Nature-based Education in the 21st century

A potential role for Augmented Reality?

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

This report was commissioned by Natural England to explore how Augmented Reality technology can be used to support access, engagement, education, and recreation in the natural environment due to the increased use of technology and decreased time spent in nature by young people. The report reviews the development of nature-based education, the use cases of augmented reality and how the technology could be used as a support tool to enhance nature education, engagement, recreation, and access. The report will help inform future initiatives to support equity of access to greenspace and contribute to understanding of ways in which best to engage young people with the natural environment.

Executive summary

Current generations will have to contend with challenges and opportunities that previous generations have not had to deal with – namely, the unpredictable impacts of climate change as well as a rapidly evolving, and often equally unpredictable, technological landscape. Navigating these areas will require new ways of learning, new skills, and new ways of interacting with and shaping our environments and societies.

In the 21st century, children have three broad learning environments – the personal world which consists of family and friends; the digital world; and the natural world. None of these learning environments on their own will be sufficient to provide children with the skills they need to deal with the challenges they will face but combinations of these learning environments can create strong synergies of complementarity and supplementarity. This report outlines the uses and strengths of two important pedagogical modalities – nature-based learning and augmented reality.

Nature-based learning

The use of Nature-based Education dates back to the Industrial Revolution where it was used to support young people to connect with nature and learn independently. The underlying principles of nature-based learning are nature literacy (i.e. learners are provided with access to information about nature) and nature-based learning (i.e. learners are exposed to nature and nature-based activities in natural settings to support the acquisition of knowledge, skills, values, attitudes and behaviours).

There have been several nature-based education initiatives in the UK dating back to the Natural Connections Demonstration project in 2012 to the more recent Children and Nature Programme delivered through three large scale projects in England – Nature Friendly Schools, Community Forest and Woodland Outreach Project ad Growing Care Farming.

There have been several positive impacts associated with nature-based education including improved self-concept and self-discipline, social, cognitive, emotional and interpersonal skills development, mental/emotional/psychological health and wellbeing, stress relief, improved environmental knowledge/attitude, improved attention and engagement with learning, general learnings skills, improved academic performance, increased physical activity levels, and better school attendance rate.

Augmented Reality based Education

Teachers in the UK acknowledge the importance of using technology in education – indeed, in a survey of over 1500 education professionals, 51% of respondents agreed that technology was a strategic priority for them, 75% highlighted technology as a way to engage students and 54% mentioned they are trying to use technology in their teaching.

Extended reality (XR) - which includes Augmented (AR), mixed and Virtual Reality (VR) – is a novel way to engage with learning content especially where cost and distance are

limiting factors. Among XR modalities, AR is one of the most accessible forms because it can be delivered across a variety of technological levels ranging from virtual headsets down to modern smart phones. The general principle of AR is to support the user to interact with the digital:physical environment created by AR that allows for the overlay of information, visuals and other content onto the physical environment. Through this approach, AR can help students to experience objects that are not accessible physically or to engage with physical objects in new ways. AR leverages several pedagogical approaches including: hedonic values, utilitarian, theory of situated learning, Bruner's spiral curriculum theory and/or Vygotsky's theory of the zone of proximal development.

AR is currently used in multiple settings including primary/secondary schools, special education, and skills training. When utilised well, AR can support students to: increase personalisation, increase motivation to learn, promote active learning, improve memory recall, improve learning outcomes, and create opportunities for novel social interactions. Some limitations of AR include: its lack of suitability for all subject types, difficulty for teachers to integrate into existing lesson plans, accessibility and affordability of some AR technology and an increase in cognitive load for learners.

Using nature- and/or AR-based education

Both nature-based and AR-based education can be integrated into curricula through a wide variety of approaches but for whatever format, setting or subject they are used, there are some fundamental questions that teachers need to ask that can guide decisions about whether to, firstly, introduce these modalities of education and if they are to be introduced, how it would be best to introduce them:

- What learning outcomes can be delivered and impacted better through these modes of education?
- Will my learners be able to effectively use and engage with these modes of education?
- A consideration of the contextual factors that need to be considered (frequency and duration of sessions).
- Support that must be given to teaching staff and students to be able to effectively engage with these modes of education
- Resource (time, money, space/appropriate settings) constraints.

