversity); heredity and the inheritance and variation of traits (including the growth and development of organisms via reproduction; inheritance via genes; variation via genes/chromosomes and mutations); biological evolution via unity and diversity (evidence of common ancestry and diversity via fossils and anatomical similarities and differences; natural selection; adaptation). Areas covered within the Earth's systems (such as plate tectonics and large-scale system interactions, via investigation of rocks and fossils) may also be relevant to natural history.

Students at high school (Grades 9–12) may learn about: ecosystems and their interactions, energy and dynamics (including interdependence via carrying capacities; cycles of matter and energy via photosynthesis and levels in food webs and carbon cycles; dynamics and resilience; group behaviour via evolution/survival; biodiversity and human activities); heredity and the inheritance and variation of traits (including structure, function, inheritance and variation via DNA, genes, and reproduction); biological evolution via unity and diversity (evidence of common ancestry and diversity / evolution via DNA; natural selection; adaptation).

Content is expected to vary according to student age, for example with inheritance and variation being introduced simply at Grade 1 via the ideas that offspring are similar but not identical to their parents and that individuals of the same species are similar but not identical to each other; at Grade 3, inheritance from parents and the influence of interactions with the environment are introduced; at middle school (Grades 6–8), genes, chromosomes, sexual reproduction and mutations are introduced; at high school (Grades 9–12), DNA and DNA replication are introduced.

This brief review of content highlights that many areas of natural history (such as exploring the classification of species via observed characteristics, adaptation via structural/skeletal features of animals and plants, ecosystems and biodiversity, and evolution via fossil records) are represented within the various curricula. However, content varies by age, which has implications for addressing curriculum content via activities and resources at NHMs; for example, at higher grades, curricula require advanced concepts such as genes or DNA to be explicitly covered.

The curricula also cover the ecological aspects of natural history, including topics such as ecosystems and biodiversity, and the influence of human activities on such topics. As a specific area, climate change is introduced at Key Stage 3 in England (via the chemistry area of Earth and atmosphere, including the production of carbon dioxide by human activity and the impact on climate) and developed at Key Stage 4 (via the chemistry area of Earth and atmospheric science, including covering evidence and uncertainties in evidence, for additional anthropogenic causes of climate change). In the United States, climate change is introduced in middle school (within the area of the Earth and human activity, specifically via ESS3.D global climate change); in high school climate change is also related to associated areas that include the impact on ecosystems and biodiversity (LS2.C, ecosystem dynamics, functioning and resilience, and LS4.D, biodiversity and humans).

Curricula and standards reported in educational activities from NHMs

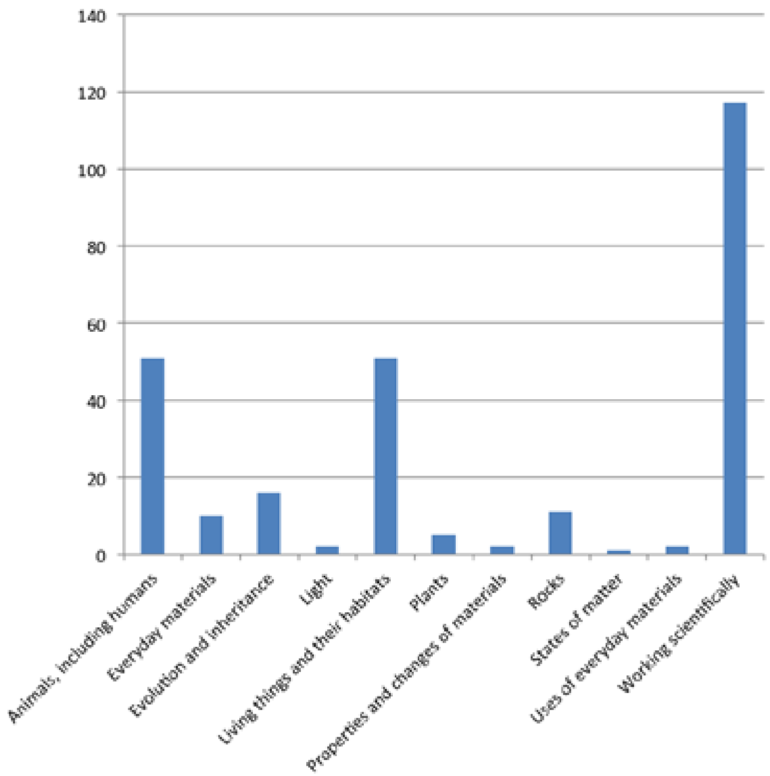
NHMs provide various educational activities, such as specialised sessions, workshops or events, and may highlight how these help to cover specific curriculum areas. Undertaking a comprehensive survey of these educational activities and their associated curriculum coverage across all national museums would be a valuable exercise. As an initial exploration, a limited selection of museums was considered. In England: the NHM London; the Manchester Museum; the Oxford University Museum of Natural History; the Grant Museum of Zoology, UCL. In the United States: the Smithsonian National Museum of Natural History; the Yale Peabody Museum of Natural History; the Harvard Museums of Science and Culture; the California Academy of Sciences; the American Museum of Natural History; and the Natural History Museum of LA County.

When curriculum areas were not listed (or were listed against older or other, for example, U.S. State standards), approximate areas were identified given the available description and information on the activity. Activities could address multiple curriculum areas, and/or be targeted or applicable to multiple age groups; the frequencies of identified curriculum areas do not sum to the numbers of activities considered. The frequencies themselves are inherently variable and imprecise: some activities may have been classified by their museums against fewer broad headings while other museums may have classified against multiple, more specific topics or ideas. Any frequencies are perhaps less relevant compared to whether curriculum areas are reported or not. Of course, even these indicators are dependent on the particular (and small number of) museums considered, their collections, their educational teams and provision of resources, and other factors. However, overall this survey captures a majority of the likely curriculum areas covered by most NHMs.

