Review of marine formal education

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1. Introduction

The goal of the Sea Change project is to bring about a fundamental "Sea Change" in the way European citizens view their relationship with the sea, by empowering them – as 'Ocean Literate' citizens - to take direct and sustainable action towards healthy seas and ocean, healthy communities and ultimately - a healthy planet.

Ocean literacy can also be seen as a way of incorporating scientific literacy in practice in education, whereby scientific literacy not only refers to a person's knowledge of science but also to his or her ability to use this knowledge in making socially responsible decisions (Lambert, 2005). But Fletcher *et al*. (2009) suggest that concepts of responsibility towards the marine environment and marine citizenship are far from being fully developed.

1.1 Purpose

This literature review is set in the context of two main project objectives, i) to review the links that are established between Seas and Ocean and human health and ii) to help design and implement successful mobilisation activities focused on education, community, governance actors and directly targeted at citizens.

The purpose of the literature review is to consider the extent of marine education research and its findings. The results of the review will inform WP3 by providing the basis for introducing initiatives and testing case studies. WP3 intends to **identify best practice**, develop **new resources** and **pilot new methods** with a view to implementing transfer / dissemination activities.

1.2 Ocean Literacy

Based on the Ocean Literacy Framework, Ocean Literacy is defined as:

> "an understanding of the ocean's influence on you, and your influence on the ocean," (http://oceanliteracy.wp2.coexploration.org/ocean-literacy-framework/).

Ocean Literacy is a relatively new term, elaborated in a framework of the Essential Principles and Fundamental Concepts (OLEPFC) of Ocean Sciences (Schoedinger *et al.*, 2010). There are seven Essential Principles, which cover 45 Fundamental Concepts. These represent the major ideas that high school graduates should know and understand about the ocean and its significance in the earth system (Plankis and Marrero, 2010) and were aligned with the US National Science Education Standards. They were published in Strang and Tran (2010) and are available at http://oceanliteracy.wp2.coexploration.org/

Table 1. The essential principles of ocean literacy

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 inextricable interconnected
7. The ocean is largely unexplored

Definition of an Ocean Literate person, as adapted from Cava *et al.* (2005):

- Understands the importance of the ocean to humankind

- Can communicate about the ocean in a meaningful way
- Is able to make informed and responsible decisions regarding the ocean and its resources

In using this definition, the Sea Change Project aims to go beyond a simple reproduction of knowledge *about* the ocean, and instead trigger the ability to make informed and responsible decisions of ocean issues. This implies moving European citizens closer to an accountable position of acting responsibly and in protection of marine resources. An ocean-literate citizen a) translates ocean knowledge into action; b) is capable of communicating about the interdependencies between humans and the ocean in a meaningful way and c) can make informed and responsible decisions.

Ocean Literacy (OL) in this sense presupposes not only that the public is knowledgeable but also will be concerned about marine issues and develop responsible behaviour towards the seas and ocean and their resources. Developing ocean education is therefore a logical step to develop a more ocean-literate public and enhance marine citizenship, as participation in environmental education has been identified as the most important predictor of environmental behaviour (Hawthorne and Alabaster, 1999).

Education in its broader understanding (i.e. in both formal and informal settings) serves as a high potential channel to reach young citizens. As a lack of sufficient ‘ocean literacy’ has been identified in many countries (Guest *et al*., 2015), this clearly presents a barrier for citizens to engage in environmentally responsible behaviour or consider ocean-related careers. To overcome this, Beierle (1998) recommends developing education to provide the capacity to understand environmental issues, to participate in decision-making processes and to bring about changes in behaviour.

In secondary schools, ocean and aquatic concepts are infrequently taught and they rarely appear in secondary school curricula, materials, textbooks, assessments or standards (Hoffman and Barstow 2007; Castle *et al*., 2010; Boaventura *et al*., 2013). Additionally, educational research has paid little attention to teaching and learning of ocean and aquatic science concepts in contrast to other areas of science such as chemistry, physics, and biology. The absence of ocean and aquatic science in science education points to the need for developing ocean literacy also among adults (Ocean Project, 2009).

In general in North America and in Europe, there has been no statutory requirement to cover ocean topics in formal education. In countries like Canada, US and UK this has been the subject of criticism (Guest *et al*., 2015). Despite this, specific educational programs about the ocean have been developed (Ramirez-Llodra *et al*., 2010; Steel *et al*., 2005). Their use has been reported in the literature but any findings regarding their significance are generally neglected and as a result their impact is misunderstood. Payne and Zimmerman (2010) comment on the importance of establishing ocean and aquatic issues in national and state frameworks and standards, as these drive the curriculum, instruction and assessment.

A greater understanding of the marine environment is likely to prompt citizens to feel a responsibility to act as stewards of the ocean (McKinley and Fletcher, 2010). Knowledge, personal values and attitudes towards environmental issues are preconditions for action (Jensen, 2002) and an integral part of marine and environmental citizenship (Berkowitz *et al*., 2005).

1.3 Prospects

In the early 1970’s, Awkerman *et al*. (1974) predicted that as the seas are explored and utilised, further emphasis on the ocean in high school study would be expected. Their forecast, that the study of ocean science would become a part of many secondary science programs, has not yet materialised.

According to Castle *et al*. (2010), there has been limited research concerning public understanding of the marine environment and that the evidence that has been gathered conveys mixed messages. This is surprising, given that the oceans cover approximately 70% of the earth's surface, ocean literacy and marine education should be a significant component of school studies (Lu and Liu, 2015).

Unfortunately, it appears that ocean science topics are typically minimized or ignored in the secondary school classroom and there is a scarcity of peer-reviewed research on secondary school students' ocean literacy*,* very limited research published utilizing the Ocean Literacy Essential Principles and Fundamental Concepts (Plankis and Marrero, 2010) or related to teacher education and training (Payne and Zimmerman, 2010).

2. Methodology

2.1 Search strategy – article selection, eligibility criteria

Web of Science, EBSCO (Education Research Complete, ERIC, GreenFile, MEDLINE,) Scopus, ResearchGate, Academia.edu and Google Scholar were searched using the following keywords: ocean science, ocean*, marine science, marine*, science education, ocean literacy, environmental education, education*, ocean pedagogy, best practices. The timespan of the search strategy included all years and did not contain any language restrictions.

