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OCEAN CONNECTIONS

Ocean Connections State-of-the-Art Review
Synthesis and Pedagogical Framework

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1. Introduction

The term Ocean Literacy was first used in a project by the Marine Biology Associate (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 in recent years, assisted in part by awareness raised through documentary features such as the BBC's 'Blue Planet' films (2001, 2017) which showed hard hitting images and narration of the impact of plastics, in particular, on the health of the oceans and the implications for the wider health of the planet. Despite this increased awareness, at the outset of the project the partners identified that the term Ocean Literacy is not typically made explicit within school curricula, and the use of marine examples to teach scientific concepts such as adaptation, ecology and diversity are less common than terrestrial ones meaning that it has a limited implicit presence, also. It was therefore important to identify the current position regarding Ocean Literacy in education in the partner countries in this review.

In planning for education for Ocean Literacy in the future, the Ocean Connections project takes inspiration from two 'future oriented' strands within education: creativity and creative pedagogies, and the use of digital technologies, particularly Virtual and Augmented Reality, in education. Creativity is important because of its interdisciplinary scope in taking transdisciplinary approaches to addressing 'wicked' problems such as those issues of sustainability currently facing our planet in general and our ocean in particular. Ocean Literacy within Ocean Connections involves not only understanding what is known about the Ocean and its interconnectedness and importance for life on Earth, but also involves exploring, questioning and taking an ethical, responsible stance to the future of the Ocean as an emergent educational aim. Creative pedagogies situate creativity at the nexus of teaching and learning, encouraging creative teaching and teaching for creativity. Not the sole province of the Arts, creativity is found in all disciplines, including science, and in the way they interact.

Our interest in drawing on digital technologies to support this learning stems from the fact that, despite programmes such as the Blue Planet, the Ocean often remains intangible to young people. Many young people who live inland have never visited the Ocean, and even for those who have been to the Coast, the deep Ocean is distant and difficult to apprehend. Ocean Connections rests on the initial premise that relatively recent emerging technologies such as VR and AR have the potential to enable young people to interact with and experience the Ocean differently, fostering deeper understanding and new connections with it. The research reported here aimed to scope out and test these premises on which the Ocean Connections project rests, developing a set of educative principles and pedagogic framework for the intervention and pilot testing phase of the project.

The main objective of this State-of-the-Art synthesis report is to document current and emerging educational trends, innovative/excellent practice, and research in the field in relation to the objectives of the Ocean Connections project: to develop creative, digital approaches (AR/VR) to teaching/learning ocean literacy in schools and aquaria. Partners in the three European countries participating in this project, (Denmark, Spain and England[1]) undertook a detailed examination of the curriculum and practices in their own national context, and review of international literature with respect to one of the project's core themes. This synthesis report introduces the guiding research questions and summarises the methodology used, before comparing the curricula and practices in the relevant settings. Next, a summary of the focused international literature review is offered. Finally, a set of educative principles and associated pedagogical framework for teaching Ocean Literacy through creative and digital pedagogies is developed, which underpins the implementation phase of the Ocean Connections project. This synthesis report is of necessity much condensed and we refer the reader to the associated national reports for full details of the findings that underpin this synthesis and recommendations.

1.1 Research questions

RQ1 How and where is ocean literacy taught in science and geography in Denmark, Spain and England?
RQ2 What innovative technologies and applications using AR/VR are used to support learning in science in these countries and in the international literature?
RQ3 What innovative creative pedagogies are used to support learning in science in these countries and in the international literature?
RQ4 How are these technologies/pedagogies used to support students' ocean literacy in these countries and in the international literature?
  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

A 'state of the art' review allows for wide, comprehensive searching of current knowledge and priorities for future initiatives/investigation/research without need of a formal assessment of quality "to address more current matters in contrast to the combined retrospective and current approaches of the literature review" (Grant, Booth and Centre, 2009, p. 101). This review combines such an approach to the state of the art with a focused literature review into the international literature.

