Ocean Connections State-of-the-Art Review
National report UK

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1. Introduction

The main objective of this state-of-the-art National report is to document current and emerging educational trends, innovative/excellent practice and research in the field relating to the objectives of the Ocean Connections project, namely to develop creative, digital approaches (AR/VR) to teaching/learning ocean literacy in schools and aquaria in each partner country. In this report, we explain the educational context, curriculum and good practice pedagogical approaches relevant to the Ocean Connections project in the United Kingdom, focusing primarily on the curriculum in England (note that each devolved nation has a different approach to curriculum). We also report on three elements of a focused literature review of the international literature across the domains relevant to the Ocean Connections Project, including background to the concept of Ocean Literacy, a review of Creative Pedagogies in science and geography education, and a review of literature drawing on multiple elements of the three domains of interest. The most relevant findings from this national report will contribute to the synthesis State of the Art Report.

1.1 Research questions

RQ1 How and where is Ocean Literacy taught in Science and Geography in Denmark, United Kingdom and Spain (or just partner countries)?

RQ2 What innovative technologies and applications using AR/VR are used to support learning in Science and Geography?

RQ3 What innovative creative pedagogies are used to support learning in Science and Geography?

RQ4 How are these technologies/pedagogies used to support students' ocean literacy?

i. What positive experiences exist in current practices in schools, aquariums and in cooperation between those?

ii. What barriers exist?

RQ5 What pedagogical principals for teaching ocean literacy can be identified based on RQ1-RQ4?

[Limits: Science and Geography in primary and lower secondary (equivalent to) UK Key Stage 2 (ages 7-11) and Key Stage 3 (ages 11-14).]

2. Methodology

Please refer to the "Handbook for State-of-the-Art review in Ocean Connections" for information about how the UK partners conducted their review of Ocean Literacy within the UK Curriculum and the identification of good practice examples from which we can learn. Plymouth School of Creative Arts and Leigham Primary School responded to RQ1, "How and where is Ocean Literacy taught in Science and Geography in the UK?" in the formal context of the school curriculum, and Living Coasts added additional information exploring the teaching of Ocean Literacy in informal learning contexts. All three of these partners used web searches, site visits and interviews to identify positive experiences in current practices, and barriers, in both schools and informal learning environments. In addition to the methods outlined in the handbook, Living Coasts undertook interviews with a convenience sample of teachers visiting their site. All notes on interviews and site visits are available on request. Please refer to table 1 for a summary of data sources.

Table 1 Data Sources

Data Type	Examples
Teacher Interviews	Carla Jenkinson; Alan Parkinson; n=6 on site anonymised interviews at Living Coast aquarium
Non-teacher interviews	Stuart Higgs, National Marine Aquarium; Lewis Brown; National Marine Aquarium Outreach for Wales; De Morra, Plymouth Marine Laboratory; Juliette Jackson, Seadream;
Site Visits	National Marine Aquarium, Plymouth.
Desk Research	Examples from Galway Altantaquarium; Bournemouth Oceanarium, SeaLife Centres; Longleat Safari Park; Paignton Zoo; Newquay Zoo.

The University of Exeter undertook responsibility for an international literature review with respect to ocean literacy, creative pedagogies in science and geography education (RQ3) and the use of digital technologies and creative pedagogies together, to support the teaching of ocean literacy (RQ4). Table 2 shows the search terms used for each of the searches conducted for the UK national report. These terms were used in the following databases: BEI, ERC, ERIC, JSTOR, Web of Science and IBSS. Two geography experts were also consulted because of a dearth of articles emerging in geography education. The reference lists of a number of highly relevant papers in the field were also searched (K. Chappell et al., 2019; Kerry Chappell, Hetherington, Ruck Keene, Slade, & Cukurova, 2015; Cremin & Chappell, Under Review). Papers were identified for inclusion the grading process outlined below. Table 2 shows the number identified for grading in initial screening for each section of the report, and the number of studies included in the final review. Following screening, papers were graded according to the strength of their methods on a scale of Low, Medium and High. Where papers were theoretical or review papers, this grading was left blank. Relevance of the paper for Ocean Connections was also graded as Low, Medium or High. Papers were included in the final review where the grades were in the following combinations: N/A,M; N/A,H; M,M; M,H H,M; H,H.

Table 2 Focused Review Searches

Report section	Search terms	# for inclusion in grading process	# included in final review
Ocean Literacy (Background)	tbc	tbc	67
Creative Pedagogies in Science and Geography Education (RQ3)	creative pedagogy and science education; creativity pedagogy and geography education; innovative pedagogy and science education; innovative pedagogy and geography education; creative learning and science education; creative learning and geography education; creative teaching and science education; creative teaching and geography education; innovative teaching and science education; innovative teaching and geography education	42	17
Digital Technologies and Creative Pedagogies to support Ocean Literacy (RQ4)	Creativity and ocean literacy; creativity and marine literacy; creativity and ocean learning; creativity and marine learning; creativity and augmented reality and education; creativity and virtual reality and education; digital technology and ocean literacy and education; digital technology and ocean learning and education; augmented reality and marine learning and education; augmented reality and ocean literacy and education; virtual reality and ocean literacy and education; augmented reality and ocean learning and education; virtual reality and ocean learning and education; digital technology and environmental education; augmented reality and environmental education; virtual reality and environmental education; creativity and digital technology and environmental education; creativity and digital	24	14

	technology and ocean literacy.		
Relating Digital Technology and Creative Pedagogies (additional search)	Creativity and digital pedagogy; creativity and digital storytelling (in a number of fields)	53	51

3. National Practices

3.1 Curriculum

Educational context

The educational context for the United Kingdom is complex due to the differing national curricula for each of the four home nations. However, there is a common element in that the phrase 'Ocean Literacy' is not mentioned at any point anywhere in each document. This is particularly surprising in the case of the newer curricula: the National Curriculum for England (Department for Education, 2014) and the Draft Curriculum for Wales 2022 (Llywodraeth Cymru; Welsh Government, 2019) as the phrase 'Ocean Literacy' is now more commonly heard and one would expect the subject to be an essential element of any child's learning in order to support the long-term preservation of our planet.

The term 'Ocean Literacy' was first used in a project by the Marine Biology Association (led by Fiona Crouch) less than ten years ago. Seven Principles of Ocean Literacy have since been defined (http://oceanliteracy.wp2.coexploration.org/ocean-literacy-framework/):

1. The Earth has one big ocean with many features
2. The ocean and life in the ocean shape the features of the Earth
3. The ocean is a major influence on weather and climate
4. The ocean made the Earth habitable
5. The ocean supports a great diversity of life and ecosystems
6. The ocean and humans are inextricably interconnected
7. The ocean is largely unexplored.

Awareness of the importance of looking after the world's oceans has increased astronomically following the BBC's 'Blue Planet[1]' documentary which first appeared on television screens around the world in 2001, with the pace intensified considerably by 'Blue Planet 2[2]' in 2017 which showed hard-hitting images and narration of the impact of plastics, in particular, upon the health of our oceans and the implications for the wider health of the planet. Since the schools and aquarium involved in Ocean Connections in the UK are located in England, we focus on the English context in the remainder of this section.

Resume of curriculum mapping for Key Stage Two (7-11 years) in England

In the Science Purpose of Study section of the National Curriculum for England (2014), Science is acknowledged as being 'vital to the world's future prosperity' yet there is no mention of the need to protect planet Earth's oceans. The closest it comes to addressing this essential issue is within the Year 4 Programme of Study which states that children should 'recognise that environments can change and that this can sometimes pose dangers to living things'. The non-statutory guidance builds upon this by suggesting '*pupils should explore examples of human impact (both positive and negative) on environments*'. The subsequent list of examples, however, makes no mention whatsoever of oceans or seas.

[1] https://www.bbc.co.uk/programmes/b008044n
[2] https://www.bbc.co.uk/programmes/p04tjbtx

Resume of curriculum mapping for Key Stages Three and Four (11-16 years) in England

Science is considered a 'core' subject in the key stage 3 national curriculum (https://www.gov.uk/national-curriculum/key-stage-3-and-4). The core referring to science as a compulsory subject for all students up until key stage 4, generally in the form of a GCSE or a level 2-equivalent qualification. There are two main ways the government and department for Education in England measure the 'success' of schools; progress 8 and English Baccalaureate (EBacc). Science provides vital points towards a school's Progress 8 and EBacc scores and therefore is another reason science is compulsory for all students in some form at key stage 3 and 4.
Geography is a 'Foundation' Subject and is included in the EBacc and is usually compulsory for all students in some form at Key Stage 3 and optional at Key Stage 4.

<u>Key stage 3 (11-14 years)</u>

The following quotes have been taken from the key stage 3 (KS3) national curriculum for science that are relevant to ocean literacy.

- 'the dependence of almost all life on Earth on the ability of photosynthetic organisms, such as plants and algae'
- 'the interdependence of organisms in an ecosystem'
- 'changes in the environment may leave individuals within a species, and some entire species, less well adapted to compete successfully and reproduce, which in turn may lead to extinction' 'the importance of maintaining biodiversity'

Although the English curriculum does not specifically allude to any of the ocean principles there are close links between the some of the learning outcomes and the 7 principles of ocean literacy including:

□ The Ocean supports a great diversity of life and ecosystems
□ The Ocean and humans are inextricably connected
□ The Earth has one big Ocean with many features

The national curriculum focuses more on the organisms within an ecosystem and how important they are to maintaining biodiversity. Although there are no specific mentions of the oceans, ecosystems does encompass the oceans. Many of the KS3 textbooks mention oceans and the food chain and food webs within it.

The curriculum goes on to state 'the importance of maintaining biodiversity' this directly relates to two of the key ocean literacy principles of 'The Ocean supports a great diversity of life and ecosystems' and 'the interdependence of organisms in an ecosystem' highlighting the importance that students understand the relevance of the ocean and ocean literacy.

The national curriculum states 'changes in the environment may leave individuals within a species, and some entire species, less well adapted to compete successfully and reproduce, which in turn may lead to extinction' this may link to how humans are impacting the environment and how this affects the oceans and its inhabitants relating to the ocean literacy principle ' The Ocean and humans are inextricably connected'.

The national curriculum has to be followed by maintained schools in England but most of the 3,408 secondary schools are multi-academy trusts (MATs). MATs do not have to necessarily follow the national curriculum but most do, since the GCSE exams at age 16 are devised from the national curriculum. Teachers working in Academy schools do however have more freedom to teach the curriculum in a manner that they find conducive to the learning of their students. If teachers deem it appropriate and are confident that they will be able to evidence students' progress then they could teach the 7 principles of ocean literacy with little problem.

Key Stage 4 (14-16 years)

We mapped the mention of Ocean Literacy in three commonly used textbooks that support the English national curriculum at GCSE level (aged 14-16), CGP AQA GCSE Biology (CGP 2016), CGP AQA GCSE Combined science (1-9) (CGP, 2016) and Combined science trilogy (Dixon, et al, 2016).

Although there are no mentions of Ocean literacy in these textbooks there are certain aspects of the 7 key principles that are present. There are mentions of humans' impact on the environment namely global warming and the oceans. There are comments made discussing the 'loss of habitats' which relates to 'the importance of maintaining biodiversity'.

Combined science discusses how human impact can pollute certain rivers, streams and eventually the seas. This links to oceans literacy principles 6 and 7 whereby the ocean and humans are inextricably linked and their effect (positive and negative) can be influenced by us as humans. There are specific examples that are given such as the Deepwater Horizon oil spill in the Gulf of Mexico. As there is a named area of the GCSE specification 'humans impact on the environment' this inherently leads to discussions and questions in books and exams about the effect of the ocean on humans and vice versa. DIscussing these with students may help to improve ocean literacy alongside gaining a GCSE qualification in science.

Questions are present in GCSE examinations at the end of Key Stage 4 (age 16) that relate to Ocean literacy including food chains, food webs and ocean pollution but no question has appeared to date directly referencing ocean literacy.