This initial search strategy produced a total of 171 articles. The authors of this review examined them and jointly decided which articles fulfilled the five criteria previously agreed upon:

a. Research grounded paper
b. Peer-reviewed
c. Classroom practice (formal education)
d. Addressing ocean science topic
e. Secondary education

This search strategy initially yielded 31 articles relevant to these criteria. The authors of this publication independently reviewed their respective articles and compiled summaries, which were used as the basis for this review. Additional sources and citations were added to the reference list, obtained through the articles reviewed and the main issues that resulted. Once the summaries had been evaluated, the publication search was repeated and five new articles, mostly published in 2015 were added to the list. As a result, in total, 35 articles were included in this literature review.

2.2 Analysis of the review

The authors all followed the same procedure in analysing the articles. For each summary of an article, the reviewers aimed at including the following:

- content related to ocean literacy
- (new) methodology presented
- research strategy with results and discussions,
- test case (if present)
- if interesting: graphs and tables.

All reviews were collected and aggregated into four parts, which formed the structure of this review:

- extend of the research
- ocean literary content
- ocean literacy outcomes
- recommendations

3. Extent of Research

3.1 Type of literature

There is only a relatively small body of literature regarding the teaching and learning of ocean and aquatic science topics at secondary (high) school level. Extensive searches yielded a total of 35 peer-reviewed academic papers, which were published between 1974 and 2015. The literature revealed work from around the world, on many different aspects and themes, a wide array of research approaches were adopted and promising but largely unfulfilled ideas, which had not been widely implemented. There were no significant meta or review studies.

Most publications were based on research in US education contexts (19). Relatively few were from Asia or Europe (Table 2). Most school studies were carried out in places close to the ocean, for example by Castle *et al*. (2010) whose research focused on schools in Dorset in SW England, of high schools in Florida (Lambert, 2001), a school in British Columbia, Canada (Cummins and Snively, 2000) and students in Nova Scotia (Guest *et al*., 2015).

Table 2. Research contexts of reviewed papers

Place of study	Number of articles
US	19
Europe	5 (England, Greece, Portugal, UK (2))
Asia	4 (Taiwan, Japan, Pacific Rim, Philippines)
Canada	4
no specific location	3

3.2 Scientific approaches used

Some researchers used an earth systems approach. Payne and Zimmerman (2010) suggested ocean science should be embedded within earth system science, so that they can be better represented in high schools. Orion (2002) introduced a practical model for using an earth systems approach as a framework for the science curricula. This emphasised the study of geochemical and biogeochemical cycles and the interrelations among the different subsystems in terms of transitions of matter and energy from one subsystem to another. Ashraf and Orion (2005) advocated for effective system thinking. They stated that the main goal of the schools' science education should be to provide students with the skills needed to translate the complexity of environmental problems and achieved through an earth systems approach. This is because it requires good scientific reasoning skills and the ability to use a wide range of qualitative and quantitative data. The authors argued that these abilities are attributed to higher-order thinking abilities. Orion (2007) claimed that understanding each of the earth's subsystems, and the environment as a whole was indispensable for people to coexist peacefully with the environment.

The analysis and use of literacy in the reviewed papers took several forms.

> "Scientific literacy is commonly portrayed as the ability to make informed decisions on science- and technology-based issues and is linked to deep understandings of scientific concepts, the processes of scientific inquiry, and the nature of science." (Bell, Blair, Crawford, and Lederman, 2003: 248)

The scientific literacy of students was examined by Lambert (2001) as they participated in naturally integrated marine science courses. Marine science was commonly cited as the main subject area, for example Healy (2005) explored the implementation of a marine science curriculum and Lu and Liu (2015) reported on the design of an innovative simulated environment for marine learning to introduce Taiwan's marine ecology and water resources. Gebbels *et al*. (2010) sought to evaluate the effectiveness of a cross-curricular science program taught to a group of pupils aged 11 to 12.

Boaventura *et al*. (2013) examined children's conceptual understandings of science and analysed the promotion of scientific literacy. Lambert (2006) sought to make a strong connection between marine science and scientific literacy. Research by Adams and Matsumoto (2011) was based on ecological literacy (after Powers, 2010), as providing a higher level of understanding and appreciation for aquatic ecosystems. Castle *et al*. (2010) examined the extent to which marine and coastal topics were taught in English schools and Dimopoulos *et al*. (2009) used environmental education in planning marine educational activities and teaching strategies.

Marine education was generally considered to be complex for teachers to deal with because of its integrated nature. Awkerman *et al*. (1974) said the complexity of the vast realm of ocean science prohibits teachers from covering all significant ocean science topics within the available class time.

> "Most problems do not fit into neat disciplinary niches; with teams of interdisciplinary workers as the norm, and with the most effective investigators, as those who are able to combine the insights and techniques of two or more disciplines" (Gardner, 1999: 219).

Several researchers dealt directly with ocean literacy. Plankis and Marrero (2010) tested the construct of ocean literacy within the context of an ocean education program. The study analysed the role of content knowledge specifically conceptual understanding and attitudes about the ocean as mediating factors contributing to ocean literacy. Cudaback (2006) suggests that given the declining quality of the marine environment, ocean educators have the responsibility to teach not only the science of the ocean, but also the interdependence between humans and the ocean. Cummins and Snively (2000) examined student attitudes towards the seashore and ocean and their stance towards specific issues. Guest *et al*. (2015) developed a survey aligned with Ocean Literacy principles to assess the degree the ocean is valued by students.

3.3 Topics and classroom resources covered

Some of the literature dealt with specific topics related to ocean and marine sciences, such as ocean acidification (Fauville *et al*., 2011; 2013; Gorospe *et al*., 2013), marine mammals (Fortner, 1985), coral reefs (Stepath, 2006) and mangrove depletion (Luther *et al*., 2013).

Several of the articles evaluated different types of learning (curriculum) programmes and teaching resources and their use with students. There is an increasing abundance of digital data about the ocean available online. DiCerbo *et al*. (2014) explored its potential and likely future impact on ocean education. Adams and Matsumoto (2011) discussed the advantages of using real-time authentic aquatic data in the classroom from monitoring to students collecting their own data. Healy (2005) assessed the data and materials developed as part of the Exploring Marine Science with GIS (Geographic Information Systems) curriculum, which was written and developed to support teachers and students at the secondary level. The authors suggested there was a need to provide quality resources to educators at different levels supporting ocean science. Stepath (2006) surveyed and interviewed students from five schools while they were trained in coral reef ecology in the classroom and in the field.

Lu and Liu (2015) evaluated a simulated, game-based environment for marine learning among children, which integrated augmented reality (AR) technology. AR allows users to see and experience virtual reality content and layers of information in a computer-generated environment (Zhou *et al*., 2008). In this instance, the format was based on interactive storytelling with 3D visual images and game-based tests to assess the childrens' engagement.