In England, 57 activities were targeted at or highlighted to be relevant to Key Stages 1 and 2; 13 to Key Stage 3; 10 to Key Stage 4; and 14 to older students (studying non-compulsory upper-secondary qualifications). Classifications were variously made against National Curriculum content areas or headings (as per the activity material), but are summarised under their wider headings for brevity (therefore not every area or idea under a heading may be explicitly covered by the activities).

In England for Key Stages 1 and 2 (Figure 2), the curriculum areas within 'working scientifically' were frequently highlighted (117 classifications). Other identified Key Stages 1 and 2 curriculum areas were: animals including humans (51); living things and their habitats (51); evolution and inheritance (16); rocks (11); everyday materials (10); plants (5); properties and changes of materials (2); uses of everyday materials (2); light (2); and states of matter (1).

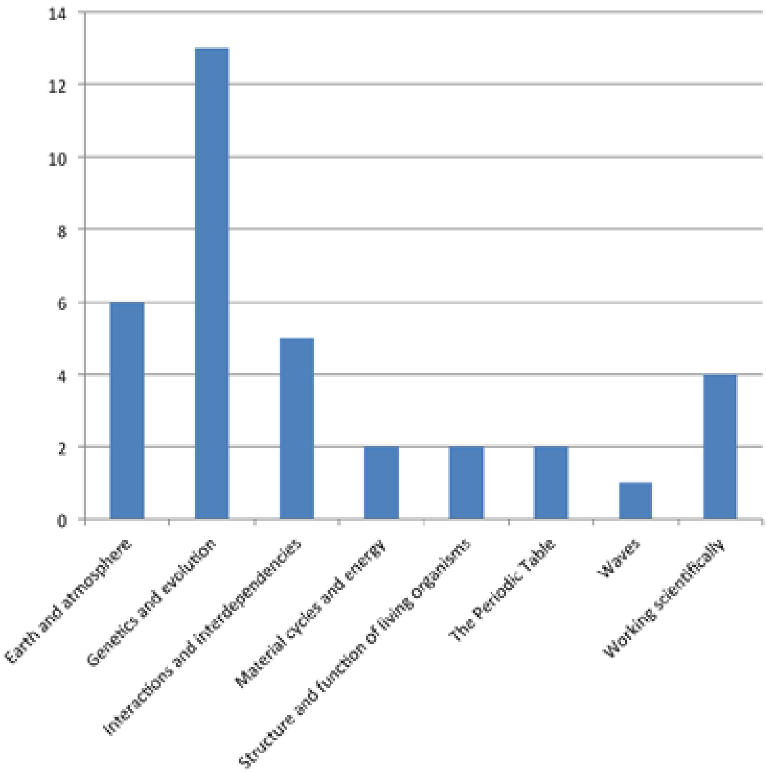
Figure 2. England: Key Stage 1 and 2 curriculum areas covered in activities from the selected natural history museums



Notes: The graph shows counts of classifications; one activity may have been classified against numerous areas within the different curricula headings. The considered museums and their activities were not nationally representative.

For Key Stage 3 (Figure 3), identified curriculum areas were: genetics and evolution (inheritance, chromosomes, DNA and genes; 13 classifications); interactions and interdependencies (relationships in an ecosystem; 5); working scientifically (4); Earth and atmosphere (within chemistry; 6); the Periodic Table (within chemistry; 2); material cycles and energy (cellular respiration and photosynthesis; 2); structure and function of living organisms (the skeletal and muscular systems, and reproduction; 2); and waves (light waves within physics; 1).

Figure 3. England: Key Stage 3 curriculum areas covered in activities from the selected natural history museums



Notes: The graph shows counts of classification; one activity may have been classified against numerous areas within the different curricula headings. The considered museums and their activities were not nationally representative.

For Key Stage 4 (not displayed graphically due to the lower numbers and varying categories), identified curriculum areas were: evolution, inheritance and variation (including genes, inheritance, evidence for evolution, and natural section; 16 classifications); working scientifically (7); ecosystems (including levels of organisation, cycles, interactions; 6); coordination and control (including the nervous system, structure and function, regulation; 4); cell biology (1); health, disease and the development of medicines (1); chemical and allied industries (1); and Earth and atmospheric science (1).

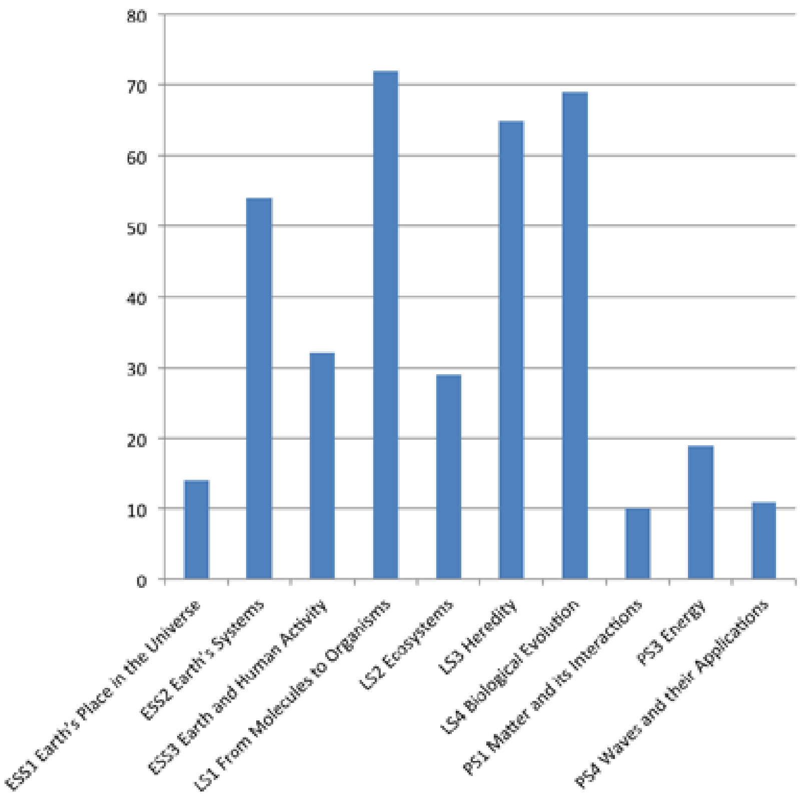
The National Curriculum in England does not cover upper-secondary education. Less information about the activities for this age group was available, and some NHMs provided no details so that no potential curriculum or assessment areas could be identified; content may also slightly vary per assessment scheme or examination board for upper-secondary qualifications. The broad areas for upper-secondary activities included: biodiversity, adaption, selection, and evolution (4 classifications);

specifics of DNA and reactions (3); medicine and diseases (3); working scientifically or 'how science works' (1); classification systems (1); and wildlife conservation (1).