Key considerations on using AR to support nature-based education include:

- AR should be used to enhance nature-based experiences without replacing them.
- AR should augment or stimulate nature-based learning in a way that would not be possible without it, i.e., presenting nature in a new way to learners.
- AR should provide learners with other and novel forms of engagement with nature; for example, seeing things at different scales (zooming in or zooming out) or over different time periods that wouldn’t be possible otherwise.

Contents

Introduction

In the 21st century, children have three broad learning environments – the personal world which consists of family and friends; the digital world; and the natural world. There will be interactions between these different learning environments for children that will vary for individual children as well as for different contexts but one thing is certain - none of these learning environments on their own will be mutually exclusive or collectively exhaustive. If utilised well, they can augment the strengths of any of these learning environments alone while also addressing some of their limitations (Favretti, 2023; Wolf, Kunz & Robin, 2022).

In this document, we highlight the background, uses and strengths of two important pedagogical modalities – nature-based learning and augmented reality – and outline some design considerations for how they can be combined to support teachers to more easily leverage two learning environments (digital and natural) to support better health, wellbeing and educational outcomes for children.

Nature-based Education

History

The recognition of the importance of nature connection for children and youth is not new. During the Industrial Revolution, members of the German Sturm and Drang movement, the Romantics and American transcendentalists advocated for increased nature exposure for children and young people to support connection to nature and to improve mental and physical health. From a pedagogical perspective, learning outdoors and in nature was also seen as an efficient and effective means by which children could interact with their environment and support independent learning. This subsequently led to experiments with incorporation of learning outdoors in the mid-19th and early 20th centuries through initiatives like Margaret McMillan's 'Open Air Movement' as well as the pioneering work of Italian physician Maria Montessorri and Susan Isaac's Malting House School – all of which contributed to modern nature-based pedagogical approaches like forest schools (Cree & McCree, 2012; 2013; Kwon, 2002, Prochner, 2021).

Educational principles

Schools as an important place for increasing exposure to the outdoors and nature is corroborated by Natural England's 2022 Children's People and Nature Survey, which found that schools were the place where children were most likely to spend time outside, though incorporation of outdoor exposure during lessons was not very frequent (85% of children reported they spent time outside at schools vs. 23% of children reporting exposure to the outdoors through lesson plans) (Natural England, 2022a).

Despite the use of a variety of pedagogical approaches in nature and the outdoors for several decades, there is no standard approach for the design and implementation of nature-based experiences/lessons for children at school (Miller et al., 2021). Experts in

the field highlight that there are two general principles that guide the design and delivery of these types of interventions:

- Nature literacy: “providing access to information about nature and nature conservation (both science and values-related information), and the ability to use that information outside the classroom, can empower students to become more actively engaged with the natural world. The aim of nature literacy is to raise awareness of the importance of nature conservation.” (Grace, Griffiths & Hughes, 2021).
- Nature-based learning/education: “Nature-based learning (NBL) or learning through exposure to nature and nature-based activities, occurs in natural settings and where elements of nature have been brought into built environments, such as plants, animals, and water. It encompasses the acquisition of knowledge, skills, values, attitudes, and behaviours in realms including, but not limited to, academic achievement, personal development, and environmental stewardship. It includes learning about the natural world, but extends to engagement in any subject, skill or interest while in natural surroundings. NBL can occur with varying degrees of guidance or structure, across the age span, alone or with others, and in urban, suburban, rural, and wilderness settings.” (Jordan & Chawla, 2019).

Leveraging these two broad principles where “nature is utilised as setting, as resource and as educator” (MacQuarrie, Nugent & Warden, 2015) there are a variety of approaches that can be used based on local, social, and cultural preferences as well as the resource constraints of what is possible in a given context.

Nature-based education in the UK

In the UK, there have been several initiatives aimed at increasing nature connection for children and young people through school-based programmes, such as Forest Schools, which are incorporated within the curricula for subjects such as physical education, science, geography, and environmental education (Prince, 2019). The success of these programmes informed the design and delivery of the Natural Connections Demonstration project (2012-2016), which was run with the goal of increasing the demand for, support for and provision of high-quality learning in natural environments. Over 40,000 children from 125 primary and secondary school across the South West of England were involved in the programme, the impact of which was impressive including increased satisfaction with lessons from both children and teachers and positive impacts on health, happiness, behaviour, social skills and educational outcomes (Maynard, 2017; Natural England, 2016; O’Brien, 2009; Waite et al., 2016).