Foley *et al*. (2013) described a series of portable, hands-on science kits on selected topics. These "labs in a box" were designed to supplement curriculum or be used as a teaching unit. No prior content knowledge or specialized training was required to use these kits. They could be borrowed at no cost from libraries, while paper and electronic materials were made available for open access and use online.

Greely (2008) examined the impact of an outdoor education program to determine if the learning experience resulted in improvements in ocean literacy. The goal was to produce empirical evidence that connected field studies with improvements in scientific literacy, especially related to reasoning and socio-scientific issues (Marrero and Mensah, 2011).

Lambert (2005) looked at assessment outcomes from programmes where textbooks remained the leading source of resource materials for teachers. As part of several outreach and education programs, Gorospe *et al*. (2013) analysed an enquiry-based instructional model and lesson about ocean acidification.

More innovative teaching resources were also discussed, for example Fauville *et al*. (2013) presented hands on kits, computer-supported experiments and students as knowledge creators through the analysis of scientific data used to support teaching about ocean acidification in school. Fauville *et al*. (2011) described in detail an open access virtual animation and laboratory developed as an educational tool to address ocean acidification in high school. Bishop and Walters (2007) reviewed the impact of a national high school science competition and Fortner (1985) the relative effectiveness of documentary film as media and approaches for learning and raising awareness of ocean issues. Gunckel (2015) focused on linguistic issues, examining strategies and effective STEM-integrated practices for teachers to use effective scientific language in the classroom.

3.4 Research approaches and target groups

Within the literature, a vast array of research approaches and methodologies were used to investigate ocean and marine science studies in schools. Students, teachers, professionals and researchers were investigated using qualitative, quantitative and mixed-methods approaches. These varied from an ethnographic logic-of-enquiry, which was used to examine the ways in which cultural practices of science were constructed through interaction by the class members (Crawford *et al*., 2000), to qualitative case studies of a number of secondary schools (Castle *et al*., 2010). Lambert (2006) undertook a descriptive analysis of curricula, this was followed by pre and post-tests administered to students at the beginning and end of the marine science course in order to evaluate 1) their knowledge of general science concepts, (2) self-perception of their understanding of issues and (3) self-perceptions on marine issues.

Plankis and Marrero (2010) described a collective case study approach used to examine the degree of ocean literacy achieved by two classrooms of students. A constructivist theoretical framework was used to examine student learning, with the view that they learn mostly from experiences. The two teachers were interviewed and students completed questionnaires about their experiences engaged in a NOAA-sponsored ocean literacy-focused program called Signals of Spring – ACES (http://signalsofspring.net/aces/about.cfm) and how students perceived the ocean affecting their lives.

Castle *et al*. (2010) examined the teaching of coastal and marine education in schools. They used a mixed methods approach by i) reviewing the National Curriculum (by a keyword search) to identifying coastal and marine content; ii) a survey of teachers identifying the extent to which coastal and marine topics were taught in their schools; and iii) a series of face-to-face interviews with teachers exploring the barriers and school-specific influences affecting the teaching of these topics.

To identify the impact of a marine training course, contrast group as well as 'before and after' curricula interventions were organised by Stepath (2006), who used both quantitative and qualitative approaches to data gathering, with a questionnaire survey and in depth interviews.

Through a questionnaire, Awkerman *et al*. (1974) sought to prioritise the importance of introductory ocean science topics by seeking the opinions of professional scientists working in the field. Cudaback (2006) identified topics of interest to students and organised them using the Essential Principles of Ocean Literacy. Lambert (2005) analysed the impact of a semester-long marine science course to high school students across Florida through a before and after survey. In addition, quizzes and surveys were used to assess resources (Fortner, 1985; Guest *et al*., 2015).

A number of specific tools to determine the impact of Ocean Literacy interventions were implemented by researchers. Lambert (2001), for example, examined the attitudes of students using Science Assessment in Literacy (SAIL) tests before and after taking a marine science course. Qualitative surveys were used to validate the results and explain the relationship between scientific literacy and key aspects of the curriculum and instruction through descriptive case profiles.

Greely (2008) applied a Four-Component Model (moral sensitivity, moral judgment, moral motivation, moral character) to evaluate how and under what circumstances young people think morally about ocean environmental dilemmas. Greely (ibid) used a mixed methods approach and developed three quantitative measuring instruments: i) Survey of Ocean Literacy and Engagement (SOLE), ii) Survey of Ocean Stewardship (SOS) and Scenarios of Ocean Environmental Morality (SOEM).

Plankis and Marrero (2010) examined the reliability of two quantitative instruments to assess environmental literacy (measured by the SSELI instrument) and ocean literacy (by the Students' Ocean Literacy Viewpoints and Engagement (SOLVE) instrument). They were used after students had participated in the Ocean Foundation-sponsored Connecting the Ocean Reefs Aquariums Literacy and Stewardship (CORALS) ocean literacy program. In depth teacher interviews were also undertaken.

4. Ocean literacy content

4.1 Subject areas

Although Ocean Literacy primarily concerns marine science, it is an inherently integrated discipline, engaging literature in Biology, Chemistry, Environmental Education, Geography, Oceanography, Physics and Citizenship as school curriculum areas. Integrated science could be addressed through marine science as, according to Lambert (2005), it provides a means to address all of the national science standards in one course and through a unified instructional approach (Fig. 1).