In the United States, approximately equal numbers of activities were targeted or highlighted to be relevant to elementary / younger students, to middle school students, and to high school students. Identifying and classifying coverage was undertaken by specific Disciplinary Core Ideas where possible (as these involve age-dependent content), but these are summarised under their wider headings for brevity (therefore not every idea under a heading may be explicitly covered by the activities).

At elementary school (and any earlier ages; Figure 4), identified core areas were: from molecules to organisms, structures and processes (LS1 heading, within which various disciplinary core ideas could be covered; 72 overall classifications of core ideas); biological evolution, unity and diversity (LS4, including evidence of common ancestry and diversity, natural selection, adaptation, and biodiversity and humans; 69); heredity, inheritance and variation of traits (LS3; 65); Earth's systems (ESS2; 54); Earth and human activity (ESS3; 32); ecosystems, interactions, energy, and dynamics (LS2; 29); energy (PS3; 19); Earth's place in the universe (ESS1; 14); waves and their applications in technologies for information transfer (PS4; 11); and matter and its interactions (PS1; 10).

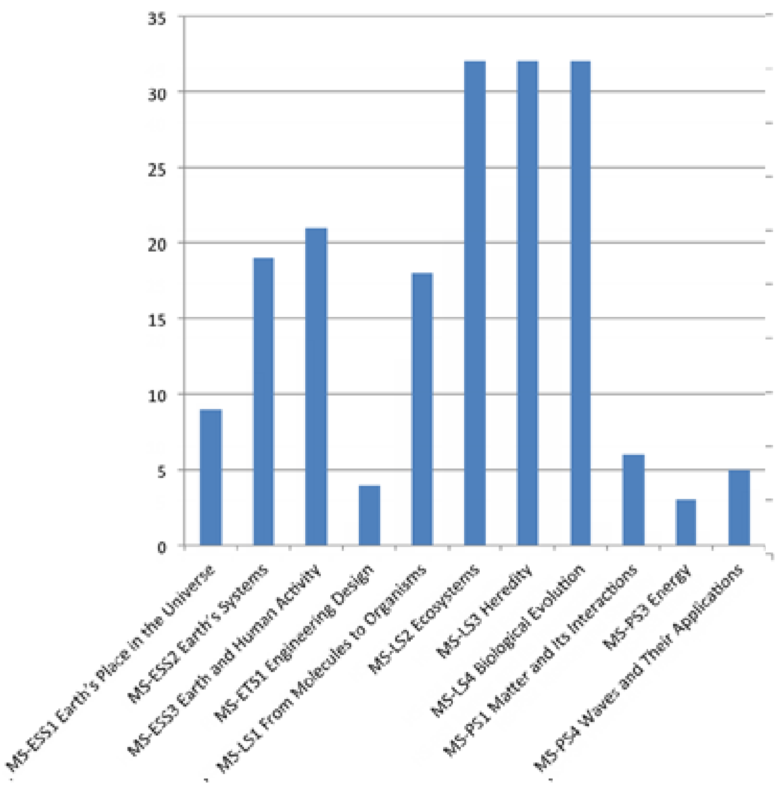
Figure 4. United States: elementary school core disciplinary ideas covered in activities from the selected natural history museums



Notes: The graph shows counts of classifications; one activity may have been classified against numerous areas within the different curricula headings. The considered museums and their activities were not nationally representative.

For middle school (Figure 5), listed core areas were: ecosystems, interactions, energy, and dynamics (MS-LS2 heading, within which various disciplinary core ideas could be covered; 32 overall classifications of core ideas); heredity, inheritance and variation of traits (MS-LS3; 32); biological evolution, unity and diversity (MS-LS4; 32); Earth and human activity (MS-ESS3; 21); Earth's systems (MS-ESS2; 19); from molecules to organisms, structures and processes (MS-LS1; 18); Earth's place in the universe (MS-ESS1; 9); matter and its interactions (MS-PS1; 6); waves and their applications in technologies for information transfer (MS-PS4; 5); engineering design (MS-ETS1; 4); and energy (MS-PS3; 3).

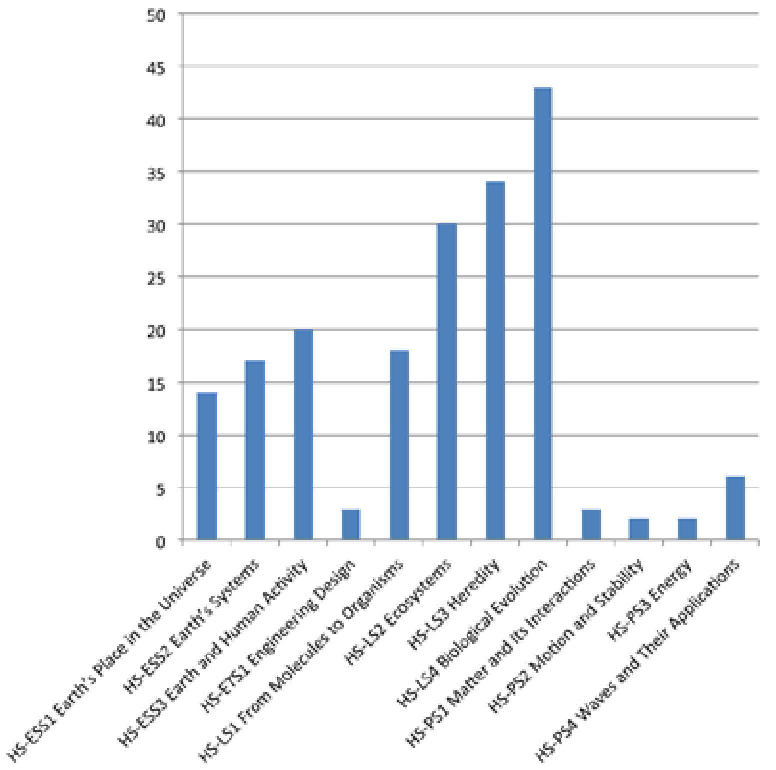
Figure 5. United States: middle school core disciplinary ideas covered in activities from the selected natural history museums