Evidence from the Nature Connections Demo was used to inform policy commitments in the 25 year environment plan to encourage children to be close to nature inside as well as outside of school settings (HM Government, 2018). The 25 Year Environment Plan, in turn, provided a framework for the ground breaking Children and Nature Programme that Natural England has been leading, which include three large scale projects in England – Nature Friendly Schools, Community Forest and Woodland Outreach Project and Growing Care Farming (Natural England, 2022b).

The commitment to increasing nature-based exposure for children in schools in England is a necessary step but there are still several common challenges seen across these programmes including (Barfod & Mygind, 2022; Harris, 2021; Mann, Gray, Truong, 2022; Miller at al., 2022; Prince, 2019):

- Curriculum and time pressures
- Confidence of teachers in delivering sessions
- Safety concerns
- Unpredictability, particularly because of weather
- Cost

Furthermore, for children, there are inequalities in regular access to these types of resources, especially children in dense urban environments and those who have mobility-related challenges (Davis & Jones, 1999; Freeman & Tranter, 2011; Sipe, Buchanan & Dodson, 2006). A key driver of these inequalities is the design and subsequent structuring of urban environments, which are largely driven by adult needs. Children are rarely consulted in the design of greenspace features that meet their needs, especially the different play requirements for different age, groups, genders, cultures and mobility levels (Markevych et al., 2014; Prellwitz & Skär, 2006; Tamm & Skär, 2000).

Impact

It is well established that exposure to nature has many physical and mental health benefits for children as well as adults (Camasso & Jagannathan, 2017; Coates & Pimlott-Wilson, 2018; Fyfe-Johnson et al., 2021; Johnstone et al., 2022; Miller et al., 2021; Slee & Allan, 2019; Sprague & Ekenga, 2022). There are a variety of different nature-based education approaches in use in the UK and globally that are delivered across different learning settings and school subjects including, for example: adventure therapy; adventure education; field trips; and curricular lessons in local outdoors, residential camps and/or school grounds (Collado, Rosa & Corraliza, 2020; Fiennes et al., 2015; Harvey et al., 2020; Kuo, Barnes, Jordan, 2022; Mann et al., 2022; Montgomery et al., 2022; The Wildlife Trusts, 2021). These different approaches can yield a variety of benefits for health, wellbeing and education outcomes including:

- improved self-concept and self-discipline,
- social, cognitive, emotional and interpersonal skills development,
- mental/emotional/psychological health, mood, wellbeing and resilience,
- stress relief,
- improved environmental knowledge/attitude,
- improved attention and engagement with learning,
- general learnings skills,
- improved academic performance,
- increased physical activity levels,
- better school attendance rate

These results are also, importantly, seen across different socio-economic demographics demonstrating how nature-based education can also be useful in reducing educational

inequalities (Camasso & Jagannathan, 2016; Slee & Alla, 2019). They can also positively impact teacher's wellbeing and job satisfaction (Natural England, 2016).

Studies comparing nature-based education to traditional approaches have highlighted that nature-based education is generally more effective than traditional approaches; its effects hold across topics, learners, instructors, and places; and it shows a 'dose-response relationship' where an increase in the amount of nature-based education also demonstrates an increase in the outcomes. The exact mechanisms underlying these outcomes is not known but it is thought that nature-based education has its effects because of the greater engagement it affords for children as well as the rejuvenating effect of nature (Kuo, Barnes & Jordan, 2022), including increased happiness and subjective well-being, a decrease in stress, improvements in cognitive function as well as memory and attention (Bratman et al., 2019).

Augmented Reality in Education

Technology is an unavoidable element in the lives of children and young people and teachers in the UK and globally recognise this (Pimental et al., 2022). In a survey of over 1500 education professions (including teachers, head of schools, etc.) in the UK and Ireland, 51% of respondents agreed that technology is a strategic priority for them because of the recognition that technology is necessary for everyday life and, therefore, needs to be incorporated into lessons. Further to this, over 75% of respondents highlighted that technology is also a way to engage with students and can also support teachers to do their jobs better. In practice, 54% of the respondents mentioned that they are actively trying to use technology as a tool to support their educational curricula despite a lack of training and funding support (Promethean, 2022).