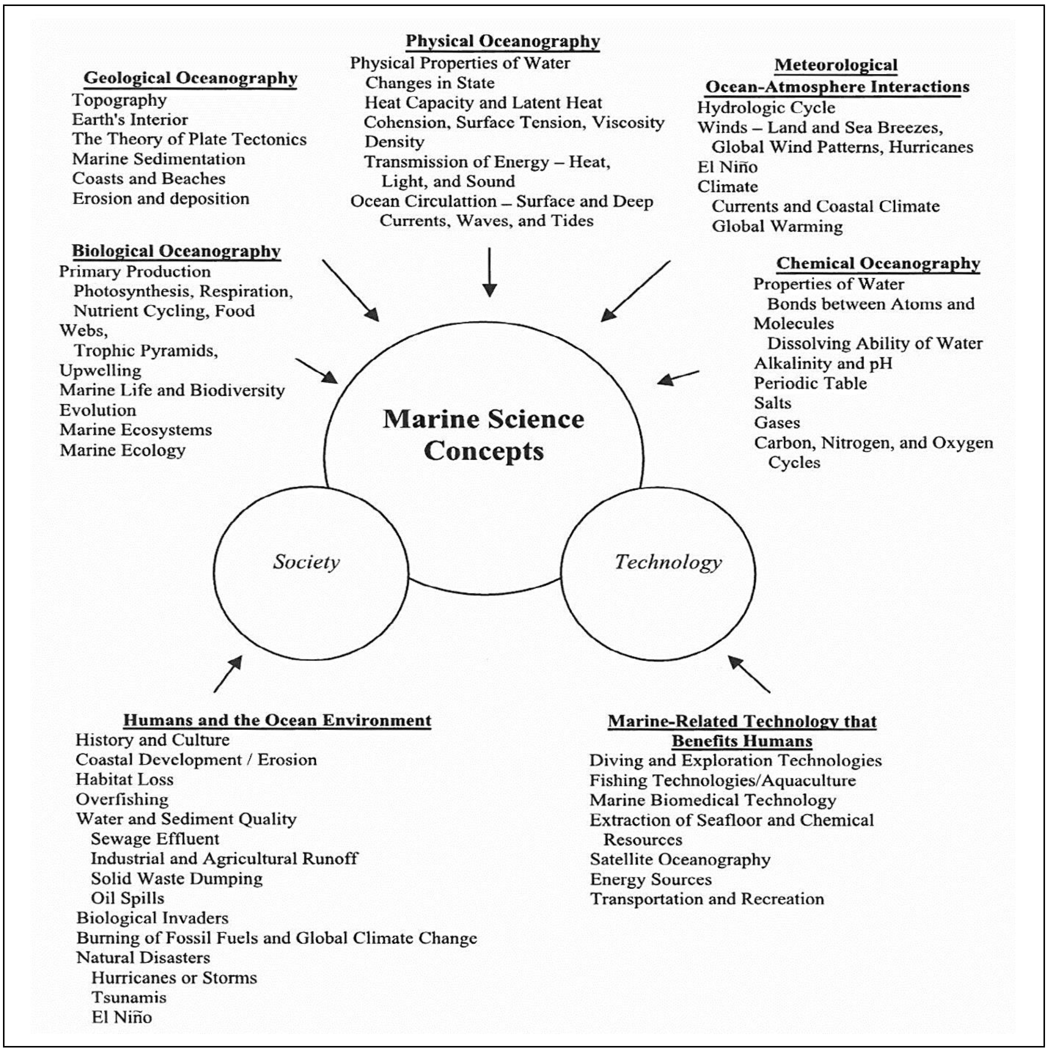

Fig 1. A model for integrating Science, Technology and Society-related National Science Education Standards into Marine Science curricula (from Lambert, J., 2005).

The development of the Ocean Literacy Essential Principles and Fundamental Concepts (OLEPFC) inspired a variety of projects. These projects designed and tested ocean-related curricular materials and provided professional development opportunities for teachers to help them in incorporating ocean sciences concepts into their classrooms and also in outdoor education. This, in turn, allowed students to make connections to their environment, helped them appreciate nature and learn in ways that would not be possible in a traditional classroom setting (McGovern, 2015).

4.2 Pedagogical approaches

Different pedagogical approaches were addressed within the literature. Nowell (2000) thought ocean science should be interdisciplinary, integrated by nature, enquiry-based and hands-on. Adams and Matsumoto (2011) suggested student engagement and exploratory (self-discovery) learning were essential components. Younger students could use data to account for specific phenomena, while older students could use scientific methods, like hypothesis testing, so that reasoned explanations for the patterns and processes could be developed. The authors suggest this would encourage students to become highly motivated to undertake further investigations. Gorospe *et al*. (2013) examined student knowledge and understanding of hypothesis testing before and after enquiry-based experiments. The authors stated that the students gained an increased understanding of the science and also a better grasp of the scientific process.

Gebbels *et al*. (2010) evaluated the effectiveness of an enquiry-based cross-curricular program that connected science closely with the arts, citizenship and ethics. This was taught to a group of students with moderate learning difficulties to examine their interest in, attitude and motivation towards science. Concepts in science were introduced by starting with features of the local marine and coastal environment with a special emphasis on fieldwork and enquiry-based learning. The class also published and distributed an information booklet on the coast to other schools and the general public.

According to Boaventura *et al*. (2013) engaging students requires active methodologies such as guided laboratory or museum visits, the presentation of research and the development of experiments. Healy (2005) advocated for an increased emphasis on real-world problem solving in which enquiry-based learning and thinking is triggered. Technology should be used both as a tool for and as a goal of learning. Lu and Liu (2015) aimed to make learning fun by using augmented reality to encourage students to engage in an interactive online environment and Wiener and Matsumoto (2014) described a scheme of “Ecosystem pen pals” used as an interactive learning tool.

Assaraf and Orion (2005) explored student engagement in the development of system thinking skills at the junior high school level. They identified three levels of students' learning involvement: i) minimal involvement ii) partial involvement in the learning process and iii) full involvement where students participated actively in all the learning activities. Bishop and Walters (2007) focused on the positive impacts of a science competition as an important dimension of student’s exposure to science information. This was identified as an excellent opportunity to encourage and motivate students. Fortner (1985) assessed the knowledge and attitude changes resulting from high school students (ninth grade) who viewed a science documentary on marine mammals in comparison with students that were taught the same content but in a classroom with other classroom aids. Stepath (2006) was concerned with experiential approaches, adopting awareness, attitude and action as three goals of the learning programme under investigation.

To summarise, preferred methods usually incorporated hands-on, scientific enquiry-based approaches. These methods often included “real-world experiences”, like museum visits, contact with scientists, experimental activities or fieldwork, and were viewed as productive pedagogical approaches to teaching and learning.

4.3 Knowledge, values and attitudes

Many of the research papers examined either knowledge, or values, or attitudes in relation to ocean science and Ocean Literacy. In terms of knowledge, Cudaback (2006) asked where students had learned about the ocean prior to taking an oceanography class. A wide variety of sources were cited, with formal education, personal experience and media being most important. Student interests were mainly connected with marine life, the large unexplored ocean and connections between humans and oceans. Students recognized the role of science in understanding how the world works and how humans impact on the world. Their knowledge was assessed based on how the perceptions of their actions affected the ocean and how scientists study the ocean.

Cummins and Snively (2000) looked at the effect of instruction on students' knowledge of marine ecology as well as their attitude towards the seashore and ocean, and their stances (preservationist, conservationist, exploitive) towards marine resource issues. Prior to their classes, student knowledge level was low, but their ocean attitudes were positive and they were mainly preservationist and conservationist in their stances. Emphasis on experiential learning and field trips to the seashore and the investigation of a local marine resource issue led to a significant increase in knowledge and positive attitudes. Students' stances toward marine resource issues became less polarized. It thus appeared that environmental education was effective in producing highly positive attitudes and that it was possible for these attitudes to be retained over time. From the results of their study, Snively and Sheppy (1991) advocated for the identification of students' beliefs and opinions as an important way educators could monitor and resolve conflicts that may exist between students' beliefs prior to their studies and the concepts that were being taught in the classroom.