2.1 State-of-the Art in Curriculum and Practice: Methodology

Partners used desk research to explore national and regional curriculum documentation in Science and Geography for pupils between the ages of 7 and 14 in each partner country. They also used information from national associations and learned societies (e.g. the Association for Science Education in the UK), and commonly used text books, to explore the nature of the curriculum with respect to Ocean Literacy. To identify examples of excellent practices, partners conducted web searches, site visits and interviews with practitioners to identify positive experiences in current practices and barriers to using creative pedagogies and digital technologies in both schools and informal learning environments.

[1] For the purposes of this report, we focus on England as a devolved Educational context within the United Kingdom.

Table 1: State of the Art Data Sources

Data Type	Examples	Sample
Teacher interviews		8 (UK);
Non-teacher interviews	Seadream Education, UK; National Marine Aquarium of Wales Outreach Lead	4 (UK);
Site visits	National Marine Aquarium	1 (UK)
Desk research	Bournemouth Oceanarium; SeaLife Centres	6 informal learning sites (UK);

2.2 Focused Literature Review: Methodology

Each partner undertook a focused literature review regarding an aspect of the three core strands of the project, and a synthesis of the different elements. Search terms for each search are documented in the relevant national reports. Search terms were used in the following databases: British Education Index (BEI), Education Research Complete (ERC), ERIC, JSTOR, Web of Science and IBSS. Where relevant, experts were consulted if initial searches revealed a limited number of relevant articles in any given field (e.g. in creative pedagogies in Geography education, see UK national report). Reference lists of a number of highly relevant papers in each field were also searched. Papers were identified for inclusion using a grading process, with records kept regarding the number of papers identified for grading in the initial screening for each focus area, and the number of studies included in the final review. Initial screening via reading abstracts to identify relevance was followed by grading of papers 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. The 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: NA, M; NA, H; M, M, M, H; H, M; H, H.

3. Curriculum and Pedagogy Comparison

In this section, we synthesise our national reviews of curriculum and pedagogy in relation to the three core strands of the Ocean Connections project: Ocean Literacy, Creative Pedagogies and Digital Technology. With respect to each strand, we compare and contrast the framing of the school curriculum, associated common resources and examples of excellent practice, including out-of-school learning practices.

3.1 Ocean Literacy in the Curriculum

Ocean Literacy was not a well known term amongst teachers in any of the partner countries. However, when it was explained, teachers were able to give examples of how they might draw on these principles in their teaching of central concepts in the Science and Geography curricula.

The curricula related to Science and Geography are rather different in each national context in terms of their focus on, and sequencing of, knowledge and skills. However, in common is a lack of specific mention of the Ocean within the key concepts introduced. Rather, aspects of the Ocean can be used as examples in relation to central concepts should the teachers choose. The use of models and modelling is much more foregrounded in the Danish curriculum than in that of England and Spain. In Spain, the focus on local ecosystems as examples for teaching and learning comes to the fore. In England, content knowledge is the main focus of the national curriculum.

Table 2: Ocean Literacy in formal Curricula

Age range	Ocean Learning Explicit or Implicit?	Curriculum topics in Science and Geography related to Ocean Literacy		
		England	Denmark	Spain
7-11	Explicit	None	None	None
	Implicit	human impact on the environment (both positive and negative); environmental change	Influence of humans on nature; water cycle; interaction of organisms; food chains and webs	The focus is on learning skills and knowledge in science, observing, caring, identifying and studying living creatures in a local environment, which could be marine to explore life cycles and human impact on the environment
11-14	Explicit		No explicit reference to ocean literacy. Weather and Climate; Ocean currents in physics/chemistry	No explicit reference to ocean literacy. Aquatic ecosystems
	Implicit	dependence of life on photosynthetic organisms; ecosystems; adaptation and extinction; biodiversity	Ecosystems, Evolution, carbon cycle, global warming, greenhouse effect, Milankovitch cycles, acid rain, water cycle, interaction between humans and nature including production technologies, earth systems, weather and climate	Biodiversity, environmental responsibility. Ecosystems.