There are a variety of different technological modalities that can be used to support educators with one of the most promising being immersive technologies which have been explored in educational settings since the 1990s (Dick, 2021).

Background on Augmented Reality

Immersive experiences or extended reality (XR) provide novel and more engaging ways for students to engage with learning content especially where cost and distance are limiting factors. XR is a broad term that captures a variety of approaches including augmented reality (AR), mixed and virtual reality (VR). The key difference between these XR modalities is the degree of 'virtuality' they utilise with VR having the highest virtuality because it consists of a completely computer-generated virtual environment that replaces the real world with a digital one, while AR has a lower level of virtuality and normally consists of digital content superimposed onto the physical world (examples of AR applications include Pokemon Go (Niantic, Inc., 2023), Ikea Place (Inter IKEA Systems B.V., 2017), Google Lens (Google LLC, 2021), Snapchat (Snap Inc.), and AR direction in Live View within Google Maps (Hall, 2023)) (Loveless, 2023; Dick, 2021; Pimentel, 2022).

Though they have existed for many decades, XR has only recently become affordable and accessible enough for their consideration in educational settings (Dick, 2021). Among XR

modalities, AR is one of the most accessible forms because it can be delivered across a variety of technological levels. At the most immersive end, AR can include virtual headsets and customised controls while at the more accessible end, AR can be utilised through simple tools like modern smart phones that many students already have access to. Regardless of the technology used, however, the general principle of AR remains the same – namely, to support the user to interact with the digital: physical environment created by AR (Apple Inc., 2018; Dick, 2021; Loveless, 2023); that allows for the overlay of information, visuals and other content onto the physical environment. AR applications "create a three-dimensional reality that can present the digital world as a physical phenomenon."

From a pedagogical perspective, AR offers many powerful opportunities for teachers to effectively engage students in their learning from theoretical and practical perspectives (the latter will be covered in the Use Cases section below). Table 1 provides an overview of some of the important pedagogical theories underlying the benefits of AR in education:

Table 1. Pedagogical underpinnings of AR

Pedagogical considerations	Description
Hedonic Value	Digital experiences that are matched with real sensory experiences in the physical experiences can deliver hedonic value, which can provide real time understanding to users, improve playfulness, promote real knowledge and increase student's commitment to the course (Batool, 2022).
Utilitarian	AR can provide opportunities for interactions with specific objects that can increase the object's visibility and increase its recognition in real environments (Batool, 2022).
Theory of situated learning	By providing information in a contextually relevant environment, AR can increase the understanding of how new information can be practically applied in the physical world (Miller & Dousay, 2015).
Bruner's spiral curriculum theory	AR can provide customised and on demand learning support for students when they need it, especially through accessible devices like smart phone (Miller & Dousay, 2015).

Pedagogical considerations	Description
Vygotsky's theory of the Zone of Proximal Development	AR can provide timely support when students need it (Miller & Dousay, 2015).

AR use cases

AR has been and could be used for a variety of different approaches to support children to engage better with their education and achieve educational outcomes. AR-based education generally rests on three core pillars that rely on providing opportunities for immersion, interactivity and making the invisible/ inaccessible visible/ accessible (Apple Inc., 2018; Batool, 2022; Dick, 2021; Jerowsky & Borda, 2022; Loveless, 2023; Pimentel et al., 2022) to support students to:

- experience physical objects in new ways and visualising things that were invisible (for example, due to their scale or the timeframes over which changes occur).
- experience objects that are not accessible physically (for example, due to distance, historical event, safety concerns, economic barriers, or ability).)
- increase engagement because of the ability to explore different scales (i.e. zooming in and zooming out)
- increase motivation and collaborative learning, especially when integrated with gamified approaches, including role-playing and perspective-taking

In non-university settings, teachers have used these different functions of AR in varied settings including in primary and secondary schools, special education as well as for skills training:

Primary/secondary schools: the subjects for which AR has been used most include science, humanities and the arts, mostly through interactive experiences including virtual field trips (Loveless, 2023). There are many existing solutions that can be easily adopted by teachers into their lesson plans (Appendix 1 provides some examples). In addition to this, several books have been designed to work with AR – students use their phones to scan images or content in the book and the AR application introduces the students to immersive and interactive activities suitable to their age groups.