Notes: The graph shows counts of classifications; one activity may have been classified against numerous areas within the different curricula headings. The considered museums and their activities were not nationally representative.

For high school (Figure 6), listed core areas/headings were: biological evolution, unity and diversity (HS-LS4 heading, within which various disciplinary core ideas could be covered; 43 overall classifications of core ideas); heredity, inheritance and variation of traits (HS-LS3; 34); ecosystems, interactions, energy, and dynamics (HS-LS2; 30); Earth and human activity (HS-ESS3; 20); from molecules to organisms, structures and processes (HS-LS1; 18); Earth's systems (HS-ESS2; 17); Earth's place in the universe (HS-ESS1; 14); waves and their applications in technologies for information transfer (HS-PS4; 6); engineering design (HS-ETS1; 3); matter and its interactions (HS-PS1; 3); motion and stability, forces and interactions (HS-PS2; 2); and energy (HS-PS3; 2).

Figure 6. United States: high school core disciplinary ideas covered in activities from the selected natural history museums



Notes: The graph shows counts of classifications; one activity may have been classified against numerous areas within the different curricula headings. The considered museums and their activities were not nationally representative.

This illustrative review highlights that NHMs have the potential to cover more curriculum areas than may be assumed: for example, some activities covered various areas of Earth science and physical science (such as forces, energy, waves). Furthermore, and particularly in the U.S., many museum activities focus on anthropology and/or history, and these could not be included in and classified here. While perhaps outside the (science) scope of this report, historical and cultural aspects (which, for example, overlap with considering the lives and influence of particular scientists) have the potential for development within educational activities. This is indeed recognised within activities such as the 'Remarkable Victorian Women' workshop with Mary Anning and Mary Kingsley at the Oxford University Museum of Natural History or the programme on the California Gold Rush 'A Miner's Life for Me' at Natural History Museum of LA County, which cover scientific areas through the perspective of the humanities. Equally, the 'nature of science', 'working scientifically' or 'how science works' can also be presented through a historical and cultural perspective to highlight how ideas, methods and theories (and perceived 'truths' and 'knowledge') may themselves change over time; natural history could then overlap with or draw from the history of science (which is also, of course, a field in itself). Other curriculum areas, particularly the U.S. Common Core Standards for English Language Arts/Literacy and Mathematics, are also referenced frequently in programme descriptions as NHMs think carefully about maximizing the potential of a field trip. For example, it is often noted in the US that students' technical writing skills lag behind their skills in other types of writing and NHM visits provide ideal opportunities to practice these.

Given the limited number of museums considered, no conclusions can be drawn with any certainty regarding whether curriculum areas are frequently listed or omitted by museums in general, although practices did appear to vary. For example, in England, museums sometimes only provided details of learning points/objectives but no explicit National Curriculum areas, and/or provided (curriculum) themes that appeared to draw from older Qualifications and Curriculum Authority standards rather than specific National Curriculum headings or explanations; in such cases, coverage of curriculum areas could nevertheless be inferred. Providing no curriculum details at all appeared to be the exception (but did occur). Alternately, some museums provided comprehensive details of current curriculum areas. For example, activities at the NHM London, such as the extensive 'Explore and Discover' guides intended for Key Stage 3 students, listed the current National Curriculum areas covered by the activities; however, some other material (including the 'Explore and Discover' guides intended for Key Stages 1, 2, and 4) still appeared to reference an older National Curriculum version or older Qualifications and Curriculum Authority standards. In the United States, activities from the Q?rius program at the Smithsonian National Museum of Natural History provided comprehensive curriculum areas, listed for both middle school and high school students, from the relevant Next Generation Science Standards and from various other state or district curricula. At the Natural History Museum of LA County, field trip programmes are described for each grade with very detailed links to individual NGSS standards, California State Science Standards and Common Core Standards. It should be noted, in regard to the U.S., that many states have yet formally to adopt NGSS standards and may not do so. Therefore, it is not surprising that museums in the states that have done so, such as California, are more likely to list such details in their programmes.

Given the limited number of museums considered, it was not possible to determine whether wider curriculum areas of 'working scientifically' or equivalent were consistently omitted or included from activities. For example, the various 'Storytelling with puppets' activities at the NHM London, intended for Key Stage 1 students, highlighted that the shows helped cover specific areas of 'working scientifically' together with topic content from the various programmes of study per school year. Similarly, activities from the Q?rius program at the Smithsonian National Museum of Natural History and the programmes at the Natural History Museum of LA County listed relevant 'crosscutting concepts' and 'science and engineering practices', together with other relevant topic-based 'disciplinary core ideas'. Alternately, the 'Explore and Discover' guides from the NHM London often appeared to focus on listing topic content without listing areas related to 'working scientifically' (with exceptions such as 'Evolution on Earth', targeted at Key Stage 4 students, which covered 'Data, evidence theories and explanations'). As another example, activities from the Yale Peabody Museum of Natural History listed curriculum areas from their state's curricula (the Connecticut Science Curriculum Standards and Assessment Expectations from 2010). While the Connecticut curriculum appeared to cover areas of 'core scientific inquiry, literacy and numeracy' (including 'how is scientific knowledge created and communicated?' via areas such as identifying questions, designing and conducting experiments, and so on), the museum activities appeared to list only topic-based areas. Museums may have different expectations of what curriculum areas are available or may be relevant, and/or may have varying resources available within their education departments to help tailor or develop activities given their collections and expertise.