3.2 Pedagogical Approaches in schools

Ocean literacy as a term in and of itself was not well known amongst teachers interviewed for this report, with, for example, only one of the 4 teachers interviewed during a school visit to the Living Coasts aquarium having (limited) prior knowledge of what it relates to. Once a basic description was provided to the teachers, all were able to provide firm examples of how they embed this in their learning, with most able to point to specific examples in science (habitats, animals and adaptation themes) and others in geography (location, ocean currents and climate), or both. As all of the schools were situated within a short distance of the coast, many of the experiences in developing the children's understanding of the ocean relate to native habitats, including the rocky shore, with visits to the beach a fairly common practice in order to observe the features of the coast first-hand.

Specific examples of the development of ocean literacy within the classroom include practical investigations which are part of many of the schemes of work being followed by the school (e.g. 'Snap Science'), which involve small experiments and demonstrations to do with the properties of water. Whilst these are just a few examples of the trends that suggest schools are attempting to improve the ocean literacy of their children, there are several trends in relation to the barriers perceived by teachers. Specifically, the rigours of testing, and the preparation and focus required in order to ensure that the children are ready for this testing, is a hindrance and means that, more often than not, the development of ocean literacy is by happy accident rather than design.

RQ2: What innovative technologies and applications using AR/VR are used to support learning in Science?

From the interviews undertaken, the use of AR/VR technologies mainly linked to ocean literacy. The other examples of using creative pedagogies within science did not require these technologies. Good examples of the use of digital technologies that did not use AR/VR were found.

Citizen Science – ARGO floats and Deep Sea Cameras (age 7-18)

Professor Stephen De Morra, CEO of Plymouth Marine Laboratory, noted the potential of several online resources for primary or secondary students. Though primarily an academic and university professor, Stephen was aware of several projects that GCSE students had undertaken using information from ARGO floats and deep sea cameras. ARGO floats are used to observe temperature, salinity, currents and bio-optical properties of the Earth's oceans. There are an estimated four thousand floats deployed worldwide. There is potential to use the data published from these floats as learning opportunities. Stephen told of a competition run in a GCSE class where each student picked a float to follow for an entire term. Throughout the term, the students closely tracked the movement and temperature of their chosen float. 'Prizes' were awarded for the furthest distance travelled and for the most extreme temperatures. In addition to this, Stephen mentioned that the same class had systematically observed images from deep sea cameras broadcast on numerous websites. Though the potential to spot an unidentified creature is slim, this citizen science project depends on crowdsourcing observations to observe new marine life. This has the potential to really 'hook' learners.

Creating an Immersive Crab Pot experience (age 11-12)

Developed by Plymouth School of Creative Arts (PSCA) in response to 'GoPro in a crabpot' YouTube videos, this project aims to develop their understanding of the near shore marine habitat and marine biodiversity through a creative, immersive VR experience. PSCA is situated within 50m of the shoreline on the South Devon coast in the south west of the UK. Most students come from the immediate catchment area and this is ranked in the bottom 1% of deprivation nationally with 25% of students presenting with SEN. There is limited interaction with the marine environment, but the school has 'Learning in the Environment' (LITE) consent meaning that students can easily be taken out of school to identify sites for the experiment. This cross-curricular science pilot project is currently underway with Y7 students who are building an immersive underwater video/VR experience. An array of digital cameras has been set up within a crabpot to film marine fauna in the local area. The test footage will be stitched together to be used on VR headsets and in the i-DAT Immersive Vision Theatre. I-DAT has a 360 camera that can be used for the final project. The project places students as the producers of an immersive VR experience. The learning intention is to develop a wider understanding of the marine habitat and marine biodiversity at a range of sites in the immediate vicinity of the school. Students carry out site visits and judge them on a range of criteria, before selecting the optimum site. They build a prototype waterproof camera array within a crabpot and submerge it at the chosen site. When the pot is retrieved, the students 'stitch' the footage together to enable it to be used with VR headsets and in the Immersive Vision Theatre at University of Plymouth. In terms of creative pedagogies, the activity focuses on Risk, Immersion and play, Ethics and trusteeship. Students understand the impact that humans have on the marine environment and select sites that have both significant human impact and as little impact as possible for comparison. Students use video editing so create a playful immersive experience. The project provides opportunities for crossover between science, digital skills and design/technology. This combines labwork, in which students develop a base level of knowledge and understanding of local marine habitats; protoyping, in which students apply an iterative model for rapid prototyping; field work – assessing the sites and placing/retrieving the crabpot and camera array; studio work – using video editing tools to stitch together the footage. Waterproof HD cameras with video editing features, and VR headsets or Immersive Vision Theatre is needed to view the end result.

RQ3: What innovative creative pedagogies are used to support learning in Science?

All teachers interviewed were able to point towards specific examples of creative pedagogy being used in teaching science, with all but one of the teachers confident in employing these techniques. One example prevalent in all interviews was the affordances made for children to lead their own learning experience (free-choice learning – Empowerment and Agency), through either the development of a project or cross-curricular approach between topics, such as English/maths and science. The range of barriers for this particular theme were more varied than with respect to the use of digital technologies to support teaching, with teachers highlighting a combination of time restrictions, curriculum requirements needing to be met and resource limitations.

From the interviews, it is clear to see that in the opinion of a convenience sample of expert educators in the UK, creative teaching in Science does not require digital technology to be engaging, though this is not to say that it cannot support both engagement and learning. For example, Carla Jenkinson stated that teaching in primary science should be taught entirely through enquiry. This means that no two experiments will look the same, as children should be leading the experiment and forming their own conclusions, with teachers acting as the facilitators for children to feedback their findings.

The examples of creative or innovative pedagogies used to support learning in Science in UK schools referred to in this section focus on learning about the ocean and are drawn from web searches, interviews and site visits. For each example in this section, and in section 3.3, we highlight where each draws implicitly on the 'features of creative pedagogy' (Dialogue; Transdisciplinarity; Risk, Immersion and Play; Balance and Navigation; Possibilities; Ethics and Trusteeship; Empowerment and Agency; Individual, Collaborative and Communal activities for change) and the definition of creative pedagogies in science education developed through the CREATIONS project (see section 5.2 of this report for details).

The Tsunami Project (Age 13-14)

Alan Parkinson, with Year 9 pupils, set a challenging task for his pupils to reinvent an entire city following a natural disaster. The unit of work is nicknamed 'The Tsunami Project'. In this hypothetical scenario, a modern city is destroyed by a cataclysmic wave. After this major event, the pupils must design their own (Empowerment and Agency) new city from scratch (potential for Transdisciplinarity). The project requires them to think carefully about infrastructure, housing, waste disposal and energy (Balance and Navigation). To find solutions, the pupils must engage in plenty of collaborative research to find greener options (ICC). A particular focus of the project is that of sustainable energy (Ethics and Trusteeship).

Timed Litter Pick (Age 7-11)

Dr Juliette Jackson mentioned two school projects she had run which resulted in strong learning outcomes for key stage two children. The first being a timed litter pick of two sites (Ethics and Trusteeship), a marina and a local tourist beach. The pupils compared samples and speculated reasons for the similarities and differences (Dialogue/Possibilities).

Microplastics (Age 7-11)

The second project investigated the occurrence of marine plastics. A bag of sand and a bag of seaweed were collected from a local beach. Children mixed their own salt water solution and mixed it with the two bags. Micro-plastics rise to the surface enabling the children to sieve and collect them. This provided a powerful visual representation of how much plastic is in the ocean. This particular experiment has the potential for many cross-curricular links (potential for Transdisciplinarity but not realised yet).

You Are What You Eat (Age 7-11)

The 'You Are What You Eat Project' was a unit of work delivered by Alan Parkinson to raise awareness of the impact of commercial fishing on many eco-systems. Students were introduced to various methods used to catch their 'fish and chips'. Among other activities, children made their own models of trawlers with string to demonstrate the damage to the sea bed (Inter-disciplinarity rather than trans). The purpose of the project was to illustrate how human activity affects the environment as well as explore ideas like seasonality, animal welfare and food miles (possibilities).

RQ4: How are these technologies/pedagogies used to support students' ocean literacy?

In stark contrast to the wealth of examples of improving ocean literacy, teachers interviewed suggested that the use of AR/VR in teaching science was limited. Of the ten interviewees, only three had experience in using AR/VR, and two of these worked in informal learning contexts (aquaria) rather than in schools. Examples of current practices are listed below.

Of the six interviewees, three had had experience of using virtual reality headsets to engage learners about ocean literacy. Lewis Brown (National Marine Aquarium Outreach for Wales, NMAOW) and Stu Higgs (National Marine Aquarium) use VR to engage children in the teaching of marine principles. Lewis Brown explained that the software NMAOW uses focuses on the issue of plastics in the ocean. The animation used for the headsets is a particular favourite as it includes a CGI sperm whale battling with a giant squid. The condition of coral reefs was raised by several of the interviewees. 'Coral Calamity' is a session provided by the NMAOW which uses VR headsets to enable children to 'dive' in the Red Sea. Pupils find this both engaging and motivating as it helps transform the issue into a more tangible problem. Alan Parkinson, a secondary school geography teacher, expressed how effective VR systems are in providing experiences to students by eliminating geographical or economical barriers. Alongside others, Alan helped to create numerous AR geographical fieldtrips with the Google Expeditions Project. The aim of the project was to deliver high quality fieldtrip experiences to mainstream classrooms. One example focused on the event of coral bleaching in the Great Barrier Reef. All agreed that these technologies would be useful in raising consciousness of ocean literacy, however, not all personally utilised them.

i. What positive experiences exist in current practices in schools?

One example of the successful use of AR used motion sensors to track the flight path of a ball. The replay of the flight helped to teach key stage two children about air resistance. Additionally, virtual t-shirts, which enable AR, are a powerful way of enabling children to see internal organs when learning about the digestive system. Practitioners express that AR/VR, although useful as an aid to immerse children into science, have limitations when delivering to a standard-sized class (30 children).

ii. What barriers exist?

Teacher interviews suggest that the use of AR/VR technology in schools is limited, including with respect to Ocean Literacy. This is mainly due to the lack of equipment in the first instance, although alongside this is a fundamental lack of training available for teachers to build their confidence in using these new technologies. Other barriers include the lack of funding towards technology of any kind in primary schools, with the general consensus one of acceptance that this equipment is much more limited in primary schools (due to budget constraints) than secondary teaching.

In order to incorporate AR/VR systems into practice, schools will need to raise finances for the initial cost of purchasing these sophisticated technologies. With mounting pressure on mainstream schools' budgets, many are unable to afford the required tablets or headsets. Alan Parkinson, who currently works in a public school, explained that fee-paying schools are privileged with the ability to ensure access to devices for most if not all children. In addition, to ensure that lessons remain purposeful, a minimum number of devices need to be available as the technology does not lend itself to large scale group work. With particular reference to AR, access to Wi-Fi is also necessary. Therefore, a reliable network is essential to ensure lessons are not stilted by buffering. Another point to consider is the responsibility of schools to safeguard young children and their personal information. Whether or not this has an impact on what devices schools can use depends on the brand of software. Additionally, high security settings could adversely impact the potential success of the technology.

The pace of technological change is another barrier. How quickly would the technology become outdated or outmoded? As a result, would it constitute good value for money in the first place? It should also be noted that the AR/VR technology may not have the same 'wow factor' for the pupils/students as it may have for the current generation of teachers, such is the pace of technological advancement and the fact that many young people can access similar technology in their bedrooms.

Carla Jenkinson referred to advice which suggests that children under the age of thirteen should not use VR headsets due to potential health and safety risks. However, Stu Higgs from his experiences is comfortable with using the technology with children from the start of KS2 as they mostly cope with the concept of virtual reality. He believes children below the age of six are ill-equipped to manage the departure from reality and can in fact find the experience quite disturbing. He continued by suggesting that, although AR/VR can be captivating for some, it is not for all. Higgs emphasised that AR/VR are tools that might capture the attention of some of those not already captured by other means and activities. They work best when used amongst a variety of tools and methods. They should not form the basis of an entire unit of work but rather be one of many sources of information.

From the people who were interviewed who had prior experience of using AR/VR, all agreed that they would be confident in delivering a lesson that incorporated these technologies. However, the lack of experience for most teachers was acknowledged as a possible concern. Consequently, it would be crucial to ensure that training was provided to guarantee that the systems were used effectively and regularly. Likewise, it would be prudent to mention that delivering an immersive lesson would mean that teachers would need to deviate from the ordinary, stepping away from PowerPoint presentations. This could pose a challenge from various perspectives such as the expectations upon teachers from schools may differ immensely.