Special Education: AR can be very helpful to students with special education needs (e.g. those with cognitive/learning disabilities such as autism spectrum disorders, attention deficit hyperactivity disorder, dyslexia as well as other conditions like deafness). Through approaches likes augmenting, altering and/or enhancing existing learning tools like textbooks and flash cards, AR can more easily adapt to user needs and support self-directed learning (Dick, 2021; Loveless, 2023).

Skills training: AR can complement and supplement skills training by providing learners with the opportunity to engage with immersive and hands-on experience with skills

development while minimising the costs and risks sometimes associated with different types of skills training (Dick, 2021).

Strengths and weaknesses of AR

Strengths

AR, in its varied forms, has demonstrated several benefits including (Batool, 2021; Dick, 2021; Pimentel et al., 2022; Yildiz, 2021):

- increasing interest and motivation to learn;
- increasing personalization and flexibility of learning content to adapt to different learning styles, speeds and abilities;
- augmenting the ability to visualise learning content;
- promote active learning and engagement;
- improve memory recall, especially for complex topics;
- supporting cognitive development;
- improving learning outcomes;
- boosting self-confidence and confidence in learning content;
- creating opportunities for novel social interactions.

Weaknesses

There are several weaknesses for AR-based learning content that range from practical and logistics considerations to user-related issues. On the practical side, it is important to note that AR is not suitable for all subject types and so far has mostly been used for science, humanities and the arts. Further to this, even for subjects where AR content does exist, time constraints for teachers could mean that they cannot implement into their lessons plans and the AR content also may not comprehensively cover all key learning topics that teachers need to cover in their syllabi (Dick, 2021; Pimentel et al., 2022). Other practical considerations include accessibility and affordability of some of the more immersive AR experiences as well as privacy and safety considerations, especially when students use their personal devices. Furthermore, the developer of an AR experience will also have to work to maintain the application over time as software and hardware evolves over time. On the user experience side, AR content can sometimes be difficult to navigate and use, it could increase cognitive load and over time, the novelty and positive effects of AR could also wear off (Pimentel et al., 2022).

Using nature- and/or AR-based education

Both nature-based and AR-based education can be integrated into curricula through a wide variety of approaches but for whatever format, setting or subject they are used, there are some fundamental questions that teachers need to ask that can guide decisions about whether to, firstly, introduce these modalities of education and if they are to be introduced, how it would be best to introduce them.

When to use nature-based and/or AR-based education

The first step that a teacher needs to take when considering whether to used nature-based and/or AR-based education is to ask “why?” (Miller & Dousay, 2015; Loveless, 2023). Both nature-based and AR-based education are simply tools (means to an end) that an educator can use. If there are fundamental problems in how a school is run or in students achieving their desired learning outcomes, thinking that these modes of education will be a ‘quick fix’ that will address these more fundamental issues is misguided thinking. This type of perspective in educational technology has led to techno-optimism that has so often manifested in a “rhetoric-reality gap” that ends up leaving teachers and students frustrated (Pimentel et al., 2022). These modes of education should only be used if they can effectively and efficiently meet teacher and student needs. Some key questions that should be considered include (Jordan & Chawla, 2019; Loveless, 2023; Mann, Gray & Truong, 2022):

- what learning outcomes can be delivered and impacted better through these modes of education?
- will my learners be able to effectively use and engage with these modes of education?

If there is an affirmation that these modes of education can uniquely and effectively deliver learning outcomes for a specific group of learners, further practical considerations include (Jordan & Chawla, 2019; Mann et al., 2022; Natural England, 2022b; Loveless, 2023):

- a consideration of the contextual factors that need to be taken into account (frequency and duration of sessions)
- support that must be given to teaching staff and students to be able to effectively engage with these modes of education
- resource (time, money, space/appropriate settings) constraints

If the answers are in the affirmative for all of the above key considerations, the next steps entail exploring how to use these modes of education as well as, in certain cases, how to best design experiences using nature and/or AR to meet specific educational needs.