Stepath (2006) sought to analyse the improvements in knowledge, values and attitudes as a result of an experiential learning intervention with pupils. The three A's of coastal and marine education, awareness, attitude and action, were analysed. The study showed experiential education had a positive effect on knowledge, increased environmental attitudes and raised the intention to act among the students. The interview data confirmed that experiences in the field, including underwater proximal learning experiences, caused the greatest impacts and it appeared that knowledge itself was slowing down the intention to act.

Wiener and Matsumoto (2014) studied a pen pal exchange system based on "ecological identity". Twinning students was used as a learning tool to explore their connection with the environment and integrate marine science into the curriculum. The pupils demonstrated increased respect and appreciation for their local environment and culture, as well as new interest in the marine environment. Changes in their perceptions were shown as a result of the new connections made amongst Pacific Rim students from different ecosystems and cultural communities. The development of a sense of place could be accomplished through recognizing biodiversity, understanding relationships, learning from elders, and revitalizing traditional knowledge.

Dimopoulos *et al*. (2009) described the design of an educational module to raise awareness and change the attitudes of students about endangered species in protected areas. This study was focused on the Bay of Laganas on the island of Zakynthos in Greece, hosting the largest known nesting rookery of the endangered *Caretta caretta* sea turtle in the Mediterranean. The idea was that viability and success of the National Marine Park would depend on the level of social consensus and well-informed local support. The results verified that the educational module had a significant effect on the cognitive level and the attitudes of the students.

Some research examined knowledge, as well as values and attitudes. McKinley and Fletcher, (2010; cited in Guest *et al*., 2015) proposed a greater understanding of the marine environment would be likely to prompt citizens to feel a responsibility to act as stewards of the ocean. They suggested their knowledge, personal values and attitudes towards an environment would be preconditions for action and an integral part in developing marine and environmental citizenship.

Guest *et al*. (2015) suggested that grade 7–12 students in Nova Scotia value the ocean highly and are interested in learning more about the marine environment; yet they possess low levels of ocean knowledge. They found knowledge was positively correlated to the number of activities students pursued on or near the ocean, which indicated the importance of the complex relationships between personal interests and their awareness of ocean science concepts. Students' level of interaction with the ocean was positively linked with their knowledge level, substantiating previous research in the US (Steel *et al*., 2005) and the UK (Jefferson *et al*., 2014). They suggested experiential learning methods strengthen the impact of marine education.

Plankis and Marrero (2010) summarised the results of two research studies (Marrero, 2009; Plankis, 2009; cited in Plankis and Marrero, 2010) that focused on K-12 students' ocean literacy. Many students were not aware of the urgent need to address oceanic environmental issues. In terms of learning, pupils focused on the relationship between humans and the ocean and education programmes were able to create student-reported interest in protecting the ocean. This research indicated that larger scale and longitudinal empirical studies are needed to determine whether students do in fact behave differently than their peers who have not been engaged in ocean literacy-focused programs.

Greely (2008) said socio-scientific issues should occupy a central role in the promotion of scientific literacy, and these are normally based on scientific concepts or problems controversial in nature, discussed in public arenas, and frequently subject to political and ethical influences. The significance of content, culture, beliefs, experience, morality, critical thinking skills and the nature of science were highlighted as components. Greely (ibid) identified three different types of environmental moral reasoning, demonstrated by teenagers when making reasoned decisions about ocean environmental dilemmas. These were a) egocentric, viewing everything in relation to oneself; b) anthropocentric, where nature has value and deserves to be protected as it affects human well-being; and c) biocentric is when nature is perceived as worthy of rights and protection because of its intrinsic value. The study identified biocentric environmental reasoning as most important to young people in helping them resolve 'ocean dilemmas' as they create concern and interest for the ocean environment, and can lead to positive actions. The significance in understanding these orientations has potential implications for designing more effective ocean education and awareness raising programs (Marrero and Mensah, 2011).

Lubell *et al*. (2007, cited in Fauville *et al*., 2011) said three different kinds of environmental behaviour can be adopted by citizens in response to such global threats, a) policy support, b) environmental political action or c) engaging in personal sustainable behaviour. Four main factors can stimulate this: i) the major factor is the perception of threat, ii) perception that people can make a difference iii) the level of education and iv) awareness of the benefits of their environmental actions. Therefore education should be directed at these four factors.

4.4 The use of ICT and digital data

The opportunities for educators to access open data have never been so great. Busey *et al*. (2015) report on the *Ocean Tracks: Investigating Marine Migrations in a Changing Ocean* project, an innovative program that provides students free access to authentic data collected from migrating elephant seals, white sharks, albatross, tuna, drifting buoys, and satellites, as well as customized analytical tools modelled after those used by scientists. Teachers and students were able to use large, professionally collected data sets to investigate important scientific questions. With such abundant data, enquiry approaches help students ask and answer their own questions, set up experiments and then identify patterns and processes from the data gathered in scientifically relevant ways, as done by scientists (Adams and Matsumoto, 2011). However, they suggest much still needs to be learned about the teaching strategies needed to help students (and teachers) learn to work with and analyse big data.

Lu and Liu (2015) used a Markerless AR (Augmented Reality) system to design Wall Stickers as AR Markers to help create a virtual marine ecological environment inside the classroom. They discovered the novel design and the use of gamification increased pupil engagement and participation in the learning process and improved their learning outcomes. Their results indicated that augmented reality could be used to provide enhanced learning through interactive storytelling. The learning activities were immersive, interactive and very enjoyable

Tarng *et al*. (2008) investigated the potential of computer animation and virtual reality technologies for developing a virtual marine museum that would provide 3D visual effects and an interactive user interface. Using modern Web-based animation technologies, fish models were described and the potential components of a virtual marine museum were introduced.

Plankis and Marrero (2010) examined the effects of technology on "issue investigations" like pollution on high school students' environmental and ocean literacies. They suggested that engagement in an ocean literacy-focused program could lead to higher levels of ocean literacy and increase their responsible environmental behaviour. They suggested 'hooks' like exploring coral reefs online and animal tracking could be used to create greater student engagement and as an effective means for promoting ocean literacy.