Mainstream schools have a packed curriculum so delivering all of the content under time constraints is challenging. Since the reinvention of GSCEs several years ago, children in a third of secondary schools begin learning towards the KS4 curriculum in Year 9, squeezing the KS3 curriculum yet further. Key Stage Two is similar in that there is a requirement to teach more subjects in less time and there is increased scrutiny on published test results, meaning a topic-based approach is the only way to cover all subjects and objectives. This is where Ocean Literacy would fit best.

RQ5: What pedagogical principles for teaching ocean literacy can be identified based on RQ1-RQ4?

It is evident from the responses of all the interviewees, that hands-on experience is critical for children to truly understand the nature of ocean literacy. The topic lends itself well to the use of many different sources thus ensuring that learning will be varied and engaging. Teaching ocean literacy provides opportunities for practitioners to be creative and approach the curriculum from a broad, topical perspective.

3.2 Pedagogical Approaches in out-of-school contexts

By contrast with the pedagogical approaches in school contexts revealed through our interviews with teachers, there seems to be relatively more practice in all 3 areas (ocean literacy, technology and creative pedagogy) within informal learning environments, with aquariums and museums free from many of the restrictions mentioned above that are faced by the teachers within schools. We summarise here a range of practices described by interviewees, observed on site visits or identified through desk research online.

RQ1: How and where is Ocean Literacy taught in Science and Geography in out-of-school contexts?

Galway Atlantaquaria

Extensive integration of ocean literacy into their educational offer, delivered as part of the Marine Institute Explorers education programme
https://www.marine.ie/Home/site-area/areas-activity/education-outreach/explorers-education-programme
Wide range of resources for teachers and although they believe there is significant opportunity to introduce aspects of digital technology to many of these topics (i.e. to explain tides or explore the seabed) the sessions currently are delivered via a mixture of PowerPoint presentations and hands on discovery, either at the aquarium itself or on the seashore.
Galway also work with the SFI Discover Primary Science and Maths to cover STEM topics with an ocean literacy focus. Again, oceans provide a context for investigating STEM topics but do not currently utilise digital technology. The potential for using digital technology to explain STEM topics is significant, although the scope of the subject matter is currently wider here than many other aquariums.

Bournemouth Oceanarium

The topic is broadly considered in guided tours, although the lack of a classroom facility precludes activities that cannot be undertaken in a public viewing area. Topics relating to Ocean Literacy are covered in some interpretive installations – primarily printed signage. The 'Global Meltdown' exhibit features interactive touch screens to explain the consequences of sea level change to general visitors, although there has been no formal evaluation of their usage and impact.

RQ2: What innovative technologies and applications using AR/VR are used to support learning in Science and Geography?

As part of our State of the Art Review, it became quickly apparent that within the UK at least, there were very few examples of how digital and creative technologies are being used to enhance learning in aquariums. This dearth of examples led to a widening of the search to include zoos and museums, as well as looking at the use of said technologies for non-educational purposes in these settings (for example marketing and wider visiting experience). We also investigated a number of non-UK examples of the creative use of technology, and, on the specific subject of Ocean Literacy, took a look at how the topic was addressed by aquariums in the absence of digital technology. Similarly, there was limited use of AR and VR technology, so the examples given draw on a broader range of digital technologies in order to offer an illustration of the current situation in the UK.

Living Coasts: Draw Alive

Interactive visitor display. Visitors can colour in their own fish and then scan the picture into a reader. The fish then appears on a large screen and swims around on the wall. Installed as a means of extending visitor dwell time although has potential as a learning tool, in terms of helping pupils to understand topics like camouflage in marine species. Location wise, this would not be feasible however as it would cause a visitor bottleneck. Feedback from visitors suggests that the wall is very popular as a fun side activity.

Living Coasts: Interactive digital sand pits

Interactive sand pits. Projectors display tropical sea and island image onto the sand pit beneath. Moving the sand changes the topography of the image and the marine species that inhabit the different areas. Limitations due to location and impediment of visitor flow. Has potential to be used as a means of visualizing marine topography although this would be a very expensive way of doing this, and I would suspect, one that would not be warranted.

Longleat Safari Park: VR Experience

A marketing venture rather than educational. Visitors could experience (through VR) a range of arctic species in a special experience room. Uptake was generally low. The species in the experience were not found at the park and it is likely that the lack of relevance to the rest of the day out was in part responsible for the lack of uptake.

Paignton Zoo: Pokemon Trail

Delivered in 2017 as a marketing event to capitalise on the (then) current trend of Pokemon Go. One off event that allowed gamers into the zoo after hours to catch the pokemon characters. Extremely successful in terms of uptake and demographic capture. Some areas of the site proved patchy in terms of signal coverage. Highlighted the use of hand held devices as a means of embellishing a self-guided trail, although with potential limitations regarding signal. Although there was no clear educational intention it did allow the zoo to engage with an audience sector (primarily teens and young adults) who are traditionally difficult to attract. This in itself is an interesting outcome as it suggests that the use of tech (particularly the persons own) can be a viable engagement tool if used with an appropriate stimulus.

Sealife London: Polar Adventure

Opened in April 2019, this public exhibit features AR and other sensory experiences (frozen wall, wind chambers) to simulate polar conditions and explain how certain key species are adapted to survive. No obvious mention of Ocean Literacy.

Newquay Zoo: QR codes

Several trials have taken place using QR codes on educational signage to provide additional information to visitors. Results consistently indicate that uptake and impact are low (see e.g. Ojalammi & Nygren, 2018). Methods of promoting learning in visitors are an ongoing discussion point amongst zoo educators. It is clear that simply providing information (either directly, or as here, via other means) is ineffective. If digital tech is used, it needs to develop beyond simple provision of factual information.
There is potential value in QR codes as part of a structured learning task for formal education however, a view supported by museum sector research (Mogali et al., 2018).

RQ4: How are these technologies/pedagogies used to support students' ocean literacy?

i. What positive experiences exist in current practices in schools, aquariums and in cooperation between those?

The recreational nature of an aquarium visit means that educators must provide 'hooks' to engage visitors with the exhibits and the topics they wish to discuss. The inherent excitement of a school trip makes this particularly challenging in what is already a sensorally rich environment. Digital technologies and creative approaches have the potential to provide a hook to visitors, many of whom are tech-savvy and arrive with expectations regarding information accessibility and immediacy of answers.

The real USP of aquariums however is that they have 'the thing itself' – the live animals that visitors are unable to experience elsewhere and the hope amongst educators is that these animals should be the hook that draws people in. Digital Technology can be seen as a distractive gimmick, and moreover, one that many people now have access to at home (although this can of course be seen as advantageous as familiarity can facilitate easy usage). Aquariums and zoos are places where socially mediated learning can occur. There is a feeling that some forms of technology, specifically VR, can be socially isolating, and therefore counterproductive to the purpose of the visit. The NMA utilise a 3 minute centrally controlled VR experience to introduce a topic in a classroom however this is only possible due to the number of headsets they can provide (30). It is also felt that there is no definable link between use and impact. VR in particular was seen as being something that may receive high levels of use, but there is currently no way of determining whether that use translated to any kind of measurable impact in terms of learning. There is a general feeling that contextualized, location based AR provides the greatest potential for a digital and creative technological approach – a feeling shared by Apple CEO Tim Cook and Disney CEO Bob Eiger amongst others.

Aquarium staff are of the opinion that digital technologies and creative methods can create incredible opportunities to develop skills (for example coding) that will prepare young people well for an ever changing future economy. It can be used to bring alive hidden landscapes (for example using software and sonar to visualize sea bed environments, or to explore the Titanic or sea grass beds) and to reveal species that may be shy or nocturnal. It can develop communication, creativity, collaboration, and critical thinking, and could use the aquarium to contextualize and test ideas and topics covered in class (both pre and post visit).

ii. What barriers exist?

Replacing rather than augmenting the experience

From speaking to teachers, there is some reservation about how AR would be accessed at an aquarium location. Aquariums are places for physical exertion and fun as well as learning, and as children are likely to be distracted by their environment, having their hands free is very useful. Requiring children to bring their own device isn't feasible, which puts the onus on the school or aquarium to provide. The risk of damage is an issue here if a large class are moving around a constrained space with expensive equipment.

Having single access points can also be problematic due to queues and bottlenecks. Aquarium staff are keen to avoid people experiencing the visit *through* a device – a potential pitfall of an AR overlay. Devices could be controlled by teachers or supervising staff who could use AR to provide contextually relevant reminders to children engaged in the activity. The excitement of the visit can easily cause children to forget what they were told earlier so can be used to keep participants on track and on topic. These can be accessed through a device but should be a reminder to look at an exhibit rather than a 'thing' to be viewed through a screen. Aquarium staff suggest that interventions that direct an engagement before experiencing the living animals, or supplement the viewing, or contextual material to create a connection. The digital technology should augment an experience, not replace an experience with augmentation.

There is an overwhelming opinion amongst zoo and aquarium educators that the use of digital technology needs to be very carefully considered before using in such a setting. The USP of these sites is that they have live animals, which cannot be feasibly experienced in any other setting. Although many zoos recognise the potential value of using technology as a 'hook' or embellishment to sessions, there is a reluctance to adopt

new approaches which may be replicated off site. School funding is precarious and trips to zoos and aquariums can be difficult to organise. They need to be able to show that the trip offers something unique – if it (or elements of it) can be delivered in the classroom there is a risk of visit numbers dropping off. Given the financial situation that many places find themselves in, there is a reluctance to commit to a significant expense for something that has an unproven ability to add to the sites unique impact.
Many schools align a zoo trip to the idea of Learning outside the Classroom, and many collections promote the value of a trip as being something that gets children ‘into nature’ or ‘connecting with nature’. Rightly or wrongly, the use of digitech in a zoo or aquarium setting is frequently considered anathema to that ethos. We return to this point in the literature review (section 5).

Cost

Other than a concern about the possibility that digital technology might in itself be a barrier to the unique experience offered by zoos and acquaria, the single biggest practical barrier was financial. In the UK at least, zoo and aquarium education budgets do not generally stretch sufficiently to cover the initial outlay for kit. Because Digital & Creative Technologies are viewed as an embellishment rather than a necessity it is difficult to secure funds unless the equipment can be used more commercially elsewhere. The UK school funding landscape is such that many aquariums and zoos are experiencing a drop in school visitor numbers, which means it is difficult for places to look at introducing new experiences that will likely increase the trip price for schools.

Where digital technology has been used effectively in terms of discussing ocean literacy topics (ie at the National Marine Aquarium) it has required a significant financial outlay (30 headsets + associated equipment) which would realistically be out of reach for most aquariums, and which has not been without problems.

There is a concern amongst aquarium educators that equipment would rapidly become dated, due to the speed with which technology has developed. Many zoos and aquariums have used digital signage in the past and after only a couple of years, found themselves hindered with technology that pales in comparison to that which is now found on even the most basic pocket devices. This can have a negative impact on how they are perceived by visitors, particularly if, as often happens, the equipment breaks or cannot easily be updated.

4. National literature review/perspectives

This section is brief as we have largely drawn on direct interviews, site visits and literature reviews for this national report.

4.2 Blogs

In exploring the grey literature in relation to creative, digital technologies in museum and aquarium contexts, some interesting and relevant examples from beyond the UK, Denmark and Spain were found and are included here.

<u>AR and VR</u>

6 Attraction Technology Trends for 2019, 14th Jan 19, Michael Mander
https://blooloop.com/features/attraction-technology-trends-2019/
AR has greater potential than VR. Issue with VR being accessible at home so you need to do something really innovative to impress. Location based has more scope, for VR and AR.
Integrating media in art at the museum of fine arts, Boston, 5th Dec 2018, Lalla Merlin
https://blooloop.com/features/mfa-museum-of-fine-arts-boston/

“This move towards media is a bit of a social outcome, because everybody has a screen in their pocket; and that’s how people communicate.” Aim to augment an experience (for example using soundscapes). Don’t replace the experience with augmentation.
American Museum of Natural History – microrangers – using AR and gamification to engage kids. Solve environmental problems by thinking like a scientist. Each child gets a coin which acts as a target they can take home to re-access key content. The interaction enhances a visit – exhibits are a necessary element of the game and requires the kids to interact with the exhibit itself.