In published teaching materials and examples of standard teaching approaches found in our desk research and teacher interviews, it is apparent that there are some common examples that many teachers have access to and use that do relate to the ocean, even if not explicitly linked to the seven Ocean literacy principles. For age 7-11 pupils, these tend to focus on the relationship between humans and the Ocean, whereas for 11-14 year olds, the focus is more on examples linked to ecosystems/ecology, weather and climate. It is interesting that despite the differences in national curriculum approach, similar kinds of examples are found, often coastal ecosystems and probably related to ease of access and the accessibility of understanding direct human impact on the Ocean.

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Table 3: Ocean Literacy in Published Teaching Materials

Age range	Ocean Learning Explicit or Implicit?	Ocean Literacy in published teaching materials		
		England	Denmark	Spain
7-11	Explicit	Rocky shore ecology	Natural Science and Technology materials usually have a chapter about the Ocean, for example focusing on the relation between humans and nature in the context of coral reefs.	Not explicitly included. Some marine examples
	Implicit	Habitats, adaptation and variation	Range of examples linked to wider concepts	
11-14	Explicit	Rocky shore ecology is a common piece of field work; ocean currents and climate	Biology materials all have a chapter concerning the Sea, linked to the Ocean as an ecosystem	
	Implicit		Range of examples linked to wider concepts in the curriculum	Ocean examples linked to wider concepts in the curriculum

3.2 Creativity in Curricula and Pedagogies

In the three partner countries, creativity was not found to be a central element in the curriculum, but did appear in a range of practices reported through our interviews with teachers and others.

In Denmark, the tradition for 'methodological freedom' leaves diverse practices with respect to teaching methods and pedagogical strategies, as reflected in, for example, the use of problem-based learning cycles in Science and the notion of using 'design' processes and model making (see Danish National Report). In Spain, creative and innovative pedagogies are similarly found in examples of innovative practice rather than fully bedded into the curriculum. For example, the Climatica project drew on the notion of learners as creators with technology in a project learning about climate change. In England, all teachers interviewed were able to point to specific examples of creative pedagogies being used to teach science (See English National Report), with a key point being the provision of opportunities for pupils to lead their own learning as a key aspect of creativity, but creativity is, again, not an explicit goal in the framing of the English national curriculum.

It seems that creativity, though not explicit as a curriculum goal, can be found in excellent practices in all partner countries, with many ‘features’ of creative pedagogies (see Section 4.2) apparent in examples drawn from teacher interviews and online materials.

3.3 Digital Technologies (VR/AR) in Curricula and Pedagogies

The curricula in all three countries specify that pupils should learn to use digital technologies, and broadly, use is made of a range of technologies including tablets and apps. However, there was differential uptake in the use of digital technologies such as VR/AR in the three partner countries and it’s use was less common. In England, in stark contrast with the wealth of examples provided related to 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 rather than in schools. Teachers recognised the power in some examples of using AR/VR to visualise things that are often difficult to see, and to engage students with an immersive experience, but felt that there were limitations and barriers to delivery with large classes of children due to a lack of equipment, training and quality wifi access. In Spain, examples suggest that AR/VR has been implemented in schools connected to the project partners with great success, though the breadth of uptake more widely may be more limited. In Denmark, like Spain, some excellent practices with AR/VR were identified, using innovative games that combine AR/VR technology with approaches that enable pupils to be creative in creating and playing games related to scientific content on AR/VR platforms. Some concerns were raised, by teachers and aquarium educators interviews, that there is a risk of the technology replacing the experience of an aquarium visit or field trip to the ocean, rather than augmenting such an experience.

3.4 Summary and interim conclusions

In exploring the curriculum, teaching materials, interviews with teachers and some examples of best practice, it is clear that whilst there are some differences in terms of emphasis and experience in the three partner countries, the following general conclusions can be drawn:

- Ocean literacy tends to be promoted implicitly within curricula, related to specific topics in science and geography within the curriculum
- Creativity is not explicit within the curriculum, but is found in teachers’ and aquarium educators’ pedagogies, most commonly where pupils are empowered to be creative with respect to a specific content-focused activity. This includes creativity with technologies such a AR/VR.
- Digital technologies are widespread but the use of AR/VR is not. Whilst excellent examples of the use of AR/VR technologies in learning, and learning creatively within science were found, barriers to the use of such technology are significant, including both time, access to hardware, sufficiently powerful wifi capability, and training.
- Examples were not found of practices which combined all three Ocean Connection strands.