Fauville *et al*. (2011) introduced the Inquiry-to-Insight (i2i) project, a collaboration between Stanford University, California, USA and Gothenburg University, Sweden and their respective marine stations. I2I offered an educational programme combining various ICT tools, pairing classes from different countries within a private social network. This gave students the opportunity to compare views, attitudes, and their habits related to environmental issues and to broaden their points of view. A virtual scientific conference from a leading researcher was used to support the learning context, helping to clarify students' understanding of the issues by enabling interactions between scientists and students. An open access curriculum was then developed on ocean acidification, with an interactive and a virtual lab addressing how ocean acidification affects sea urchin larval development. The I2I project suggested that sharing views on common environmental problems by social networking motivates students, enhances learning, and enriches education, providing global perspectives.

The use of social networking as an arena for interaction between citizens and scientists in order to promote citizens' scientific literacy is the focus of recent research by Fauville *et al*. (2015). They evaluated the potential by scrutinizing the Facebook page of the Monterey Bay Aquarium Research Institute and the consequences for users' ocean literacy. Practices were investigated which could increase the number of users reached by a Facebook story. However, they confirmed the tools made available through Facebook did not offer the appropriate social context to foster learner participation.

GIS, and its use of digital data, offers a significant opportunity to investigate the ocean and undertake enquiries. A huge amount of research has been conducted on the use of GIS in the K-12 environment and its effects on specific content knowledge, cognitive skills, and spatial skills. However, very little has been done concerning the use of GIS to enhance awareness and learning of marine science and the ocean environment, despite the available datasets and opportunities. Indeed, the research strategies used identified only one study relevant to this review. Healy (2005) looked at the benefits of GIS technology in the classroom in order to determine whether the integration of ArcView® GIS technology improves students' performance of marine science content, effects cognitive skills, and spatial abilities.

Research on the use of ICT in ocean and marine education indicated that it provides positive impact on motivation, attitudes and learning.

4.5 Researching the design of resources and materials

There were a few papers that evaluated the design of resources for ocean literacy and marine sciences. These included research of an enquiry-based lesson on ocean acidification (Gorospe *et al*., 2013), a sequence of lessons about mangroves (Luther *et al*., 2013), a conservation module (Dimopoulos *et al*., 2009), a year-long science course (Gebbels *et al*., 2010), a virtual marine museum (Tarng *et al*., 2008) and the use of science kits as learning tools (Foley *et al*., 2013).

Fauville *et al*. (2013) highlighted the general lack of evaluations of the resources created to support Ocean Literacy, a situation they suggested partly created as a result of the fact that they tended to be mainly produced by natural scientists lacking expertise in education science research and theories of learning. The principal issues that emerged from this research included the importance of creating a flexible teaching model, where the instructor can choose the issue, determine methods to be used and make decisions concerning the depth to which the issue will be analysed (Dimopolous *et al*., 2009). In addition, research suggested teachers should be encouraged to be adaptable when using hands-on resources like science kits (Foley *et al*., 2013) and when they are using predictive approaches to experiments, which can help students in understanding the topic but also raises issues of error and expected results (Gorospe *et al*., 2013). Furthermore, the use of dynamic visual effects and an interactive user interface were considered more interesting and dynamic to learners than the texts and images provided by textbooks (Tarng *et al*., 2008).

4.6 Ethical issues

A few attempts have been made to examine ethical and societal aspects. Julie Lambert (2006) looked at ways to integrate Science Technology and Society (STS) to improve science education. Luther *et al*. (2013) offer an approach where students can explore scientific concepts relating to mangrove ecosystems while fostering moral and ethical reasoning to determine what is affected and valued, and who shares responsibility. Gebbels *et al*. (2010) evaluated the effectiveness of an enquiry-based program that connected science closely with the arts, citizenship and ethics.

4.7 Capacity building and networks

A number of papers explored the importance of capacity building and networking in ocean literacy. Chen *et al*. (2013) sought to understand the characteristics necessary for network success and their interactions by analysing the New England Ocean Science Education Collaborative (NEOSEC), an ocean science education network and the Center for Ocean Science Education Excellence-Ocean Communities in Education And social Networks (COSEE OCEAN), an NSF-funded ocean science literacy centre, looked at the effectiveness and sustainability of networks of education communities. Network analysis was conducted based on the Himmelman model (Himmelman 2002, cited in Chen, 2013) to assess the increase in collaboration among members. The survey asked about depth of interactions with collaborative members and found the NEOSEC network had grown significantly and evolved from a loosely affiliated set of organizations into a tightly knit network with a regional capacity for expanding ocean literacy in New England. This network responds to opportunity and has a high degree of trust, which has enhanced its sustainability and created support structures for taking on complex funded projects.

In investigating successful networking, Sayama *et al.* (2015) were inspired by the “Ocean Literacy” movement and the work of its grassroots group of scientists and educators. They identified the significance of the widespread distribution of a simple, concise, high-level ‘guiding document’ that could facilitate the process of developing resources. Keylon and Hollister (2015) described how a well-timed push for increased partnerships in ocean science led to the initiation of the US National Oceanographic Partnership Program (NOPP) in the 1990s, established to connect stakeholders to scientists across scientific disciplines, government agencies, and among various sectors, including academia, education, industry, and non-governmental organizations.

Castle *et al*. (2010) attempted to incorporate marine education into schools. They cited a) the "Enviroschools" program of New Zealand, which encouraged environmental education and marine conservation. The schools were given special status and were encouraged to take a holistic approach to environmental education (http://www.enviroschools.org.nz); and b) Coastlink, set up in 1995, as the first marine awareness network in the UK and the National Maritime Museum's Planet Ocean Initiative. The latter was a cross-curricular program tied to the national curriculum, consisting of educational material (hardcopy and online), outreach activities with schools, and galleries within the museum. Neither of these initiatives is still operating. They commented that most marine education in England has been undertaken by charities, voluntary or commercial interests (such as tourist attractions, land owners, conservation bodies, etc.), rather than by schools.

Greely (2008) analysed the Ocean Camp for Girls programme who provided a series of integrated ocean learning activities that successfully built content knowledge and reasoning about ocean issues via direct experiences with the ocean and ocean research settings. Greely (ibid) discovered that following the ocean camp environmental, conceptual understanding about the oceans was increased and participants were able to engage in reasoned argumentation about socio-scientific dilemmas related to the ocean environment and many of the direct experiences carried an emotional component. Environmental attitudes (e.g., care, concern and connection) contributed to conceptual understanding about the ocean and possible stewardship in the future.