Tailoring activities to age-specific curriculum content may be challenging, and may mean that teachers need to interpret or enquire whether activities are relevant to their particular students. For example, the 'The Variety of Life: Classification' activity from the Oxford University Museum of Natural History was targeted at Key Stage 1 students (Years 1–2), and listed National Curriculum areas of 'working scientifically', 'animals including humans' and 'living things and their habitats'. The activity included classification, characteristics or organisms and discovering who Carl Linnaeus was and the importance of his classification system; such classification systems are covered through 'living things and their habitats' at Year 6. Within the 'animals including humans' area at Year 6, students should discover about the human circulatory system, diet and lifestyle, and nutrient and water transportation in various animals; however, simple classification is indeed covered within the 'animals including humans' area at Year 1. Similarly, 'Dinosaur Detectives' at the Oxford University Museum of Natural History was targeted at Key Stage 2 students (Years 3–6) and listed curriculum areas of 'working scientifically', 'rocks', 'living things and their habitats' and 'evolution and inheritance'; 'evolution and inheritance' is a requirement at Year 6 while 'rocks' (covering areas including how fossils are formed) is a requirement at Year 3. While activities can easily and beneficially reiterate or develop areas from earlier years, and some material required for older students may not necessarily be too difficult for younger students, such differences may lead to confusion in teachers as to whether activities are too simple or too advanced for different student ages.

Teachers may assume that museums (that know their collections and educational activities better than anyone else) accurately identity and list curriculum areas (when this is attempted). Realistically, contextualised educational activities in and from museums may closely or loosely fit with curriculum areas; this is indeed highlighted by the Harvard Museums of Science and Culture, where activities are listed with either light or strong coverage or application to broad learning areas. Given the limited number of museums considered, and given that limited information was publicly available, it was not possible to explore whether any listed curriculum areas were 'accurate' (which may involve a researcher-dependent judgment and/or require undertaking the educational activities themselves). The risk of 'name dropping' curriculum areas is perhaps relevant, where activities would appear to cover curriculum topics or areas but realistically might not cover them, and/or where activities may cover topics or areas that occur somewhere within curricula but are not relevant to the targeted students. Despite sometimes aggregating different age-specific content, museums appeared reassuringly to identify limited numbers of selected curriculum areas and not extensive lists of potentially over-claimed areas.

The nature of curricula themselves may also complicate the identification of relevant areas for educational or contextual activities: it is possible that areas of 'working scientifically' in England or 'crosscutting concepts' or 'science and engineering practices' in the United States could be interpreted as being relevant to many (or potentially any) educational activities or instances of learning; their universal application may then lead to reduced practical meaning. Additionally, the nature of the Next Generation Science Standards, which involve both 'cross-cutting concepts' and cross-cutting ‘science and engineering practices’, together with content-based or topic-based ‘disciplinary core ideas’ and/or performance expectations (where ‘students who demonstrate understanding’ can do or show various things, linked to the disciplinary core ideas), may also provide a practical complication (such as whether performance expectations and/or disciplinary core ideas are identified) and may require more time or effort to apply or work with. In contrast, the National Curriculum in England may appear simpler or more accessible, through involving only one cross-cutting area and a generally brief and concise approach to listing topic-based ideas (where students are expected to know, apply and understand the various matters, skills, and processes specified in the relevant topic-based programmes of study).

Ultimately, the exercise highlights the benefit of NHMs regularly reviewing curricula and standards and their own activities. Prior research has highlighted that teachers intend their museum visits to reinforce and expand on the classroom curriculum; teachers have also highlighted that success criteria for visits involve students enjoying the experience, students demonstrating new knowledge, and through connecting the visit to the classroom curriculum (Kisiel, 2005). Other research has highlighted, for example, that worksheets can facilitate students’ explicit exploration of curriculum topics during visits (Mortensen & Smart, 2007). Further research, and considering the views of students and teachers before, during and after their visits, may also provide more insights.

Insights and case studies from staff at NHMs

Staff at NHMs involved in the production of this report considered that they could offer opportunities not available in schools such as: their collections and specimens that students might not otherwise encounter; engagement with scientists; and engagement with ‘real world’ applications of science in specialised workshops. Nevertheless, they also recognised that their activities might be frequently targeted to broad age groups and to generalised curriculum themes rather than be targeted to specific curriculum objectives.

Staff at NHMs considered that they were able to address some educational areas especially well, specifically: the topic or area of evolution (including intra-species and inter-species diversity, given the museums’ collections); showing ‘real life’ applications of practical science using specialised equipment and resources (such as within university museums with access to large-scale or varied equipment used for analysis or research); providing opportunities for student-led scientific enquiries using a range of real objects; showing applications of varied fields of science such as palaeontology, using actual specimens and equipment; and providing careers information or access to and engagement with scientists (such as university museums involving researchers within educational activities).

For example, the ‘Diversity of Life’ workshop at the Manchester Museum covers areas including adaptation, variation and classification (aspects of the genetics and evolution Key Stage 3 biology curriculum), through handling real museum specimens. Similarly, the ‘Dinosaur Day: ideas and evidence’ workshop at the Oxford University Museum of Natural History involves Key Stage 3 students learning through hands-on experience with fossils and specimens, facilitating aspects of the

curriculum area of ‘working scientifically’.
Facilitating student-led enquiries and highlighting the applications of science may help cover the curriculum areas of ‘working scientifically’ or ‘scientific and engineering practices’. The capacity of NHMs to cover these areas could perhaps be extended and developed further, which may also help museums to address wider curriculum aims. In England, such aims are to ensure that all students: “develop scientific knowledge and conceptual understanding through the specific disciplines of biology, chemistry and physics”; “develop understanding of the nature, processes and methods of science through different types of science enquiries that help them to answer scientific questions about the world around them”; and “are equipped with the scientific knowledge required to understand the uses and implications of science, today and for the future” (Department for Education, 2013).