Gamification
Museum of London
https://www.museumoflondon.org.uk/news-room/press-releases/museum-london-releases-third-and-final-great-fire-1666-minecraft-map
Use Minecraft to engage users in the Great Fire of London

Digital technologies to develop datasets for analysis
A useful potential benefit of some digital technology that can be used for wider curriculum topics in both formal and informal settings is in the collection and collation of large datasets that can be analysed and explored by students See e.g. https://oceanconservancy.org/trash-free-seas/international-coastal-cleanup/cleanswell/)

QR codes
Several collections have trialled QR codes for visitor engagement although formal evaluation for many is lacking. The findings from Newquay are believed to be typical, and there is a general consensus in the museum sector that they offer little of value in terms of meaningful impact (for summary, see here https://cuseum.com/blog/life-death-of-qr-codes-in-museums)

5. International literature review

In this section of the report, we begin with an overview of international literature in the field of education for ocean literacy, as background to the field in which the Ocean Connections project is situated. We then focus in on RQ3, ”What innovative, creative pedagogies are used to support learning in Science and Geography?” and RQ4, ”How are these technologies/pedagogies used to support students’ ocean literacy?”. Please refer to section 2, Methodology, for details about how the literature review was conducted. The review conducted by the University of Exeter is in three parts: Ocean Literacy in Education, Creative Pedagogies, and Creative Pedagogies, Digital Technologies and Ocean Literacy together. These will be combined with the international reviews in the National Reports from Denmark (REF) and Spain (REF) to produce a summary of key learning, informing the pedagogical framework to be used in the Ocean Connections project. The conclusion offered at the end of this section is a short summary of key learning from the UK National Report only.

5.1 Ocean Literacy in Education

While the concept of environmental literacy can be traced back to 1968 (Roth, 1992), ocean literacy seems to have emerged as a term at the start of the 21st century (Cava, 2002). The term ‘ocean literacy’ seems to have replaced ‘marine education literacy’ which was in use in the late 1970s and beyond (Spector, 1979, 1980)

Participants at a virtual ocean literacy conference directed by Francesca Cava in January 2002 agreed that to be ‘ocean literate’ pre-college graduates should:

- Be aware of issues concerning the usage and sustainability of the oceans as a finite resource;
- Be cognizant of both global and local environmental issues and the interconnectedness of all species;
- Be knowledgeable of technological impacts on oceans.
- Be able to diagram ocean problems, policies, and issues.
- Be aware of the importance that oceans serve in our daily lives.
- Be knowledgeable of the enormity and complexity of oceans.

The report of the conference concluded:

> *Increasing accessibility to ocean content for teacher's use in the classroom has multiple goals and potential benefits. It will help teach complex topics in a way that captures students' imagination and enhance learning. It can integrate topics such as science, geography, history, and others. It can provide a portal for introduction of cutting edge science and technology into the classroom.*

Attempts to refine the definition a few years later resulted in this definition:

> *Ocean literacy is an understanding of the ocean's influence on you and your influence on the ocean. An ocean-literate person understands the fundamental concepts about the functioning of the ocean, can communicate about the ocean in a meaningful way, and is able to make informed and responsible decisions regarding the ocean and its resources.*
> (Cava, Schoedinger, Strang, & Tuddenham, 2005, p.9)

The same process identified seven 'essential principles' (COSEE, 2005):

> *1. The Earth has one big ocean with many features.*
> *2. The ocean and life in the ocean shape the features of the Earth. 3. The ocean is a major influence on weather and climate.*
> *4. The ocean makes the Earth habitable.*
> *5. The ocean supports a great diversity of life and ecosystems. 6. The ocean and humans are inextricably interconnected.*
> *7. The ocean is largely unexplored.*

Cava et al. provide a succinct rationale for ocean literacy:

> *The need for ocean literacy is simple. The most dominant feature on Earth is the ocean. Understanding the ocean is integral to understanding the planet on which we live. This understanding is essential to sustaining our planet and our own well-being. However, for many years core curricula for grades K-12 have not included ocean topics. In fact, in some cases, the ocean has been completely ignored in formal K-12 education. The challenge facing ocean literacy proponents has been how to incorporate concepts about the ocean into accepted curricula.*
> (Cava et al., 2005, p. 4)

Public concern about the state of the oceans has been studied for some time (Belden Russonello & Stewart, 1999; Bidwell, 2017). Despite strong claims for the value of ocean literacy, Schoedinger, Cava, Strang, and Tuddenham, (2005) comment that:

Ocean sciences were idiosyncratically left out of the [US] National Science Education Standards and most state standards, resulting in a decline in the public's attention to ocean issues.

A year later, Cynthia Cudaback (2006), noting that a number of definitions existed, wrote:

I believe the most important definition is that an ocean-literate person understands ocean science, can communicate about the ocean, and is able to make informed decisions that affect the ocean. (COSEE, 2005)

Turning to more recent writings on the topic, Kopke, Black and Dozier (2019)state that it is scientists and educators who are the primary drivers for ocean literacy noting that:

While some in the scientific community have heeded the responsibility to communicate with the general public to increase scientific literacy, reaching and engaging with diverse audiences remains a challenge. (p.60)

Uyarra and Borja (2016) argue that ocean literacy 'is not only an educational matter, but an attitude in which understanding of the ocean's influence on people and people's influence on the ocean will result in a positive human behavioural change' (p.1) (see, also, Dupont & Fauville, 2017; Fauville, 2019; Sarah Schoedinger, Tran, & Whitley, 2010; Strang, 2007).

Pedagogical approaches

Attempts to assess students' understanding of marine issues include Ballantyne's (2004) study which involved focus group interviews conducted with 54 school students aged 10-11 years-old in three primary schools in Cape Town. Students were asked a range of questions about 'the sea, its origins, its inhabitants, and ocean movements such as tides, currents and waves' (p.160).

The findings indicate that although students are interested in marine life and are familiar with terms such as currents, tides and waves, their understanding of these concepts is limited and confused. It is suggested that by addressing children's limited conceptions in their exhibits and educational programmes, aquaria can foster an understanding of the environmental processes that support marine life, thus contributing to habitat conservation and species survival. (ibid., p.159).

Leitão, Maguire, Turner, Guimarães, and Arenas (2018) undertook a quantitative study based on the assumption that 'engaging learners in experiences focused on the ocean helps them build personal correlations with the ocean and coasts, which motivate them to become ocean literate and to act on behalf of the ocean' (p. 5058). The authors used an online survey with pupils aged 12-14 years in six schools in three UK schools and six Portuguese schools. Over 300 UK students responded but only 132 Portuguese pupils completed the survey. The knowledge attempted to assess pupils' ocean literacy and identify sources of information. Leitão et al. reported that, not surprisingly, the Internet is the main source of information. They also found no significant association between the choice of media source and ocean literacy levels. The authors report that their findings 'suggest that the more the pupils know about the ocean the more important it is for them and the more they feel personal responsibility for its well-being' (ibid.).

Fauville (2017a, 2017b) examined students' online asynchronous discussion with a marine scientist. In this study, 61 secondary-age students studied ocean acidification by means of a virtual laboratory, a virtual lecture and an asynchronous discussion with a marine scientist. The author examined students' questions with a view to assessing the reasoning behind students' questions and identifying ways in which ocean literacy might be enhanced. Fauville reports that:

> *The results show how interacting with a scientist gives the students an entry point to the world of natural sciences with its complexity, uncertainty and choices that go beyond the idealised form in which natural sciences often are presented in school.* (p.2151)

The author also pointed out the cost-effectiveness of this strategy.

Dupont (2017) describes an activity – ‘I am the Ocean’ – which was developed by an artist and a scientist ‘to help students understand, connect and be equipped to take actions on marine global changes’ (p.1211). Students take part in field trips, open discussions and sensory immersion.

> *The second day focused on solutions. It started with a few outdoor activities where students had to brave the bad Swedish weather to go on a rowing boat and collect capsules containing solutions to global changes hanging on a structure in the middle of the harbour (Figure 2B). When back on land, they could open the capsule to discover that it only contained a blank page. For the rest of the activity, they were asked to work in small groups to fill up this page. They had to focus on what they care the most about in the ocean, reflect on what were the main associated threats and provide at least one solution each.* (p.1212)

The author claims that the activity ‘illustrates how art and metaphors can add an emotional and physical dimension to science communication, allowing a better understanding of otherwise invisible threats, and move from knowledge to passion’ (p.1211).

Keener-Chavis, Hotaling and Haynes (2009) describe a significant investment in teaching ocean literacy. The US National Oceanic and Atmospheric Administration (NOAA) ship Okeanos Explorer Is dedicated to ocean exploration:

> Using a systematically mission-driven exploration protocol and advanced technological instrumentation and systems to explore little-known or unknown regions of the ocean, the ship will employ an integrated telepresence system that will provide broadband satellite transmission of data and discoveries in real time for science, education, and outreach. (p.73)

The authors outline the affordances of the ship for ‘learning in new ways’ which include providing real-time data in various learning environments. More details of the ship and its activities can be found at (https://oceanexplorer.noaa.gov/okeanos/welcome.html).

Marrero and Mensah (2010) report on a case study of a group of 7th grade US students who took part in an ocean literacy-focused curriculum – *Signals of Spring - ACES*. The authors used focus group interviews, student-produced documents and a decision-making task to explore students’ decision making:

> *Findings contradict previous ones that students do not rely on what they learn in science class when making decisions. The 7th grade students in this study were able to apply ocean concepts pertaining to physical and biological processes to personal and societal decision making related to pollution, food choice, and on a sample SSI-based task. The results suggest that students are empowered by the knowledge of the ocean gained through the ACES curriculum and that using SSI may be a way to help students achieve ocean literacy. (p.1)*

For a discussion of the barriers facing teachers (primarily high stakes testing and a lack of time), see Stock (2010). For a discussion of possible negative outcomes of public visits to marine environments see Wyles, Pahl & Thompson (2014). Hall, Easley, Howard and Halfhide (2013) document an approach to teaching ocean acidification and healthy soil to inner-city communities in the US using authentic science research activities. Garrison (2007), in a short paper, lists a number of concepts that need to be taught as part of ocean literacy.

Johnson and Potts (2004) discuss the role of museums and aquaria in promoting ocean literacy noting that 'particular attention needs to be given to the translation of core terminology (i.e., scientific terms) into appropriate and accessible language; increasing the potential for interactive and IT-based interpretation; and the balance of 'intrinsic' and 'ersatz' exhibits and objects' (p.310) (ee also Johnson & Potts, 2006; 2002).

Use of social media

Kopke et al. examined the potential of Twitter to improve the public's ocean literacy (Kopke et al., 2019). In their case study of MaREI – Ireland's Centre for Marine and Renewable Energy, they examined what types of audiences were being engaged and which factors might lead to increased engagement with the audiences. The authors used retweet frequency as a function of post characteristics which allowed them to identify significant features of content, identifying two types of user: INREACH and OUTREACH.

An earlier study into the use of social networking by Fauville, Dupont, Von Thun and Lundin (2015) asked 'Can Facebook be used to increase scientific literacy?' The authors provided a case study of the Monterey Bay Aquarium Research Institute Facebook page and ocean literacy. Fauville et al. reported that Facebook pages 'do not offer the appropriate social context to foster participation since it has only a few of the features of an arena where such practices could develop' (p.60).

The authors conclude that:

> *posting practices such as frequent posting of stories with videos or photos help to reach a wider audience and thus can potentially increase the impact of a research institute's presence on Facebook. The shared stories seem to be one of the main keys to increase participation and support the development of domain specific learning on Facebook. (p.72)*

Using a case study approach, Thaler and Shiffman (2015) identify two ways that scientists can use:

> *to maximize the broad dissemination of corrective and educational content: that of an audience builder or an expert resource'. Finally, we suggests* [sic] *that scientists familiarize themselves with common sources of misinformation within their field, so that they can be better able to respond quickly when factually inaccurate content begins to spread. (p.88)*

Assessing ocean literacy

Greely and Lodge (2009) describe how they devised the Survey of Ocean Literacy and Engagement (SOLE). The SOLE is a 57-item survey instrument aligned with the Essential Principles and Fundamental Concepts of Ocean Literacy (NGS, 2007). The authors used Rasch analysis to refine and validate SOLE as a reasonable measure of ocean content knowledge (reliability, 0.91):

> *Results revealed that content knowledge and environmental attitudes significantly contributed to ocean literacy. Teens demonstrated a 2-32% increase in content knowledge following the OCG*

learning experience. The most significant content gains correlated with ocean literacy Essential Principles 1, 2 and 5. Analysis of environmental reasoning patterns revealed that biocentric reasoning (71%) was most important to teens in solving ocean dilemmas. Further, teens reasoning about challenging ocean dilemmas were capable of supporting a position, counter-argument, rebuttal, and accurately use scientific information.