5. Research Outcomes

5.1 Barriers to Ocean Literacy

The literature offered a few perspectives on the likely barriers to establishing ocean literacy in school education. Castle *et al*. (2010) considered the school National Curriculum as providing opportunities but also obstacles as it usually does not specify exactly what must be taught. In England, Geography was the main subject where marine and coastal topics were covered, but marine issues were also mentioned in Citizenship and Science.

Table 3. Marine and coastal topics taught in Secondary Education in England (reproduced from Castle Z., S. Fletcher, and E. McKinley., 2010.)

Geography	Citizenship	Science
Coastal processes Coastal landforms Coastal development Beaches Tourism	Local environment Natural disaster Tourism Marine pollution Fishing	Food chains Local environment Marine pollution

They said Geography, as a curriculum subject, had the potential to cover coastal processes and landforms, often connected with tourism and consequent environmental and socio-economic effects. In contrast, science teachers generally did not explicitly teach marine or coastal topics, but used related examples or case studies within topics such as pollution and food chains. The local environment and the teacher's personal interests were important reasons for this. The most significant barriers to teaching marine and coastal topics were the lack of teaching time and low relevance to the curriculum subjects being taught. Many teachers perceived that coastal and marine topics were not a requirement of the national curriculum. However, the most effective investigations are those who are able to combine and integrate the insights and techniques of several disciplines.

Table 4. Summary of factors affecting coastal and marine education in Dorset schools (reproduced from: Castle Z., S. Fletcher, and E. McKinley., 2010)

	Opportunities supporting coastal and marine education	Constraints limiting coastal and marine education
Curriculum	• Flexible curriculum	• Inflexible curriculum
School	• Adaptable teaching resources • Tradition of teaching coastal and marine topics • Supportive school management • Coastal location	• Lack of teaching resources • Lack of tradition of teaching coastal and marine topics • Unsupportive school management • Non-coastal location
Teacher	• Teacher interest • Time to prepare or adapt teaching material • Teacher interest and confidence to teach coastal and marine topics	• Lack of teacher interest • Lack of time to prepare or adapt teaching material • Limited teacher knowledge and confidence to teach coastal and marine topics

There can be some difficulties of employing enquiry-based instruction in the classroom due to time, motivational, and organizational limitations of the student, as well as the practical limitations of implementation within the traditional learning environment (Gorospe *et al*., 2013). Assaraf and Orion (2005) suggested that dealing issues in ocean and marine science involved an analysis of complex situations and high-order thinking skills. Using multifaceted thinking skills can create a cognitive barrier for many students. The authors recommended the development of systems thinking skills by appropriate learning strategies. Additionally, they suggested students often have difficulty in understanding common vocabulary terms that are necessary for learning fundamental scientific concepts and they display persistent scientific misconceptions (Lambert, 2005).

5.2 Research implications for Ocean Literacy

A number of implications for ocean and marine science were mentioned in the literature. Many of the papers highlighted the importance of fieldwork and enquiry-based learning (Assaraf and Orion, 2005; Stepath, 2006) and the authentic nature of experiments as crucial aspects for the development of a deep understanding about scientific activity and science processes. Boaventura *et al*. (2013) described how cognitive apprenticeships, where students are 'really engaged in realistic activities', helps students to grasp how science is done and gain a conceptually deeper and more relevant understanding of science. The use of real-time data was one example (Adams and Matsumoto, 2011). Its use is relevant, adds interest and allows scenarios to be built and tested. It also helped create connections between learners, teachers and research. Teachers however are pressed for time to cover mandatory parts of the curriculum, which makes the use of data challenging. Time needs to be spent in developing learning content and designing teaching activities to integrate it into the Science curriculum in schools. In addition, teachers may not feel confident using datasets or in helping their students produce in-depth analysis.

The evaluation of resources, programmes and initiatives was generally piecemeal and short-term. There were almost no examples of the long-term studies necessary to fully assess their impact. The one exception was a study of the effect of the National Ocean Sciences Bowl competition by Bishop and Walters (2007). These researchers set up a longitudinal study based on students who had entered the competition during their high school years. They tracked the students from high school to college and beyond to find out if participation in the competition had influenced their career choices. Their findings demonstrated that it had a positive influence on more than 40% of participant's college and career-path decisions and almost 90% of respondents strongly agreed or agreed that the competition encouraged an overall interest in science. The development of national and international Olympiad-style academic competitions could become an important contributor in students' development and lifelong interest in ocean-related activities.

Lambert (2005) advised teachers needed to present content at an appropriate level, carefully explaining terms and concepts, while providing opportunities for students to practice and apply these terms and concepts.

Advantages in using ICT to help develop ocean literacy were identified. Tarng *et al*. (2008) suggested the main perceived issues were in the availability of technology and also the need to have reliable curriculum support materials, professional development for teachers and a handbook of approaches for teachers. Further research is necessary, as most of the research relied upon anecdotal accounts, case studies, and comparisons between expert and non-expert users.

If ocean literacy programs intend to improve student knowledge, increase participatory engagement and accountable action, Plankis and Marrero (2010) proposed that i) hooks for student engagement need to be used, ii) longitudinal studies are needed to determine whether students do, in fact, change their behaviours and iii) additional work should be undertaken in order to develop a full ocean literacy assessment instrument. This allows future studies to be compared, reliably and validly measure all of the Essential Principles, and for tracking progress in attempting to improve ocean literacy over time. A baseline assessment is essential to development of marine education programs and is a critical step towards increasing marine citizenship and promotion of sustainable use and interaction with the ocean (Guest *et al*., 2015).

In creating engagement in ocean science dilemmas, Greely (2008) examined situations where scientific information had to be used accurately and the specific ways taken to take action to support a position (stewardship). Greely (ibid) found young people were capable of identifying a position and supporting that position with scientific knowledge and moral considerations. Greely (ibid) suggested eight reasoning characteristics may be involved 1) process of inquiry, 2) negotiation, 3) discourse, 4) argumentation, 5) compromise, 6) conflict, 7) decision-making, and 8) commitment. This implies that ocean literacy ought to go beyond emotive factors when dealing with issues that impact their health and well-being. Cudaback (2006) suggests the challenge is to explicitly state the connections between the ocean and daily decisions and actions of people.

5.3 Research findings

Assessing marine education programs is necessary for refining and improving ocean literacy efforts in formal and informal education (Guest *et al*., 2015). Understanding their successes and challenges is critical for a coordination of approaches to advance Ocean Literacy.

Lambert's (2001) study of a marine science course indicated it generated a significant increase in students' scientific content-knowledge. However, their attitudes toward science, technology, and society issues did not significantly change. Students said they learned more than previously due to the integrated and coherent nature of the course. Lambert (ibid) confirmed the most successful programmes were based on the deep content knowledge of the teacher, their passion for the subject and the use of a variety of teaching and learning strategies. Lambert (ibid) said that to engage fully, students must become intrinsically motivated to be responsible citizens.