While students ideally need to develop an awareness of the careers that are possible within science or are made possible through science capabilities (National Research Council, 2012, p. 248), providing information about science careers is not an explicit or statutory area of the National Curriculum in England or the Next Generation Science Standards in the United States. Teachers may nevertheless provide this information naturally during their courses. However, as teachers may not necessarily have worked within science industries or research (and would perhaps be perceived in any event as ‘teachers’ rather than as ‘former scientists’), engagement with science professionals at NHMs may be beneficial.

Staff at museums highlighted that they aim to recognise and respond to schools’ needs, for example by: providing activities relating to evolution when this was added to the curriculum in England; recognising science concepts that may be perceived as hard or difficult, and looking for ways to address them (such as via the ‘Life on Earth’ interactive exhibit at the Harvard Museum of Natural History); recognising that a museum trip can be a ‘fun day out’ and so providing fun workshops (for example, focusing on forensic science or dinosaurs); and adding or including a curriculum link ‘to help the teacher justify the visit’.

Interest and enjoyment are not necessarily irrelevant to curricula. In England, the introduction to the National Curriculum at Key Stage 4 highlights that “The sciences should be taught in ways that ensure students have the knowledge to enable them to develop curiosity about the natural world, insight into working scientifically, and appreciation of the relevance of science to their everyday live” and that “The scope and nature of their study should be broad, coherent, practical and rigorous, so that students are inspired and challenged by the subject and its achievements” (Department for Education, 2013). The spirit of the curriculum, with science being inspirational and in developing curiosity, could be partially accomplished or facilitated through interesting and enjoyable activities at NHMs. Educational research has found that students’ interest and enjoyment are indeed influential to their choices of whether to continue studying science subjects (Mujtaba & Reiss, 2014; Regan & DeWitt, 2015), highlighting that this is an important aspect of educational activities and learning.

Some educational resources and activities can be highlighted to show how specific, and varied, areas from curricula can be addressed, together with other scientific areas.

The 'Life on Earth' interactive digital table at the Harvard Museum of Natural History assists in covering the Next Generation Science Standards core disciplinary ideas of inheritance (LS3.A), variation (LS3.B), adaptation (LS4.C), and natural selection (LS4.B), which are relevant to elementary, middle school and high school students. Advanced visualisation software allows museum visitors to interactively explore the phylogenetic relationships of 70,000 species, a sub-set of 200 species representing important evolutionary groups, and to compare any two species and identity their common ancestor and see the time of divergence, major evolutionary landmarks and major traits. This helps convey complex curriculum ideas in an intuitive and interactive way, which can complement traditional teaching and learning approaches. On a wider level, the resource presents an example of an interdisciplinary project with museum developers, software developers, learning researchers and evolutionary biologists contributing to the outcome. Visitors who engaged with the display were more likely to reason correctly about core evolutionary concepts including common descent and shared ancestry, and to interpret phylogenetic tree diagrams correctly (Davis et al., 2015).

Such exhibition or collection resources can also be beneficially supplemented by enacted talks, workshops and other activities, which can allow students to work scientifically while learning about curriculum content such as evolution. For example, the Oxford University Museum of Natural History provides activities such as the 'Evolve, Adapt, Survive!' object-handling session and self-guided trail, targeted to Key Stage 2 students in England, helping cover the National Curriculum areas of 'evolution and inheritance' and 'working scientifically'. Such activities covering evolution at the Oxford University Museum of Natural History have been designed to allow students to handle specimens that schools otherwise cannot easily access. The curriculum areas within 'working scientifically' themselves form the core of the 'Investigate Centre' at the NHM London, where sessions are tailored to students from Key Stages 1, 2 and 3; students make observations, use a variety of tools, look for evidence and relationships, and ask and answer their own questions.

Given that curriculum content varies according to student age, museums are able to explore advanced areas with older students. For example, the 'Forensic Science: A Bog Body Mystery' workshop at the Manchester Museum allows Key Stage 4 students to explore DNA using laboratory equipment, and engage with young scientists in the process. This helps cover more advanced aspects of the 'evolution, inheritance and variation' Key Stage 4 curriculum area.

The topic of evolution is also covered in the 'The Great Evolution Debate' workshop for Key Stage 4 students at the NHM London, covering the National Curriculum areas of 'working scientifically' (such as the ways in which scientific methods and theories develop over time) and 'evolution, inheritance and variation': students are introduced to the area, develop an argument for or against the views of Charles Darwin, Richard Owen, Thomas Huxley or Samuel Wilberforce, using evidence from the exhibits, and then re-enact the famous historical debate that occurred at the Oxford University Museum of Natural History in 1860. The idea of debate and argumentation has been increasingly favoured as a means to facilitate scientific learning (Erduran et al., 2015); for example, conceptually, argumentation has been considered to reflect the scientific process itself through requiring evidence-based justification of knowledge claims.

Conclusions

This review of science curricula in England and the United States highlights that numerous natural history areas are present, broadly including: human and animal anatomy; physiology; classification; reproduction and life cycles; adaptation, variation, inheritance, natural selection and evolution; ecosystems, food webs, habitats and biodiversity; and Earth systems, rocks, minerals and geological processes. However, these broad terms were variously separated or merged under different curriculum headings, and these also involved different requirements at different student ages.

As students age, curricula require coverage of advanced content, such as heredity and evolution covering chromosomes, genes and DNA from Key Stage 3 in England and from middle school in the United States. Students are also required to develop understanding of the nature, processes and methods of science and different scientific enquires, broadly described as 'working scientifically'.