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. Teaching ocean literacy provides opportunities for practitioners to be creative and approach the curriculum from a broad, topical perspective.

4. Review of the Literature

As in the previous section, the following explores findings of our literature review in each core strand of the project, with a final summary of a literature search exploring any previous work connecting these distinct strands.

4.1 Ocean Literacy

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.

4.2 Creative Pedagogies

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.

4.3 Digital Technologies (VR/AR)

A search in ERIC and Teacher reference center database (Annex 5.4 International Literature Review DKD)revealed a number of resent international literature reviews focusing on VR (Jensen & Konradsen, 2018; Kavanagh, Luxton-Reilly, Wuensche, & Plimmer, 2017) and AR (Bacca, J., Baldiris, S., Fabregat, R., Graf, S., 2014; Drljevic, Wong, & Boticki, 2017; Koutromanos, Sofos, & Avraamidou, 2015; Ozdemir, Sahin, Arcagok, & Demir, 2018; Radu, 2014; Saltan & Arslan, 2017; Wu, Lee, Chang, & Liang, 2013) in education that we can rely on in our state-of-the-art.

One review points to that the examples of VR in education is currently largely skewed towards those for simulations and training purposes (Jensen & Konradsen, 2018). Increased immersion and user-motivation were the most commonly reported motivations identified in the review. However, the most commonly provided justification for increased user-motivation was that authors believed simply utilizing these technologies in education would be enough to motivate students. By far the most frequently reported issue identified in the review was that of software usability. Users reported a multitude of issues, including counter-intuitive interfaces, confusing objectives, and that they would even get lost in the virtual environments, lack of realism provided by the educational VR implementations.

A study by Parong & Mayer (2018) suggest that immersive VR significantly increase student motivation, interest, engagement, and affect, but does not improve students learning of basic scientific knowledge. However, the effectiveness of VR can be increased by prompting students to use generative learning strategies, such as summaries, without diminishing the learner's motivation, interest, engagement, and affect while using immersive VR. Another study (Makransky & Lilleholt, 2018) suggest that immersive VR has significant potential for use in lab simulations like "Labster". To improve learners' satisfaction and perceived learning outcomes the study implies to design VR environments that are enjoyable and motivating by creating a high level of usability and good VR features, which give students a sense of presence. The second is to ensure that students have a high level of autonomy through a sense of control and active learning, and to make sure that students see the cognitive benefits of the VR lesson. Embodied Mixed Reality Learning Environment (EMRELE) was found to lead to greater learning gains by Johnson-Glenberg et.al. (2014).
In a review by Radu (2014) benefits such as increased content understanding and student motivation when using AR was found, while challenges were about usability difficulties and ineffective classroom integration. Among the factors influencing student learning is in particular highlighted that the content can

be represented in multiple ways, i.e., as sound, visualization and animation facilitating students' ability to experience phenomena that are otherwise impossible or infeasible, e.g., due to spatial scales. Wu et al. (2013) point to the following affordances: learning content in 3D perspective, ubiquitous, collaborative and situated learning, learners' sense of presence, immediacy, and immersion, visualizing the invisible and bridging formal and informal learning.

A study by Hsiao & Wang (Hsiao, Chang, Lin, & Wang, 2016) study show that key characteristics of the "manipulative" AR, such as the simultaneity of virtual and real objects, high interactivity, and hands-on experience, made a greater positive impact on the students' academic achievement and motivation.

The results of the literature review on use of AR games in education (Koutromanos et al., 2015) found only a limited number of augmented reality games, however the majority focused on science. The study concluded that the AR games showed a positive effect both on the participation and involvement of students in learning and on learning outcomes.