The SOLE was used by Greely (2008) in an exploratory study of 30 females aged 13-14 years-old during an Oceanography Camp for Girls. The instrument is available in Greely's thesis (pp.199-205). The author used a mixed-methods approach and developed three quantitative instruments: the SOLE, the Survey of Ocean Stewardship (SOS) and Scenarios of Ocean Environmental Morality (SOEM). Greely found that:

SOLE and SOS revealed that content knowledge and environmental attitudes significantly contribute to ocean literacy. Analysis of SOEM demonstrated that biocentric environmental reasoning was most important to teens in solving specific ocean dilemmas. Analysis of OSSI from interview responses revealed three patterns of informal reasoning (rationalistic, emotive and intuitive). (p.x)

Markos, Boubonari, Mogias and Kevrekidis (2017) investigated the psychometric characteristics of a Greek version of the SOLE. SOLE aims to assesses conceptual understanding of general ocean sciences content, focusing on the knowledge component. In their study, Markos et al. gave the survey to 421 pre-service primary school teachers. The authors adapted the SOLE using the dichotomous Rasch model. They conclude that 'the SOLE constitutes a valuable tool which can be applied to a different cultural context and population' (p.231).

In an earlier paper Boubonari, Markos and Kevrekidis (2013) reported on Greek pre-service primary teachers' (n=435) knowledge, attitudes, and self-reported behaviour toward marine pollution issues. The authors described the participants' level of knowledge about marine pollution issues as 'moderate': 'They scored high or relatively high on all attitude factors, and scored moderately high on individual action and low on collective action' (p.232). Another commentary on the need for ocean literacy in teacher education is provided by Payne and Zimmerman (2010).

Chen and Tsai (2016) surveyed 825 Taiwanese university students and reported that they appeared to possess 'a highly positive attitude towards the marine environment and a moderate self-reported level of marine knowledge' although they were not 'actively engaged in environmental protection endeavors' (p.958).

Another Taiwanese study, by Lin and Li (2017) involved examining how 54 university students of various academic disciplines enrolled in a unit on 'Sustainable Oceans'. The authors used auto-photography:

Overall, students demonstrated vague perceptual awareness about who should take responsibility concerning lifeworld-related issues. Also, their perceptions were affected by their choice of academic discipline. Engaging students in inter-/transdisciplinary learning, integrating the arts, science and community, helped develop a more balanced, action-motivated conception of sustainability. Post-test patterns of change in students' vision and action were observed. (p.554)

A number of other studies have examined different aspects of ocean literacy (see, for example: Fletcher, Jefferson, & Mckinley, 2012; Fletcher, Potts, Heeps, & Pike, 2009; Fletcher & Potts, 2007;

Friedrich, Jefferson, & Glegg, 2014; Gelcich et al., 2014; Guest, Lotze, & Wallace, 2015; Hamilton & Safford, T.G, 2015; Hawkins et al., 2016; Heck, Paytan, Potts, & Haddad, 2016; Jefferson et al., 2015; Lotze, Guest, O'Leary, Tuda, & Wallace, 2018; Plankis & Marrero, M.E., 2010; Ressurreição, Simas, Santos, & Porteiro, 2012; Revell, Stanisstreet, & Boyes, 1994; Sattler & Bogner, n.d.; Steel, Smith, Opsommer, Curiel, & Warner-Steel, 2005; Tonin & Lucaroni, 2017; Umuhire & Fang, 2016; Wen & Lu, n.d.; Wiener, Manset, & Lemus, 2016).

McKinley and Fletcher (2010) report on a study of marine practitioners' views on the problems facing the ocean environment. Telephone interviews (n=42) were used to elicit opinions from a range of stakeholders about a number of issues including the need for marine education:

> *Interviewees considered that an increase in marine (Uyarra & Borja, 2016) availability would engender higher levels of awareness and concern about the marine environment that would ultimately generate a sense of marine citizenship. This is illustrated by one interviewee who stated that "a high level of environmental education will encourage a greater sense of citizenship". Numerous methods to encourage marine education were mentioned, including greater inclusion in school education and expanded informal learning opportunities (such as in visitor centres, interpretation, etc.), but marine-focused television programmes were highlighted as "the best way to target a wide variety of people" and "the number one method" of improving marine education.*

For a more in-depth discussion of environmental citizenship see McKinley and Fletcher (2012).

European initiatives

Copejans, Crouch and Fauville (2012) report on a number of European initiatives including the Climate Change and Marine Ecosystem Research which instigated the first European poll on public perceptions of climate change in the marine environment (Buckley et al., 2011). Fauville, Copejans and Crouch (2013) report on the European Commission's Directorate-General for Maritime Affairs and Fisheries' 'Marine Knowledge 2020' initiative.

Fauville, McHugh, Domegan, Mäkitalo, Friis Møller, Papathanassiou et al. (2018)report on the Sea Change project, a 3-year initiative funded by EU's Horizon 2020 Framework Programme for Research and Innovation. The project aims to establish a fundamental "Sea Change" in the way European citizens view their relationship with the sea.

Methodological issues regarding the literature review
This non-systematic review draws on 67 papers, reports, books and other outputs. See Costa and Caldeira (2018). See Scully (2018).

5.2 Creative Pedagogies for Science Education

Our response to the question, "What innovative, creative pedagogies are used to support learning in Science?" is structured in two parts. The first part is a thematic analysis of how pedagogies are discussed and researched in the 17 studies, taking into account the existing suggested Ocean Connections pedagogic frame (Dialogue; Transdisciplinarity; Risk, Immersion and Play; Balance and Navigation; Possibilities; Ethics and Trusteeship; Empowerment and Agency; Individual, Collaborative and Communal activities for change) drawn from the CREATIONS project. The second part offers analysis of the kinds of learning that papers claimed were ensuing from the creative pedagogies that they discussed and researched.

A few defining characteristics of the 17 studies are worthy of note. Of the 17 studies:

- Nine focused on primary education; seven focused on secondary education; three were teacher only focused; and two had a broad focus (this makes more than 17 as some studies had overlapping foci)
- Three covered more than one country; two were from the UK; three were from Taiwan; four had a European spread; four were from Turkey; and one was from the US
- One of the studies was itself a review; five used a qualitative methodology; five used a quantitative methodology; two used a mixed quantitative/qualitative methodology; three were discursive/theoretical; and one used a post-qualitative methodology
- 13 were science focused; three were STEAM focused; and one was geography focused

In relation to this last point, it must be noted that no real conclusions can be offered in relation to geography education; the majority of analysis here refers to science education.

Main themes with respect to creative pedagogy

In their review of STEAM (Science, Technology, Engineering, Arts and Maths) education Colucci-Gray et al (2017 p. 50) argue that across disciplines "there is a vast and disparate literature on creative pedagogies". Currently under review, Cremin and Chappell's systematic literature review has more recently been able to shed light on what this actually means within international formal education. Although not yet published that review offers insight which is helpful to introduce the thematic analysis undertaken here. Cremin and Chappell (Under Review) offer Dezuanni and Jetnikoff's (McWilliam, Poronnik, & Taylor, 2008) definition which asserts that creative pedagogies involve 'imaginative and innovative arrangement of curricula and teaching strategies in school classrooms' to develop children's creativity". From this Cremin and Chappell also remind their readers of the important inter-relationship within creative pedagogy of teaching for creativity and creative teaching (Jeffrey & Craft, 2004) rather than seeing these two practices as polarised. They also go on to remind their readers that any review of creative pedagogies is not about creating a "failsafe recipe" (2001, p. 21) but to understand pedagogies as emerging relational activities between teacher and learner. With this in mind, Cremin and Chappell offer seven interrelated features which their review indicates characterise creative pedagogical practice: generating and exploring ideas; encouraging autonomy and agency; playfulness; problem-solving; risk-taking; co-constructing and collaborating; and teacher creativity. It should be remembered that this is a review of creative pedagogies internationally across disciplines but it does provide a useful backdrop against which to understand the thematic analysis of creative pedagogies in science and geography education being carried out here to underpin Ocean Connections practices.

Another paper which falls out of the scope of this review because it is out of our date criteria and focused predominantly on HE-level practice , does however offer useful contextual information as to how and why we might conceptualise creative pedagogies in science education. They argue creative pedagogies are necessary within science education because

> *young people are more engaged by active tasks than with a passive consumption approach to transfer of core knowledge; that it is boredom, not rigour, that disengages them—the difference is between static and dynamic sources of knowledge; that creativity is not the antithesis of scientific rigour but the core business of scientific thinking; that we now have new understandings of creative pedagogies that make teaching strategies visible and effective; and, that these strategies can build academic, digital and social capacity simultaneously and this is the new core business of the science educator. (2008:226)*

This current focused review pulls together these 'new understandings' of creative pedagogies in science education with the aim of developing teaching and learning strategies within Ocean Connections. The Ocean Connections suggested pedagogic frame has been used deductively as a lens through which to thematically analyse the conceptualisations of creative pedagogy in the 17 articles. Simultaneously, an inductive approach has also been taken to allow additional themes to emerge from the data. The themes from the analysis are presented in order of most to least present.

Empowerment and Agency (11)

Within Chappell et al (2015) encouraging Empowerment and Agency was conceptualized as allowing both learners and adult professionals to gain a greater sense of their own agency and ability to express themselves, and to then know what to do with that in order to be more creative scientists and to develop more creative science teaching techniques. In practice, this means enabling pupil agency and encouraging children to try out (and critique) their own ideas and questions in investigations. Within the studies reviewed here there were 13 which advocated creative pedagogies which contained something of these notions. It is worthy of note that this was the strongest theme within the analysis. There were two studies with overlapping theoretical derivations to Chappell et al. (2015) which perhaps unsurprisingly highlighted empowerment and agency as named creative pedagogies (Chappell et al., 2019; Craft et al., 2016). Although interestingly another study coming from a similar theoretical base emphasised the idea of problem-solving (rather than empowerment) and agency (Cremin, Glauert, Craft, Compton, & Stylianidou, 2015). This may have been because that study was predominantly with younger learners but it also connects to the emergent theme of encouraging inquiry-based approaches below. Four further studies place an emphasis within their discussion of creative pedagogies on student/learner-centredness (Çil, Maccario, & Yanmaz, 2016; Çokadar & Yılmaz, 2010; Colucci-Gray et al., 2017; Yang, Lee, Hong, & Lin, 2016) and emphasise notions of student choice and prioritising their own interest. Quigley and Herro (2014) also directly name the importance of student choice, with Liu and Lin (2014) discussing similar in the guise of what they call 'autonomous learning'. Baron and Chen (2012) acknowledge that these shifts towards agency require a re-arrangement of traditional science-teaching power dynamics. Perhaps the most potent on this theme is Scoffham (2013, p. 368) the only geography education paper, which requires creative pedagogy to put "the children at the heart" to develop "joyful and imaginative learners".

Individual, Collaborative and Communal activities for change (9)

This creative pedagogy acknowledges that space is needed for students to engage individually, in collaborative relationships and in more communal or group-driven interactions, as they develop ideas which lead to change within the science classroom. Employing available tools such as technology (e.g. social media, online resources and sharing facilities and novel science-focused technologies) or arts processes to support this can build on what is possible creatively face to face (Chappell et al., 2015). Nine studies in this analysis proposed creative pedagogies which fitted with this theme, with Craft et al (2016) directly referencing the theme, as the Ocean Connections project draws down its pedagogical frame from Craft's CREAT-IT project. Yang et al (2016) and Liu and Lin (2014) discuss the import of group-based learning; with Cokadar and Yilmaz (2010) and Cil et al (2016) citing community atmosphere and social interaction as important to how creative pedagogies function in the science classroom. Collaborative activities are forefronted by Harris and de Bruin (2018) (emphasising teacher collaboration), and Cremin et al (2015) who emphasise its relationship with dialogue. Colucci-Gray et al (2017) perhaps come closest to bringing together the different dynamics of collaborative and communal activities when they detail the role of collaborative creativity; co-operative, and collective engagement as fundamental to creative pedagogies. Interestingly, Quigley and Herro (2016) note the difficulty with collaborative work in US science classrooms with data analysis from teacher interviews put down to students being unskilled in collaborative engagement, noting that students needed to be given the opportunity to practice collaboration skills for it to be successful creatively.