How to use nature-based and/or AR-based education

One big advantage of both nature-based and AR-based modes of learning is the huge potential they have for customisation across multiple dimensions including: resource constraints (time, money, space/appropriate settings), learner preferences, teacher preferences, and learning outcomes.

For nature-based education, for example, there can be direct (e.g., experiences in a natural setting like play in a forest or meadow), indirect (e.g., experiences in specific structured contexts like an arboretum or farm) or symbolic experiences (e.g. experiences fostered through exposure to nature through reading a book or watching a documentary about nature) (Prochner, 2021). Furthermore, there can be different degrees of formality linked with these types of experiences including formal learning (e.g. children have contact

with nature during structured activities in a school/educational setting), informal learning (e.g. children learn about nature during their free play or activities in settings such as their homes or gardens), and/or non-formal learning (e.g. children learn about nature through camps or trip to cultural heritage sites or nature centres) (Jordan & Chawla, 2019). For AR, there are already many existing assets that can be directly used (see Appendix 1 for some examples) and this list will continue to grow in the future as will the different types of technology platforms that can be used for them. These include learning opportunities through supplementary information to educational books, storytelling, and creative engagement and leverage informal interactive learning within the classroom, museums, historic environment landscapes, play settings and beyond (Dieck & Jung, 2017; Yun et al., 2021). These can be achieved via location-based (e.g., GPS enabled smart phones) AR applications, or vision-based (e.g., physical 'trigger' such as a Quick Response (QR) code) applications. Examples include, supporting students through landscape or geological visualisation in the field such as of volcanic structures (Mathiesen et al., 2012); making invisible ecological systems visible, and linking visualization of hidden processes with macro-scales (Kamarainen et al., 2018); or reconstructions of prehistoric settlements brought to life (Outer Hebrides Tourism, 2023).

Below provides an overview of some of the key considerations that should be taken into account when using nature-based and/or AR-based education in practice:

Practical considerations for using nature-based and/or AR-based education

Nature-based education

- Longer programmes are generally more effective
- Actively engage students in the choice and design of the experiences so that they can be based on their preferences (e.g. pace, exposure, interests)
- Choose/design experiences that are sensitive to the local context
- Use a variety of teaching methods based on student needs/preferences
- Include well designed preparatory work including providing basic scientific and other interesting information about the site and the experience
- Ensure there is sufficient time for direct engagement with nature to increase nature connection
- Support cognitive activation of students by encouraging them to use all of their senses when they are in nature
- Encourage students to be curious and ask questions they want to find answers to, especially tough questions for which there are no obvious solutions
- Choose/design activities that encourage active engagement with other students/teachers
- Include well designed follow-up work that allows students to reflect on and record their experiences, including through creative methods such as writing, drama or art (Fiennes et al., 2015; Grace, Griffiths & Hughes, 2021; Jucker, 2022; Waite & Aronsson, 2022).

AR-based Education

- Best used supplemental mode of education (e.g. AR enhances rather than replaces existing lessons)
- Use AR to deliver experiences that can only be delivered through it
- Use existing resources
- Cater to the technical competencies of the learners
- Use multi-platform tools that adapt for multiple grade levels and skill levels
- Use high quality content
- Use content that is sensitive to local contexts (e.g. culture, preferences)
- Give students ownership including involving them in design choices
- Make it gamified where possible
- Aim for consistent and even lighting and avoid glare and/or low light conditions
- Avoid surfaces that are reflective, glossy or dark
- Use surfaces that have various colours, textures and variations
- Consider the level of motion needed (e.g. slow/fast) for optimal function of a chosen AR app (Apple Inc., 2018; Loveless, 2023; Miller & Dousay, 2015; Pimentel, 2022; Stoltzfus, 2018).

Using AR to support Nature-based Education

- AR should be used to enhance nature-based experiences without replacing them
- AR should augment or stimulate nature-based learning in a way that would not be possible without it, i.e., presenting nature in a new way to learners
- AR should provide learners with other and novel forms of engagement with nature; for example, seeing things at different scales (zooming in or zooming out) that wouldn't be possible otherwise (Jordan & Chawla, 2019; Loveless, 2023).

AR-supported nature-based education in practice

The use of AR to support nature-based education has not been widely deployed yet but there are some interesting examples of effective examples of AR-supported nature-based education. One relatively early example that has been evaluated is Ecosystems Mobile Outdoor Blended Immersive Learning Environment (EcoMOBILE).