A simple review of the educational activities, such as specialised workshops or events, offered by a selection of NHMs highlights that these curriculum areas are indeed frequently listed as addressed or covered by the activities.

Considered broadly, in England activities for Key Stage 1 and 2 students most frequently specified or were classified as addressing areas of 'working scientifically', then areas broadly covered by human and animal anatomy, physiology, habitats and classification. Activities for Key Stage 3 and 4 students most frequently specified or were classified as addressing areas covered by adaptations, variation, inheritance, natural selection and evolution.

For the United States, activities focused on elementary students' most frequently specified areas covered by human/animal anatomy/classification, by adaptations/evolution, and by Earth's systems and ecosystems. Activities focused on middle school students' most frequently specified areas covered by ecosystems, by adaptations/evolution, and by Earth's systems. Relatively similarly, activities focused on high school students most frequently specified areas covered by adaptations/evolution, by ecosystems and by Earth's systems.

Selected areas from physics (such as waves and energy) and chemistry (some elements of minerals, resources and Earth processes, depending on the particular curricula divisions) were also (but infrequently) specified.

The concept of systems and the topic content of ecosystems, food webs, habitats and biodiversity may have greater emphasis in curriculum standards in the United States than in England; fewer activities appeared to cover this area in England compared to in the United States.

Museums may not necessarily have consistently highlighted areas related to 'working scientifically' as being relevant to their activities. The nature of the Next Generation Science Standards (with two additional cross-cutting classification systems), and the potential need to cover local state or district curricula, may also complicate any curriculum targeting by museums. Nevertheless, museum staff involved in the production of this report believed that NHMs had key strengths in helping students learn about the nature of science and science enquiry: students can engage with 'real life' applications of science and undertake student-led scientific enquiries using real objects; students can see applications of varied fields of science such as palaeontology using actual specimens and equipment, and also engage with scientists in activities at the museums.

NHMs may beneficially build on these strengths (such as considering and/or emphasising the application of 'working scientifically' through their activities), and also promote science as being inspirational and developing students' curiosity (points which are, for example, emphasised in the introduction to the National Curriculum at Key Stage 4 in England).

NHMs' activities already appear to extensively cover the topic of evolution in various ways, and this is recognised as a strength by museum staff. While areas of strength can be beneficially developed further, other areas such as ecosystems and Earth systems may also offer the potential for further development. The relevance of natural history collections and scientists and their lives to history, culture and the development of science itself may also offer further educational opportunities, as does the potential for programmes to address curricular standards in the social sciences, language/literacy and mathematics. Finally, the restricted number of museums considered here ensures that comprehensive national reviews of educational activities may be beneficial.

Objective 5

Review, through researcher-practitioner collaboration, current pedagogical approaches employed by schools and NHMs, with a view to developing and studying new practice models in Phase 2

Our initial hypothesis here is that opportunities to develop teachers' pedagogies and attitudes to teaching life and earth sciences are given insufficient attention in the resources that NHMs currently tend to provide. We are particularly keen to explore the affordances of digital resources and distance learning in ways that can complement in situ learning with tangible objects. Our project aims to develop, support and improve the culture of research-based science education practice.

Informal science learning educators in museums may have close and productive relationships when working with schools. The Informal Learning Collaborative (ILC) programme is one such example. This is a professional development programme for informal educators and currently leads on teacher development programmes (Bevan et al., 2010). Museums are well placed to enable interaction with authentic, part or whole collections, as well as stimulate interest and curiosity through digitisation of the materials, a finding which we corroborated with our own interviews.

Although spatially separated, all the NHMs participating in this research share a number of features: in particular, the museums are science centres themselves, with research-active scientist working on aspects of the collections.

> *When visitors were asked in exit interviews about their favourite aspects of the exhibition, one of the most frequent responses given was that they enjoyed its immersive environments. Summative evaluation of a prehistory exhibition that opened several years ago revealed that the hottest 'hotspot' for visitors in terms of attraction and dwell time was a recreation of an Eocene rainforest environment. The Museum is finding that the immersive spaces in 'Coast to Cactus' have a similar power. (Practitioner)*

This practitioner could not claim that any given exhibit is successful for all its visitors but she did indicate that evaluations of visitor experience indicated that many visitors to her museum are enthused by environments which transport them to another place, using multiple senses and their imaginations.

NHMs can provide opportunities for face-to-face interactions between scientists and members of the public. Practitioners can be 'on hand' to guide the learning, respond to questions, be flexible in their approach in engaging visitors and recognise the exhibits as being a central focus to the museum visitor experience.

> *You need a variety of options, so some more interactive exhibitions, some more static to wonder through, and options to go to a talk, a film, or to engage with people roving with specimens—this can be a highlight as face-to-face interactions have a positive effect.* (Practitioner)

Indeed, the current inquiry approach to teaching and learning science may impact on both science teachers and NHM practitioners, with greater structuring of preparation and follow up time in using, viewing and participating in the museum exhibits to develop analytical and evaluative skills, for example. Suggestions from practitioners included catering for learners of different needs and providing muti-sensory, visually appealing exhibits that support the development of skills and knowledge that cannot be gained at school. Teachers' interactions with NHMs are often as users of resources that are not normally available at or within school, as complementary agents to support student learning, especially when the visti has a particular focus. In interviews they reported positively experiences such as students being able to handle museum objects, the breadth of exhibits, the sense of scale, all of which are more fruitfully experienced at a NHM.