Transdisciplinarity (6)

This is grounded in the inter-relationship of different ways of thinking and knowing, which means allowing space for different ways of thinking (e.g. problem-solving, reasoning, experimenting) around shared arts/science threads. At the arts/science interface there are different ways of knowing (knowing that, knowing how, knowing this) which acknowledges the embodied alongside the verbal (Chappell et al., 2015). At its core transdisciplinary creative pedagogy is about allowing the curious questions to drive the learning with discipline knowledge and processes feeding into this (Morgan, Somerville, & Rapport, 2000). While six articles resonated with this theme in some way, only two directly reference Transdisciplinarity (Chappell et al., 2019; Harris & de Bruin, 2018), the other four take what might be referred to as a multi-disciplinary or at times instrumental approach. In their discussion of STEAM practices Harris and de Bruin (2018) perhaps not surprisingly refer to inter, trans, multi- and cross disciplinary practices as prevalent parts of STEAM pedagogy. They are clear that multi-disciplinarity can involve "a transfer of methods (Nicolescu, 1997), an integration of contents (Moran, 2010) and collaborative teacher effort through the coordination of resources and pedagogies" (Harris & de Bruin, 2018, p. 156). In this review, this 'transfer of methods' can be seen in Cil et al (2016) (between visual arts and science), and Cokadar and Yilmaz (2010) (between drama and science), neither of which push the pedagogy to fully fledged transdisciplinarity.

Quigley and Herro (2016) explore the application of STEAM pedagogies in maths and science classrooms and note difficulties with Trans-disciplinarity due to teachers struggling with a need to keep maths or science dominant, or not exploring the full aesthetic and expressive potential of arts activities, whilst Liu and Lin (2014) conclude by noting that the arts science link is overlooked in the views of the Taiwanese primary science educators that they interviewed. This highlights prevalent problems for transdisciplinary practice in neoliberal, propositional knowledge heavy, testing driven curricula which are perhaps worthy of further interrogation when working to understand creative pedagogy within Ocean Connections.

Dialogue (6)

Here Dialogue goes beyond the notion of conversation to entail a process of questions leading to answers leading to questions; which can occur between people, disciplines, creativity, identity and ideas. This dialogue acknowledges embodiment and allows for conflict and irreconcilable difference. It has the capacity to facilitate open discussion of questions generated by students (bottom up) and bring these into dialogue with live questions from professional science and science education (top down) (Chappell et al, 2015). Six studies strongly identified Dialogue as fundamental to creative pedagogies (Harris and de Bruin, 2018; Cokadar and Yilmaz, 2010; Baron and Chen, 2011; Craft et al, 2014; Cremin et al, 2015; Chappell et al, 2019). Of particular relevance to Ocean Connections because of its focus on the ocean as a system is Cokadar and Yilmaz's (2010) discussion of creative drama as a creative pedagogy for understanding ecosystems. They state that it is through "dialogue and examining different perspectives that students become knowledgeable, strategic, self-determined, and empathetic" (2010, p. 81). Also of interest, is Harris and de Bruin's (2018) connection between dialogue and organisation, noting that entire school structures and systems need re-organising to fully allow for educationally productive dialogues to feed learning.

Risk, Immersion and Play (5)

Chappell et al (2015) argue that key to creative pedagogy is allowing these three processes to happen across teaching and facilitation. This can be achieved by creating a trusting space in which mistakes are possible and there is no fear of failure. At the time, Chappell et al's (2015) language was very much driven by a particular theory of creativity (Possibility Thinking, e.g. Craft, 2002) which prioritized this conceptual language, so it is perhaps not surprising that the Craft et al (2016) article in this review also directly refer to these three qualities of creative pedagogy. Although not directly using this three-fold terminology, four other articles discuss pedagogies which are in this spirit. Resonating with the idea of play, Cokadar and Yilmaz (2010) emphasise fun and engagement in their study of drama application, which in itself is known for its playful elements; Liu and Lin (2014) similarly include the idea of diverse fun activities in their creative pedagogy discussions, and Cremin et al (2015) refer to play and exploration in primary science. Scoffham (2013) argues that creative pedagogy should prioritise puzzles, stories, trails and placemaking in geography education, highlighting the importance of risk-taking to these, and discussing play and playfulness in relation to imagination, personal growth, place-making, games and children's fundamental way of being in the world.

Possibilities (4)

Creative pedagogy can allow for multiple possibilities both in terms of thinking and spaces, and knowing when it is appropriate to narrow or broaden these in the context of asking 'what if…?' (Chappell et al., 2015)This principle is again derived from Craft's (2002) Possibility Thinking theory and so, again, it is not surprising that Craft et al (2016), in this review, highlight working with Possibilities as fundamental to creative pedagogy. However, it also emerges in three other articles in this review. Colucci-Gray et al (2017) actually name Possibility Thinking as key to creative pedagogy emphasising that teaching and learning which focuses on possibility is flexible, adaptive and generative. Using slightly more cognitive language, Cokadar and Yilmaz (2010) consider the role of divergent thinking in creative pedagogy, and Yang et al (2016) go further in discussing convergent and divergent thinking, open-endedness and exploration.

Ethics and Trusteeship (3)

Chappell et al (2015) perhaps put a slightly unusual emphasis on the idea of Ethics and Trusteeship as core to creative pedagogy, which stems from that review's heritage in Craft, Gardner and Claxton's (2008) work on the need to better prioritise wisdom in creativity in education theorizing. They argue that adult professionals and learners need to consider the ethics of their creative science processes and products and should be guided in their decision-making by what matters to them as a community, and be active as trustees of that decision-making and its outcomes. As above perhaps not surprisingly, Craft et al (2016) directly references the role of ethics and trusteeship within creative pedagogy. Two other articles discuss related creative pedagogy concepts. Cokadar and Yilmaz (2010) discuss the importance of empathetic skills exampled in science discussions of the ethical responsibilities inherent in the development of the atomic bomb. Scoffham also directly discusses "ethical learning" (Scoffham, 2013, p. 379) and connects it to autonomy and agency (see first feature above), acknowledging different ways and speeds of learning, as well as complexity and the value of "emotional and existential knowing alongside more visible cognitive achievements" (Scoffham, 2013, p. 379).

Balance and Navigation (0)

The last feature in the framework is about how practitioners might balance control and freedom, structure and openness, stepping back and stepping in, and prior and new knowledge. The feature also includes acknowledging the common educational tensions and dilemmas of accountability/assessment, marketisation and resource/time pressures and navigate these with creativity rather than pursuing a creativity v performativity mentality. None of the papers in this review referred to the idea of balance and navigation directly, but it is safe to say that in some way or another all 17 papers touched on at least one element of this feature in their discussions of the practicalities of implementing creative pedagogies.

Other emergent features: Inquiry-based pedagogy (5)

Inquiry Based Science Education or IBSE has been an increasing area of growth in science education practice in recent years, and this is reflected in six of the articles and how they refer to IBSE in relation to creative pedagogies. Trnova (2014) goes so far as to argue that IBSE principles correspond to the basic components of creativity, and uses IBSE principles in a project to develop teacher creativity. While there seems to be some efficacy to this it must be remembered that IBSE and creative pedagogy are not one and the same; the article shows that IBSE could be used as part of creative pedagogies utlitising the key IBSE principles of student activities, linking information into a meaningful context, developing critical thinking, promoting positive attitudes towards science and motivation. This relationship is also acknowledged by Yang et. al who define their approach as “creative inquiry-based science teaching”; acknowledging creative pedagogy and IBSE as strongly related but not the same.

This emergent theme is also indicative of a tendency within the articles to use cognitive/thinking skills terminology for referring to creativity and creative pedagogy. For example, Karaca and Koray (2016) test the effect of the Creative Reversal Act (differentiation, opposition, combination, elaboration); Orhan and Sahin’s (2018) research tests the impact of inquiry and problem solving; Liu and Lin (2014) researched inquiry-based teaching with a focus on convergent thinking, connecting ideas and problem-solving; Cremin et al (2015) highlight reflection and reasoning.

Other emergent features: Arts-based pedagogy (5)

In a similar way, five of the articles make a clear connection to the role of the arts in the creative pedagogy they are researching. This is in the context of the rise of STEAM which sees the arts as serving STEM to expand the STEM toolbox or to free scientist’s minds and infuse creativity (Daugherty, 2013). This emergent theme sits a little at odds with the Transdisciplinarity theme above where the onus is on questioning driving disciplinary interaction, rather than the arts serving the sciences. In this context, within these review articles the arts are seen as contributing: enjoyment, inclusion, engagement, transformative thinking, deep knowledge (knowing the central, crucial ideas of a topic and establishing complex connections) with deep understanding (of the topic in a systematic way), substantive conversation (interactions on the topic among students and with teachers) and agency (Colucci-Gray et al., 2017); encouraging divergent thinking (Çokadar & Yılmaz, 2010); bringing new approaches to problem-solving and creative synthesis of new ideas (Quigley & Herro, 2016); learner-centre learning (Çil et al., 2016); a fulcrum through which wider domain learning can occur (Harris & de Bruin, 2018).

Interestingly, Quigley and Herro (2016) note difficulty with arts integration because of lack of science teacher skill in the arts; they point to the need for arts expertise to really allow this kind of practice to reach its potential. This is indicative of many of the assumptions about expertise and power relations in this kind of practice which researchers and practitioners should be alert to when developing programmes such as Ocean Connections which rely on notions of creative pedagogy. Equally, arts as a creative pedagogy for the sciences represents one view on the inter-relationship between disciplines and needs to be critically considered in terms of what it says about science’s own perceived capacity to be creative.

Conclusion on pedagogies

Through the analysis of the 17 papers, we can therefore see that the innovative creative pedagogies used to support science and geography teaching evidenced in relation to the Ocean Connections pedagogical frame prioritise as follows: Empowerment and Agency; Individual, Collaborative and Communal activities for change; Transdisciplinarity; Dialogue; Risk, Immersion and Play; Possibilities; Ethics and Trusteeship; Balance and Navigation. The new emergent themes (Inquiry-based approaches and Arts-based approaches) although of a slightly different order to the features, and not quite features themselves, would sit in between Risk, Immersion and Play and Possibilities in terms of prioritisation through number of articles in which they were considered.

Nuances of the pedagogies include the fact that teachers and their creativity are clearly included in the articulation of Individual, Collaborative and Communal activities for change; Transdisciplinarity is not often achieved in these studies, more often mult- or inter-disciplinarity. Dialogue is interestingly seen to need to stretch as far as organisational structure and systems in order for it to really facilitate creative pedagogy (Harris & de Bruin, 2018). One paper of particular interest because of its focus on ecosystems, hence a connection to this project is Cokadar and Yilmaz (2010) who researched the pedagogy of ecosystems taught through drama, emphasising dialogue.

In the way that themes emerge in the same study, it is worth noting that there are connections between the features of dialogue, empowerment and agency and inquiry-based approaches. Similarly, there are evident connections which might be explored between risk, immersion and play, and ethics and trusteeship and arts-based approaches.

Across the 17 studies they report various difficulties which Ocean Connections practices might pay attention to: problems with in depth collaborative expectations; difficulties of arts integration without arts-skilled staff (Quigley & Herro, 2016); how it is possible to overlook the arts-science link (Liu & Lin, 2014); whether Transdisciplinarity can really be achieved in existing school curricula internationally; and how any kind of trans-, inter- or multi- disciplinary practice must be careful not to negate the creativity inherent within science. Ocean Connections might consider some of the reasons underlying these problems to see whether they can be tackled in this project or whether in fact they have deeper underlying roots that cannot be dealt with here.