An interesting study by Chen & Wang (2018) uses a game-type AR to construct a mixed-reality environment that facilitates conceptual learning among 5th and 6th graders. The study reports discrepancies in presence and perception among learners and evidence of a relationship between presence and learning achievement in AR-mediated learning environments. Low presence in an AR-mediated learning environment is correlated with low learning achievement. The study suggests that enhancing interactive experience could increase learner presence in an AR-mediated learning environment, consequently improving learning outcomes, especially among low-presence learners. Laine et.al. (2016) reports on a proof-of-concept storytelling learning games for science using AR and context-awareness. Student appreciated the game's features and its storytelling approach, implying there is a benefit to embedding pedagogical problems in a digital narrative that supports social collaboration and immediate feedback. On study (Atwood-Blaine & Huffman, 2017) indicate that male and female students achieved and perceived AR-gameplay at a science centre differently. Interestingly, females outperformed males on every measure of game achievement.

There are some other studies focusing on AR in informal learning. A study by Yoon et.al. (2018) took place in a science museum in the US for students grades 5 through 8 focusing on AR as one of several tools for scaffolding. The greatest affordance of the AR-scaffold was found to be the ability to access hidden information. The most helpful aspect of the text-based scaffolds was in their ability to provide instructions on what was expected. Finally, for the collaborative scaffolds, the most useful aspect was the ability to receive feed- back on one's own understanding. It was not one genre of scaffold, but all three scaffolds working together that pushed the group to learn more. Another study by Tscholl & Lindgren (TSCHOLL & LINDGREN, 2016) showed that mixed-reality environments at science centres appear to support significant social interaction, while still offering children playful and engaging experiences.

A developmental study also highlighting the affordances of AR-scaffolding is an inquiry-based middle school curriculum on ecosystem science that invites students into immersive experimentation (Dede, Grotzer, Kamarainen, & Metcalf, 2017). The AR-scaffolding tools supports deeper learning This includes a case-based approach situated in an unfolding eutrophication scenario in which students makes observations over space and time, "speaking" with virtual characters and gather information in the field guide. Multiple varied forms of representation convey perceptual, graphical, and experimental data, enabling students to investigate relationships between variables.

4.4 Intersections of Ocean Literacy, Creativity and Digital Technology in Education

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.

4.4 Socio-Scientific Issues

In conducting their reviews of the literature in Danish and Scandinavian journals (see Danish national report), it became apparent that research conducted into socio-scientific issues in science education had relevance for this project, and so a search was conducted exploring the intersection of research into ocean literacy, science and socio-scientific issues. It should be noted that no literature was found in searching the combination of ICT and SSI. A narrative synthesis of this review showed that some key ideas drawn from this literature have relevance to the project. Based on initial searches and team discussion, it was suggested that it might be a better approach in the international project group to work on developing a pedagogical model conceptualizing Ocean Literacy *in a specific way* and *with a specific rationale*. The rationale could e.g. be: *If* we conceptualize Ocean Literacy referring to a multidimensional understanding of Scientific Literacy (more below) and with arguments for teaching science in schools referring to *social* relevance (Holbrook & Rannikmae, 2009), *then* there are good arguments for the pedagogical principles of 1) technology-supported, 2) inquiry-based, and 3) data-driven science teaching, using 4) real-time data if possible, and with 5) communication between school students and external stakeholders: the public in general and/or scientists in the field. For more details of the route towards the recommended inclusion of SSI principles within the pedagogical framework for the project, see the Danish national report.

4.5 Summary and interim conclusions

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 has shown how the creative pedagogies discussed in section 4.2 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 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 literature, 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.

It is clear that the notion of students needing to build a 'relationship with the ocean' is also connected to the importance of citizenship found in research into socio-scientific issues in science education, and to the concept of ethics and trusteeship within creativity.