> *Evolution was introduced to the Year 6 curriculum this year and we used the Darwin exhibition to enhance our work in class. This included looking at biographical information panels, real life artefacts and specimens from his voyage and the model of DNA. To visit a place where Darwinism was actually debated and to see real life specimens really impressed the children and the teacher! and added to their learning in a way no classroom work could. We took the topic way beyond KS2 level and into KS3 as the children wanted more. The museum was the trigger and the quality of work and depth of discussion way beyond expected levels for all children, not just the very able, and led to a class debate on evolution with children playing the parts of Darwin, the journalists and the Bishops.* (Teacher)

> *I think that for the students involved in the River & Rowing Programme, especially the ambassadors that got to go to both sites, both at the Thames and here at school, they really understood the difference in the ecology and why that was happening, because they got to actually experience both. But I think the downfall of that project was that there were only a limited number of students that could attend the River & Rowing Museum. So [the others] only saw one end of the ecology, they only saw the school garden, and even though the ambassadors had taken photos and did a descriptive PowerPoint and made this presentation, they didn't get the value of actually going and seeing it. But for the ones that did, I think it was actually quite effective.* (Teacher)

> *I think the best one is the Natural History Museum but it was the Ashmolean where the work carried out in the museum and the experience they had in the museum was in the middle of a scheme of work and so was supported by lessons beforehand and then followed up in lessons afterwards. It was incredibly linked to the curriculum so that students knew that they had to participate and that what they were producing was going to contribute to…there was some outcome that was going to really benefit them not just enriching them.* (Teacher)

> *I have experienced excellent use of the museum along with students working on projects, which required experience looking at diversity of species (Rain Forest animals). They were well informed and offered first hand experience of handling creepy crawlies, categorising and noting how their bodies were equipped to suit environments.* (Teacher)

While there may be planned activities to support the time spent looking at the exhibits, some time for independent learning and exploration should be 'built in' to the visit. Both teachers and practitioners raise the issue of 'developing activities' to support learning. Some science outreach programmes highlight the gap between expectation and delivery, as a recent report by the Royal Society made clear (Fogg-Rogers, Weitkamp, & Wilkinson, 2015). Other NHMs are asked for pre-prepared packs of information, but little attention to date has been focused on pedagogical practices. Such a programme will need to embrace educators with a sound understanding of current best practice, as well as curators, science 'outreach' and museum practitioners to better understand the nature, provision and evaluation afforded in informal learning settings.

Objective 6

Identify how NHMs can help communicate what biology and earth science means to teachers and students

Our interviews have helped to uncover what teachers and students think about learning science, highlighting that there are similarities and differences in the way adults and students communicate their views. Our work in identifying how NHMs can help communicate what biology and earth sciences means to teachers and students can help to improve students' understandings of the nature and diversity of biology and earth science, leading to future engagement with nature, further study of science or the adoption of science-related careers.

One similarity between teachers and students interviewed in this study was that they talked about 'exciting' exhibits and how they were able to learn about scale, evolution and change over time, as well as being able to go into more depth about individual exhibits.

> *I liked that when we joined the dinosaur bones together. When you want to be an archaeologist you can learn from that as well so it'll be easier for you on paper when you grow up you'll have had more experience with the real bones. (Student)*
>
> *Evolving Planet at The Field Museum [exhibit that has worked well]. Dinosaurs are a tremendous avenue for students across many grades. It also fosters great pre- and post-visit activities, such as sand digs in the classroom. For reasons stated above in question one, PlayLab is also important. (Teacher)*
>
> *The Natural History Museum in London [exhibit that has worked well]. They have more objects, more experienced people and it's an older museum so it has been working very well and has really good rating. It has more objects, more specific objects so that you could learn about the museum and dinosaurs and that. (Student)*

The NHMs communicated information to, and directed visitors about, what to do next, which was noted by teachers and students. All groups of interviewees spoke about the possibility of experiencing 'augmented reality', the use of 3-D and multi-media to learn and the value of interactive exhibits. At this stage, we have very little evidence about the role of NHMs in promoting science careers.

Objective 7

Strengthen the research and knowledge base in NHMs and the ISL sector more broadly by increasing research capacity within the sector

By establishing networks among researchers and formal and informal practitioners we seek to contribute to building a more robust practitioner-researcher community, building upon the efforts of individuals currently working in Informal Science Learning (ISL) research and natural history engagement. This needs to be explored in terms of what works for students' experiences of ISL and what does not. Engaging with school teachers, practitioners and researchers was a priority of the research.

We recognise the need to strengthen the partnership between NHM practitioners, researchers and teachers. In interviewing teachers, practitioners and students about their experiences of learning in NHMs, many affective factors were volunteered with descriptions of 'exciting' exhibits 'enhancing the experience' and this is often included as part of an evaluation of a school visit. From young children visiting a zoo (Birney, 1988), to teachers' expectations of developing positive attitudes following a museum visit (Hooper-Greenhill et al., 2004a; 2004b; 2006) evaluations appearing to focus on satisfaction rather than learning are common. The immediacy of enjoyment can perhaps be easily captured whereas the learning that has taken place, developed or reinforced, is more difficult to discern. Certainly, a positive, engaging experience may augur well for learning, and gathering information about affective as well as cognitive impacts after a museum visit are not always straightforward.

For these challenges to be better matched, we need to be cognisant of the potential 'gaps' in what is asked of informal learning providers; zoos, for example, may not teach about animal welfare issues, whereas their visitors might be interested in this topic (Roe & McConney, 2015). This project has highlighted the role of NMHs in supporting learning, with practitioners and researchers focused on discerning 'what works' from a variety of perspectives. Increasingly, digitisation of exhibits, development of concepts through new ways of communicating and enabling exhibits to be experienced by more people outside the museum walls emerge as future focused topics of interest.

Dissemination

Talks about the project were given or have been confirmed at the following conferences and workshops: the Annual Conference of Association of Science & Technology Centers (2015), the Biennial Gordon Research Conference on Visualization (2015), the Geological Society of America Conference (2015), the Real World Science Conference (2015), the UK Biology Education Research Group (2015), the Wellcome Trust (2015), the Yale Peabody Museum's P. rex Club (2015), the Association for Science Education Annual Conference (2016) and the International Council of Museums UK, British Council and National Museum Directors' Council 'Working Internationally' Conference (2016).

This report is also being posted to a number of listservs and discussion groups including the American Alliance of Museums' Museum Junction Open Forum and the Association of Science & Technology Centers' General Forum and its 'Research and Evaluation Community of Practice'.

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