What kinds of learning do creative pedagogies support?

In order to respond to RQ3, ”What innovative creative pedagogies are used to support learning in Science and Geography?”, it is important to offer some insight from the 17 papers into what kinds of learning they argue ensue from the creative pedagogies that they research. The Ocean Connections state of the art bid works on the assumption that the following will ensue from creative pedagogies (Chappell et al., 2015):

> Purposive and imaginative activity generating outcomes that are original and valuable in relation to the learner. This occurs through critical reasoning using the available evidence to generate ideas, explanations and strategies as an individual or community, whilst acknowledging the role of risk and emotions in interdisciplinary contexts*.*

Hadjigeorgiou et al (2012) offer a comparable notion of the science creativity that might ensue from creativity as including: an aesthetic/transformative experience; generation of multiple ideas and evaluation of those as to being worthwhile to pursue; making associations between semantically remote ideas, events and phenomena. In the context of these two suggestions of what might ensue from creative pedagogy in science, this section will offer information as to what the 17 articles argue ensues from their creative pedagogies (insight from 16 papers will be offered as Cil et al (2016) deals with teacher training rather than direct interventions with students learning).

Cremin et al (2015) and Craft et al (2016) offer definitions either the same as or very similar to Chappell et al (2015) which is being applied here in Ocean Connections. This is because all these projects stem from the same theoretical base. These two articles particularly emphasise working with ‘little c’ creativity. Other articles offer very tight definitions of creativity: Karaca and Koray (2016) argue that creativity is fluency, flexibility, originality and elaboration; Harris and de Bruin (2018) refer to critical and creative thinking (drawing on Lucas et al’s (2013) five creative dispositions); Colluci Gray et al (2017) refer to 21stC learning but do not specifically define this; Trnova (2014) discusses student creativity defined as the ability to imagine something new, with an individual approach characterized by agreement, acceptance of change, play and flexibility, with a process of hard work and continuous mental activity with space for improvisation and order.

The other ten articles offer more disparate understandings of creativity or the learning that ensues from creative pedagogy which are fluidly written and difficult to categorise and are therefore presented in a table below.

Authors	What ensues from creative pedagogy in their study
Chappell et al (2019)	imagination; valuing the experiential; questioning right answers; role of emotions, feelings and expression; improvisation; confusion as positive
Yang et al (2016)	scientific creativity, problem solving leading to exceptional accomplishment
Baron and Chen (2012)	content retention, critical reasoning, spirit of inquiry
Liu and Lin (2014)	autonomous learning and group learning
Newton and Newton (2010)	fact-finding and practical learning, activities dominate
Orhan and Sahin (2018)	project-based, web-based and inter-disciplinary
Quigley and Herro (2016)	problem-based, technological/21st century skills eg creativity and innovation
Scoffham (2013)	Children at the heart, joy and imagination
Conradty and Bogner (2018)	introducing new impulses to science education, cognitive processes and flow
Cokadar and Yilmaz (2010)	engagement, fun, creative, original, imaginative, empathetic skills, communal, social

Conclusions on learning

Concluding in relation to the kinds of learning that studies claim ensue from the creative pedagogy they investigate, is problematic as the kinds of learning discussed are so disparate. Where there is thematization it is because studies offer a theoretically derived definition of creativity in particular. Where there is not, studies claims are as far-ranging as 21st century skills to imagination to emotions to joy to content retention.

Finally, there is a point of interest regarding the inquiry-based studies' tendency to focus on thinking skills/cognitive language to describe what ensues from the pedagogy, and arts-based studies' tendency to focus on elements such as engagement, synthesis and the metaphor of a fulcrum in one study to describe what ensues from the pedagogy. These differences perhaps stem from the different epistemological approaches that drive those studies and the pedagogical approach, and in turn the concepts that researchers are alert to and the language they use.

5.3 Creative Pedagogies, Digital Technology and Ocean Literacy

RQ4 asks 'How are digital technologies and creative pedagogies used to support students' Ocean Literacy'. In order to develop a nuanced response to this question, we conducted a broad search for literature that explored relationships between creative pedagogies and digital technology so that we are able to understand how the two elements could fruitfully combine within our pedagogical framework to support

Ocean Literacy. Given that this would be a large project in itself and was in support of, rather than the focus of, our review, we conducted a literature search to highlight key topics and connections, but have not included it here as it is not directly related to Ocean Literacy.

We then conducted a focused review to understand where creative pedagogies and digital technologies have been previously used separately to support Ocean Literacy for children aged 7-16 (ie in upper Primary and Secondary settings), and whether there are any previous studies at the nexus of all three elements. In conducting this search, we found very few studies linking creative pedagogies or digital technology to ocean literacy, so we included a search for creative and digital pedagogies together within the broader field of environmental education, in order to identify any good practices that could inform our pedagogical principles and subsequent project design. Following our search, we looked for themes across our defined areas that might enable us to find synergies between them. To facilitate this, we did not exclude literature reviews or theoretical pieces from the review, as these might afford insights useful in to helping us draw together the different elements of Ocean Connections.

In this section, we therefore responded to these sub-questions in relation to the Ocean Connections RQ4:

- To what extent have creative pedagogies been used to support ocean literacy?
- To what extent have digital technologies been used to support ocean literacy?
- To what extent have digital technologies and creative pedagogies been used together to support environmental education?

Where and how has creativity been linked to ocean literacy education for school aged children?

As demonstrated in the broader review of ocean literacy education (see section 5.1), there is limited current research in this field. It is therefore unsurprising that our search revealed no articles explicitly discussing ocean literacy and creativity, and only five articles where links between marine-based environmental education to creativity could be found at Primary and Secondary school level. Of these five, two (Lemus, Bishop, & Walters, 2010; Manousou & Lionarakis, 2013) referred to creativity as a skill that pupils' might use or develop through the programmes, but was not part of the studied outcomes. Manasou (2013) developed a distance-learning educational software to teach 5th and 6th grade Greek students about the Mediterranean Sea, with creativity identified as a desired skill to be developed through the activities. Lemus et al (2010) evaluated the QuikScience Challenge project which aimed to draw on pupils' love of the ocean to engage their interest in science, in environmental stewardship and in ocean science careers. Pupils were required to summarise their work on the project via a 'creative presentation' but this did not draw explicitly on any theorisation of creativity or creative pedagogies. Since creativity was not explicitly studied in these articles, we cannot draw strong links to the way creativity was used in relation to Ocean Literacy from them.

McRuer and Zethelius (2017) used a Critical Place Inquiry methodology to explore students' *biocultural place relationships* in the context of the Isla Grande marine preservation area in Colombia. The foregrounding of biocultural place offered the authors a stance that avoids a binary separation of nature and culture and highlights the entangled nature of

> *"the relationships that exist among humans, non-humans, (e.g. biological, material, technological, policitical, economic entitites), ideas, improvisations (i.e. the creativity of labour, influenced by place relationships), innovations, research ad more (Haraway 2018; Ingold 2008, 2010; Whatmore 2007)" (McRuer & Zethelius, 2017, p. 850)*

The study used two methods of data collection, both involving digital technologies: photovoice, and participatory mapping. These enabled co-development with their participants of their understanding of the unique biocultural place relationships and notions of sustainability and wellbeing.

Luther (2010) draws on unusual theoretical stance of erotic ethics (citing de Beauvoir) to highlight the importance of embodied, sensual (as in, of the senses) and affective relationships with the ocean and with nature in order to stimulate young peoples' interest and engagement. Drawing on Merleau-Ponty's argument for preconceptual perception, she argues that to anchor this sensibility within science education we need experiences which are 'formed through wonder and imagination, fostered through a child-like creativity…a *phenomenology of place,* allowing our students to view the world, our environments and the ocean for what it is at its basic, most primal level…making mindful meaning of their experience' (Luther, 2010, p. 418). As with McRuer and Zethelius (2017), reference to creativity here is bound up in the entanglement of human and other-than-human, emotions, ideas and innovation. In addressing students' learning in inland locations without access to the ocean, Luther argues for synaeasthetic inquiry experiences with local water systems and the fostering of erotic-ethical relations with the ocean via citizen science. In both McRuer and Zethelius and Luther's articles, digital technologies are used as a means of additional engagement with, but not in place of, physical and embodied experiences of the ocean and/or of inland water systems feeding in to the ocean.

In a related vein, Dupont (2017) describes an activity – 'I am the Ocean' – which was developed by an artist and a scientist 'to help students understand, connect and be equipped to take actions on marine global changes' (Dupont, 2017, p. 1211). Students take part in field trips, open discussions and sensory immersion.

> *The second day focused on solutions. It started with a few outdoor activities where students had to brave the bad Swedish weather to go on a rowing boat and collect capsules containing solutions to global changes hanging on a structure in the middle of the harbour (Figure 2B). When back on land, they could open the capsule to discover that it only contained a blank page. For the rest of the activity, they were asked to work in small groups to fill up this page. They had to focus on what they care the most about in the ocean, reflect on what were the main associated threats and provide at least one solution each.* (Dupont, 2017, p. 1211)

The author claims that the activity 'illustrates how art and metaphors can add an emotional and physical dimension to science communication, allowing a better understanding of otherwise invisible threats, and move from knowledge to passion' (Dupont, 2017, p. 1211). This opportunity for transdisciplinarity, including the need for 'felt knowledge' as well as 'factual knowledge' offers a creative pedagogical approach to education for ocean literacy.

Parallels exist in these three papers that may be easily linked to the features of creative science education described in section 5.2. Embodied material-dialogue, empowerment and agency, and individual, and collaborative and communal activities for change can be identified: in these articles, the argued-for emotional and physical entangled relationship with the ocean (which we might view as a creative embodied material-dialogue, see Chappell et al., 2019; Hetherington, Hardman, Noakes, & Wegerif, 2019) is seen as a means of empowering young people to individual and community action.

Where and how have digital technologies been used to support ocean literacy education for school aged pupils?

Our search for studies using digital technologies for ocean literacy education yielded 10 papers within the scope of our focused review. In their literature review of ICT in environmental education, Fauville, Lantz-Andersson and Säljö (2014) suggest that in terms of outcomes on learning, there is not yet sufficient evidence of ICT tools having significant positive impact and argue for the need for further research. Mirroring this, where the papers identified in this search discuss learning outcomes, there is no clear pattern in the extent to which digital tools have significantly impacted on learning, not least because of the broad range of contexts. Though ultimately relevant, the general impact of digital tools on learning outcomes in environmental education is beyond the scope of this review: instead, we are focusing on the particular ways creative approaches and digital tools have been used in the environmental education literature related to the ocean, and what has been learned about them as a result.

Analysis of these papers revealed some common themes, primarily in discussing the affordances and challenges of technology in terms of pupils' experiences of nature, and the motivational effect of technology. Other papers addressed specific aspects of the use of technology that did not fall into a particular category, albeit with some points of overlap apparent in the articles (for example, the scaffolding of learning with digital tools) without these being the key point of the study. The remainder of this section explores the key themes identified before drawing together some tentative conclusions about the possible relationships between creative and digital pedagogies in the Ocean Connections project.

Direct and indirect experience of nature: the affordances and challenges of digital technology

A key point identified in five articles is the balance to be struck between the potential of technology to make the inaccessible accessible, compared with the issues arising from placing a digital barrier between young people and their direct experience of the ocean/nature. This also came out strongly in the perspectives of teachers and aquarium staff discussed in section 3 of this report. In their broader review of ICT tools in environmental education, Fauville et al (2014) highlight that digital technologies offer access to new experiences for students that would not otherwise be possible. Wrzesien and Raya (2010), in their study of an AR facilitated 'serious game' within an aquarium context, note that it would be impossible for pupils to access the true context of the deep ocean about which they were learning and advocate a 'virtual field trip' in contexts where a real field visit would be impossible.