Leveraging situated learning theory (see Table 1), EcoMOBILE uses probeware through which students collect water quality measurements whose relevance is then enhanced through an AR app called FreshAiR™ that supports students to explore local pond environments through virtual media and information overlaid onto the pond. Through this approach, information was presented in a contextually relevant environment (local ponds) where AR was used to increase the understanding of how new information (as captured by water probes as well as things that were invisible to the students before) related to the context. Through this careful design approach, the teachers addressed the "why" question to ensure that the experience they were developing and delivering was delivering something that would have been impossible without the AR experience and for which a nature-based experience was the ideal delivery mechanism. The AR app was also

integrated into the experience in a way that increased nature connection rather than replacing the experience of nature. Furthermore, the teachers utilised many best practices for their experience including taking a student-centred design approach; incorporating pre-field trip training; creating active experiences for children to learn and engage; and utilising post-field trip discussions in the classroom to solidify the students' understanding. At the end of the experience, teachers found that the students interacted more with the pond and with classmates and also had a greater understanding of the principles of water quality measurement as compared to prior field trips where these types of technology were not used (Garzón, Pavón, & Baldiris, 2019; Kamarainen et al., 2013; Yu, Denham & Searight, 2022).

Conclusion

The 21st century will pose challenges and opportunities that previous generations have not had to deal with – namely, the unpredictable impacts of climate change as well as a rapidly evolving, and often equally unpredictable, technological landscape. Navigating these changing and uncertain areas will require new ways of learning, new skills, and new ways of interacting with and shaping our environments and societies. As highlighted in this report, nature-based education combined with AR-based modalities of learning can equip students with a deeper understanding of, appreciation of and engagement with the natural environment. There is, of course, the risk that the technology can mask the natural environment but if designed well and through accessible educational modalities like AR, the combination of nature-based learning and AR can provide benefits that would not be achieved with either modality alone.

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Appendix 1 –Augmented reality education applications

One of the best and most comprehensive resources on existing educational apps that can be used in different learning environments is the Educational VR Apps Databased curated by the Stanford Virtual Human Interactions Lab (2020). Below is a non-exhaustive list of some AR applications currently used in educational settings (Apple Inc., 2018; Dick, 2021; Loveless, 2023;) (in alphabetical order):

AR Makr lets students bring their own creativity and drawings into an interactive setting for storytelling. Students can draw or photograph their own scenery, characters and objects, then import and place those story elements into a physical setting using AR.

Augment Education. Students can use this tool to create presentations in augmented reality and create three dimensional designs.

BioDive web-based VR experience built to teach middle school students about marine biodiversity

Cabinet provides an intuitive and flexible interface for uploading and presenting 2D and 3D digitised images from collections in Oxford and elsewhere, which can be made available together with contextual information, notes, annotations and guidance on how to explore the material.

Civilisations AR by the BBC lets you bring historical and cultural artefacts into your classroom or learning space.

Floreo offers VR-based lessons in social and life skills for young people with ASD.58 Through story-based interactive scenarios, users can practice conversations and social cues in a gamified environment.

Free Rivers is an interactive storytelling experience, students learn how wildlife, people and the landscape depend on healthy, flowing rivers.

Froggipedia allows students to see the frog life cycle, study a living frog in AR, and explore organs, systems and vocabulary in the context of a lifelike frog.

Google Arts and Culture platform hosts many of the experiences that were previously part of Expeditions, which is an app that allows teachers to build and lead virtual field trips.

Human Anatomy Atlas brings to life three dimensional representations of the human body that students can interact with.

Measure uses the camera and AR to measure the length or area of objects around you. Measure places points on edges of objects and can recognise certain shapes automatically.

National Aeronautics and Space Administration (NASA) also offers publicly available immersive educational resources instructors can integrate into lesson plans or broader learning experiences in museums or planetariums.

Popar Toys changes the way that students engage with stories and puzzles.

SkyMap helps students learn more about the solar system.

Smithsonian Institution offers a repository of open-access 3D models that allow users to view items from Smithsonian museums' collections in their physical surroundings

Uist Unearthed allows users to explore Uist through time with life-sized AR reconstructions of prehistoric settlements

www.gov.uk/natural-england