5. Educative Principles and Pedagogical Framework

Following the synthesis of findings across the UK, Denmark and Spain regarding the curriculum, excellent practices and the national and international literature, in this section we offer a set of educative principles for using creative pedagogies and digital technologies to support the teaching of Ocean Literacy. These principles are then used to develop a Pedagogical Framework to inform the design and teaching of Ocean Literacy in Aquaria and Schools using a combination of creative and digital pedagogies.

Educative Principles for the Project:

With respect to Ocean Literacy, the key Ocean Literacy principles that connect to the curriculum in all three partner countries are **Humans and the Ocean are inextricably linked**, the **Ocean supports a great diversity of life and ecosystems**, **there is One Big Ocean,** and **the Ocean is a major influence on weather and climate**. These principles with respect to the Ocean therefore provide the substantive educational focus for the project and may be used by teachers to identify the scope and sequence for the learning, drawing on the work of the Ocean Literacy Network (2015).

Principle 1: The content sequence of the learning about Ocean Literacy in the Ocean Connections project will connect to one or more of the following principles of Ocean Literacy, as appropriate for the age of the pupils and their prior learning:

- Humans and the Ocean are inextricably linked
- The Ocean supports a great diversity of life and ecosystems
- There is one big Ocean
- The Ocean is a major influence on weather and climate

With respect to creative pedagogies, our review suggests that some key principles relating the Ocean to creative pedagogies are to do with the importance of *place* and *felt knowledge* which, in combination with the notion that technology should enhance and not replace a real experience (see section 4.3 and below), suggests that an *embodied material-dialogic interaction* with nature and technology is a key point of connection with creative pedagogies. Linked to this, the concept of an affective and emotional connection to the ocean that can be found in synergy with an affective response can be supported with creative pedagogies. Similarly, the *empowerment and agency, risk, immersion and play* and *individual, collaborative and communal action for change* were particularly notable features of creative pedagogies that should therefore form part of our key educative principles. Working creatively across disciplines, in inter- and transdisciplinary ways is another key idea drawn from the literature on creative pedagogies that will be important in teaching ocean literacy with respect to environmental sustainability.

Principle 2: Teaching and learning with respect to Ocean Literacy in the Ocean Connections project will aim to bridge disciplinary boundaries by enabling pupils to use knowledge, ideas and processes from different disciplines in order to ask and answer their own questions.

Principle 3: Teaching and learning with respect to Ocean Literacy in the Ocean Connections project will draw on key features of creative pedagogies, such as playful and immersive experiences, to connect pupils with the ocean both intellectually and affectively. They will promote embodied and material dialogic interaction with the Ocean, nature and technology, and aim to empower pupils to work individually and collaboratively.

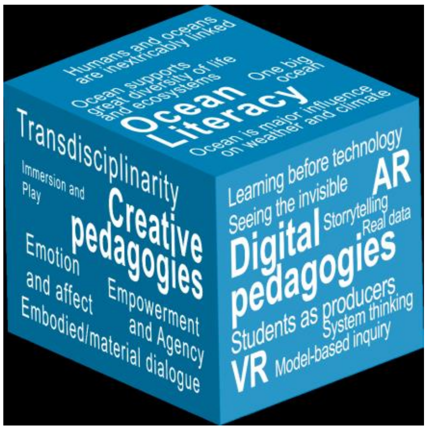
Based on practitioner reports and research about ocean literacy and digital technologies, the following educative principles stand out as key to the Ocean Connections project.

Principle 4: Digital technologies should be used to support model-based inquiry and data-driven learning as part of the ocean connections projects, using real-time data where possible. Pupils should have opportunity to design their own models and use them to explore their thinking.

Principle 5: Virtual and/or augmented reality technologies should be used to support pupil learning, enabling them to visualise otherwise difficult to access phenomena and processes, including systems approaches to critical concepts with respect to ocean learning.

Principle 6: Technologies can be used to support communication with external stakeholders such as scientists and the public, enabling pupils to learn about the ocean within a wider community context linked to the creative pedagogy feature individual, collaborative and communal action for change.

These six principles were developed into a ‘cube’ visualisation of the connection between them for use in the project as a pedagogical framework to guide planning and teaching of the Ocean Connections projects.



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