Reiterating the importance of felt knowledge and embodied experience in learning about nature highlighted above in the context of creativity and learning about the ocean, there is a clear sense in the literature that digital technology has the potential to engage individuals with marine environmental issues, but 'technology alone is not sufficient to induce the sense that nature is part of the self' (Ahn et al., 2016, p. 403). Echoing Wrzesien and Raya's (2010) point, Hougham, Nutter and Graham (2018) address this question in the context of students with low socioeconomic status in the USA using digital means to engage 'at risk populations' outdoors. They found that the use of digital technology in environmental education is beneficial in terms of increasing students' technological confidence, and does not detract from their environmental learning so long as the technology is used as an enhancement and not a replacement. A similar example of a technological enhancement of a real experience was found in Kamariainen et. al's (2013) study of a combination of AR and probeware (digital datalogging tools used to log data about the real environment) used within a real-life Lake setting to guide pupils to interact with the environment. The combination of technologies was found to enhance pupils' learning and engagement, with teachers commenting that the pupils' were able to gain more from the use of the probeware to explore the environment when supported by AR than in their previous experience using probeware alone.

Technology and Motivation

The relationship between the use of technology as an educational tool and pupils' attitudes to the Ocean (or where yielded in our search of ocean and marine terms, broader attitudes to nature and the environment) is a further common theme across four different technologies and contexts.

Exploring location-based AR, with a cohort of 135 10th-grade pupils in Cyprus, Georgiou and Kyza (2018) explored students' disciplinary and cognitive motivation and its relationship to their level of immersion in the task of undertaking an environmental inquiry in which the real landscape (a lake) was enhanced through AR hot spots where a video character shared and explained data they could incorporate into their investigation. They found that pupils' disciplinary and cognitive motivation predicted their level of immersion in the task, and that even engagement (the lowest level of immersion within their measure) correlated with learning gains. This finding parallels those seen elsewhere, where it seems that students' prior interests, commitments and values might affect their perspectives on interaction with nature either directly or through digital means. For example, although not within an Ocean context, it is of interest that Schonfelder and Bogner (2017) found that with respect to bees, pupils who were were identified as oriented towards the 'use', or 'preservation' of the environment at the outset of the study were differentially impacted by a virtual or direct interaction with a beehive in a workshop-based learning experience: those with low 'green attitudes' were more impacted by the digital workshop, whereas those with higher 'green attitudes' maintained their knowledge and interest in both conditions.

Other studies explored the relationship between motivation and digital technology by studying the impact of the digital technology on motivation (in contrast to the link between prior motivation and engagement with the digital learning). Wrzesien and Raya (2010) used both quantitative and qualitative methods to explore pupils' reactions to a 'serious game' in which they used AR to interact with a virtual deep ocean environment in an aquarium in Spain, finding that 10-12 year old pupils appeared more engaged by the game approach but that there was no significant different in learning outcomes.

Similarly, Kamarainen et al (2013)'s study of combined location-based AR with the use of probeware showed that pupils were more engaged by the combination of tools. However, despite the engaging or motivating nature of location-based AR, Kyza and Georgiou (2019) make the important point that the use of AR needs to be carefully scaffolded to avoid it being largely a fun 'treasure hunt'. They discuss the use of an application to design and scaffold location-based AR and how, in the context of a lake setting exploring environmental impact, a concept mapping tool built in to the app was most effective in scaffolding learning in comparison with a note-taking tool. It should be noted that they are explicit in highlighting that the scaffolding is not the technology or tool in itself, but in the way the location, app, scaffolding tool and young people interact with each other. This is an important aside in the context of creative pedagogies.

To what extent have digital technologies and creative pedagogies been used together to support environmental education for school aged children?

Our search yielded very few studies which were explicit about drawing on a combination of digital technology and creative pedagogies in environmental education in general, and ocean literacy in particular. Despite this, our analysis of our searches for creativity and digital technology in the field of ocean/marine education have revealed some relationships within the literature, linked with respect to the features of creative pedagogy discussed in section 5.2. Four studies between them made reference to *narrative/storytelling, games,* and *immersion.* For the purposes of this report, we describe these studies with reference to two features of creative pedagogy with which we are working in this project, namely *possibilities* and *risk, immersion and play.*

Possibilities

Our separate exploration of the relationship between creative pedagogies and digital technology, beyond the scope of this review, yielded a strong focus on the use of digital tools to support storytelling or narrative within a range of educational contexts: usually either to support conceptual learning in disciplines ranging from science to the arts to language learning, or to enable particular populations to engage more effectively with learning. Walsh, Chappell and Craft (2017), in the context of a creative, cooperative digital gaming virtual learning environment, highlight how

> *Teachers are well placed to leverage this playful reality and create opportunities in their classrooms for children and young people to engage in multimodal design (Walsh, 2009, 2010). Through thinking in technologies…children and young people authentically engage in* possibility thinking *or the transformation from 'what is' to 'what might be', as they co-create viable solutions to problems they articulate, that often emerge from their lifeworlds. (Walsh et al., 2017, p. 229)*

The notion of possibility thinking, or playing with possibilities, is a useful one to consider in the context of storytelling and narrative, where pupils co-create (with each other, with the technology, and with the natural world) responses to ideas, questions and inquiry.

In their study, Beaulieu et. al (2015) use narrative to scaffold interaction with two different aspects of ocean systems on digital globes. These narratives (Life without Sunlight and Smoke and Fire Underwater) were created by the researchers and scientists and located through space rather than through time and with non-human entities such as deep sea vents as 'characters'. The narratives were designed to aid understanding rather than be co-created by the learners, but the researchers were aware of "the effect of the untold" (Klassen, 2009 p. 422, cited by Beaulieu et al., 2015, p. 355) which leave gaps of possibility within which learners can participate in the narrative and engage in the construction of meaning. Similarly, Lu and Lui (2015) used an interactive storytelling approach within an AR game to teach primary school students in Taiwan about the 'adventures of a water drop', once again with the teachers telling the story and using storytelling as a device for the communication of information, with pupils constructing meaning through their interaction with the narrative. It is interesting that, whilst these examples involve digital storytelling, they do not employ the use of multimodal digital technology for pupils to tell the stories themselves to creatively play with possibilities in the way digital storytelling is used in other contexts. Thus, the nature of narrative must of itself leave spaces of possibility for pupils' interpretation and creation, but this is, in these examples, much more controlled. Georgiou and Kyza's (2018) use of narrative in their location-based AR study rooted in an inquiry has the capacity for pupils' to move around the narrative in a more self-directed fashion, and incorporates their own generation of a narrative explanation as the culmination of their inquiry, yet the pieces with which they can hear about and re-tell their stories are scaffolded by the teachers and activity designers. This therefore allows perhaps greater 'possibility thinking' that in the previous two examples, though as a creative pedagogy, greater student empowerment and agency to explore possibilities within their own development of a digital story using multimodal means (including AR) would likely enhance the potential for creativity.

Risk, immersion and play

The notion of immersion in the context of digital tools was explicit in two of the studies in this focused review, and can be linked to creative pedagogies by means of the feature 'risk, immersion and play' (see section 5.2). Georgiou and Kyza (2018) describe the level of immersion of students engaged in a location-based AR activity in learning about a lake ecosystem, finding that increased immersion in the activity did not yield additional conceptual learning gains over and above the engagement that they label the lowest level of immersion. In their study of an AR game within an aquarium setting in Spain, Wrzesien and Raya (2010, pp. 184–185) describe how pupils are 'deeply engaged, involved and absorbed', 'seemed quite immersed', and 'screamed with excitement' as they played the game, finding that pupils were more engaged with the game than with traditional instruction, but that there was no significant difference in learning outcome as a result. It should be noted however, that in this context the study of the impact of immersion is limited to knowledge gain, and so no comment can be made about potential broader impacts. However, neither of these studies explicitly focus on creativity so although immersion is a feature of creative pedagogy, we have no way of knowing the extent to which being immersed in these activities could impact on pupils' understanding or learning of creativity in science.

Conclusion

The lack of literature that draws on both creativity and digital technology in the context of education about the ocean highlights the unique focus of the Ocean Connections project. Despite this lack, this focused review in response to RQ4 has shown how the creative pedagogies discussed in section 5.2 may be used as a framework to understand some of the issues and affordances in using creative pedagogies together in this context. The importance of *place* and *felt knowledge* about the ocean and about nature, alongside the notion that technology should enhance but not replace a real experience points to an *embodied material-dialogic interaction* with nature and technology together as a key point of synthesis. With respect to creativity and ocean learning, *empowerment and agency* and *individual, collaborative and communal action for change* are features that were notable, mirroring the findings of the focused review of creative pedagogies in response to RQ3. It is interesting that ethics and trusteeship is not more strongly foregrounded given the conservation/sustainability driver for much environmental education – it is often present in the background but not the focus of the study, so perhaps it is the case that this is largely taken for granted as an aim of environmental education generally and ocean learning in particular. It is also interesting the dialogue has not come through strongly in section 5.3 given that it is much more common in studies of creative pedagogies. It may be the case that the dialogue is taking place but is not the focus of the studies discussing digital technology and so the extent and richness or otherwise of any dialogue goes largely unreported. A final interesting reflection with respect to the features of creative pedagogies is that where multiple disciplines are found in the studies in section 5.3, they are largely interdisciplinary rather than transdisiplinary in nature. As the Ocean Connections project goes forward, careful consideration about the nature of disciplinary interaction within the pilots will be important to consider. Chappell et al. (2019) discuss transdisciplinarity as drawing on disciplinary knowledge, skills and understandings as needed in order to respond to the questions being asked (by young people, in this case). That this was not seen in the studies in this review does not mean the Ocean Connections projects should not use this approach, but it does mean it would be novel in this context.

Key learning from the UK National State of the Art

Ocean Literacy in the Curriculum

- Ocean Literacy is not taught directly in the UK
- Topics in the English national curriculum relate directly to ecosystems, adaptation and variation, and human impact on the environment, but do not specify Ocean-based examples
- Textbooks feature few Ocean-based examples
- The main connections to Ocean Literacy lie with the principles "The Ocean supports a great diversity of life and ecosystems" and "The Ocean and humans are inextricably connected", likely via the use of the Ocean as a context for teaching key concepts.

Current use of AR and VR to support learning in Science and Geography (from UK good practice examples)

- Both used as engagement tools
- Both used to support immersion in learning

Current use of creative pedagogies to support learning in Science and Geography (from good practice examples and international literature)

- Empowerment and Agency is a key feature within good practice in the UK, with children leading their own learning.
- Ethics and trusteeship, dialogue and (nascent) transdisciplinarity also appear, strongly associated with inquiry learning.
- The broader literature view reflects this, with the addition of Individual, collaborative and communal action for change and Arts-based pedagogies within STEAM.
- Empowerment and Agency, Dialogue and Inquiry tended to be connected in the literature, as did Ethics and trusteeship, Risk and Arts-based pedagogies.
- Barriers to creative pedagogies were a lack of collaborative skills or arts skills and the presence of strong barriers between disciplines.

Combining AR/VR and Creative Pedagogies

- Very few examples or studies existed that combined these.
- Positives in using them were the level of immersion and engagement possible
- Barriers to using creative pedagogies were curriculum and time constraints
- Barriers to using AR/VR were financial, concerns over separation from the animals/ocean/live exhibits themselves, difficulty of access if class sizes are large, and concerns that the technology might swiftly become out of date.

Combining Digital Technologies and Creative Pedagogies for teaching Ocean Literacy

- There were very few studies linking creativity or creative pedagogies with Ocean Literacy.
- Where such studies existed, they made strong connections to an emotional connection with the Ocean, identity, and embodied dialogue (CP features of Individual, collaborative and communal action for change, embodied dialogue, ethics and trusteeship and empowerment and agency)
- Few studies linked digital technology with Ocean Literacy education. Affordances of using digital technology for OL education included experiences of nature (where technology supports direct engagement), improving motivation, and scaffolding concepts for school-age children.
- Few studies linked digital technology to creativity in this context; primarily studies explored digital storytelling/narrative and digital games (linked to CP features of possibilities; risk, immersion and play)

The importance of *place* and *felt knowledge* about the ocean and about nature, alongside the notion that technology should enhance but not replace a real experience points to an *embodied material-dialogic interaction* with nature and technology together as a key point of synthesis. As the Ocean Connections project goes forward, careful consideration about the nature of disciplinary interaction within the pilots will be important to consider. Chappell et al. (2019) discuss transdisciplinarity as drawing on disciplinary knowledge, skills and understandings as needed in order to respond to the questions being asked (by young people, in this case). That this was not seen in the studies and examples in this report does not mean the Ocean Connections projects should not use this approach, but it does mean it would be novel in this context.

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