Subsequently, Lambert (2006) proposed that an integrated coherent course theme, such as marine science, could provide a model for promoting students' understanding of various biological, chemical, and physical science standards and issues related to Science-Technology-Society. That is if teachers can integrate these fields of science in their curriculum and instruction. However, differences in interpreting curricula and the instructional practices used by individual teachers are likely to affect students' science learning. Gebbels *et al*. (2010) noted that pupils benefited from a cross-curricular citizenship program with a special emphasis on fieldwork and enquiry-based learning, as they were motivated to learn more science, keen to tell others about their findings and convinced of the benefits for their own development.

Greely (2008) revealed that conceptual understanding contributed significantly to ocean literacy. It is important for students to understand ocean concepts and help them to reason about ocean issues. Yet although the degree of scientific content knowledge is important, reasoning and personal experience also played a prevalent role. Environmental attitudes contribute significantly to Ocean Literacy. It was demonstrated that biocentric environmental reasoning, where nature is perceived as worthy of rights and protection, was most important to youths taking part in dealing with ocean dilemmas. In the context of direct experiences with the ocean environment, multiple patterns of informal reasoning can be displayed (rationalistic, intuitive, emotive) whilst resolving ocean socio-scientific issues. Characteristics, such as negotiation, argumentation, conflict, decision making and commitment may also be shown when reasoning about ocean socio-scientific issues. Greely's study demonstrated that learning in a natural ocean environment or meeting a scientist in a research facility can have a positive effect and concludes that an Ocean Literacy program should go beyond cognitive understanding to include social and emotive aspects of learning.

In terms of visits, according to Guest *et al*. (2015) working with touch tanks and aquaria could be a particularly important tool to improve ocean literacy. But Boaventura *et al*. (2013) claimed that the scientific experiences of the children, for instance in science fairs, museums etc., made no difference in their understanding of the experiments or in distinguishing between scientific stages. They suggested real scientific experiments are necessary, but on their own they are not sufficient to produce changes in students' perceptions about science and scientific enquiry. Guest *et al*. (2015) recommended that incorporating interactive ocean science lessons based around the Ocean Literacy Framework (COSEE, 2013) and into standard school curriculum would offer an effective solution in creating a generation of more ocean-literate young people.

Stepath (2006) comments on the importance of gender in researching the impact of marine science programmes. The study showed there was no significant difference between males and females in environmental attitudes, however females showed a significantly different increase in the knowledge they gained from the course and demonstrated a greater intention to act. On the other hand, the experiential outcomes of field visits had a greater impact on males.

In terms of the use of technology, ICT-based tools can increase students' awareness and understanding of environmental issues (Fauville *et al*., 2011). Virtual laboratory experiences were shown to offer relevant scientific and practical experiences, including the acquisition and analysis of real data, which could be enhanced by the opportunity to connect to the scientists who collected the data and discuss the results with them. Tarng *et al*., (2008) established that a virtual marine museum could raise students' interest and learning motivation. In using GIS, Healy (2005) concluded that it did not necessarily encourage pattern finding or spatial analysis, and that its use to solve problems in authentic contexts was not different when compared to conventional classroom instruction. This is in conflict with several other studies (eg Kerski, 2000; Baker, 2015; Riihelä and Mäki, 2015), which suggest that GIS fosters higher-order analytical thinking skills.

6. Recommendations

Based on the available literature, six key areas need to be addressed when making recommendations from the literature review and how it relates to the tasks of the Sea Change Project. In no particular order:

a. Overcoming barriers to Ocean Literacy
b. Building capacity for a 'Sea Change'
c. Prioritising further research
d. Taking advantage of the opportunities afforded by modern innovative technologies
e. Advocating the right approach
f. Inspiring future initiatives

a. Overcoming barriers to Ocean Literacy

Castle *et al*. (2010) suggested a multi-strand strategy was needed to remove constraints to the successful implementation of Ocean Literacy in schools. It should respond to the need for easily adaptable resources, overcoming in-school barriers to teaching "new" topics, an inflexible curriculum and nurturing teacher interest in and confidence to teach coastal and marine topics. In addition, teachers should be encouraged to participate in field studies and citizen science opportunities (McNutt, 2000). The increasing availability of cloud computing tools and mobile devices means that barriers to the successful use of ICT and GIS in particular are now much lower than the reviewed literature suggests. A paradigm shift has taken place in the use of these technologies in the workplace (Digital Agenda, 2015). It is necessary to train teachers to enable the expansion of the use of such tools in secondary schools, as indicated by the recent President Obama $1 billion initiative to integrate GIS technology in every school in the United States (Bentivegna, 2014). The Sea Change project will perform consultations in nine European countries where invited education stakeholders will discuss barriers to teaching 12-19 years old students about the ocean (Task 3.1). Sea Change will also try to overcome the barriers linked to the resources available to the teachers by identifying and facilitating the access and uptake of existing Ocean Literacy learning resources (Task 3.2).

b. Building capacity for a 'Sea Change'

Capacity building systems and initiatives are needed at all levels including influencing future policy development. In terms of capacity building, critical components for networking appear to be: increasing the level of face-to-face interactions, sharing resulting knowledge, established shared goals and vision and creating opportunities for collaboration (Chen *et al*., 2013).

To create a 'Sea Change', direct connections need to be made to education policy at European and, because of subsidiarity, at national level in Europe. In some cases (for example in Germany) regional or state level agencies also need to be involved. This review suggests developing advice and guidance for policy makers to help them develop and propose documentation, materials and courses, so that Ocean Literacy becomes embedded in curriculum materials, textbook and assessment. This guidance should clearly link the Ocean Literacy and Essential Principles and Fundamental Concepts, adapted to a European context, to national curricula as suggested by Plankis and Marrero (2010) who said:

> "It is not surprising that many students focused on the relationship between humans and the ocean, as pre-adolescents and adolescents often have an egocentric view of the world ….. Ocean literacy programs in the future should strive to develop students' understandings related to the other Essential Principles." (Plankis and Marrero, 2010; 39)

One solution would therefore be to undertake a review of national benchmarks in order to cross-reference concepts and processes that apply both to traditional science disciplines and other curriculum subjects and then offer targeted guidance and recommendations (Guest *et al*., 2015).

Capacity building concerns involving different stakeholders in advocating for Ocean Literacy. For example, Nowell (2000) suggested getting scientists to examine their values and responsibilities and encouraging them to become involved in awareness raising and translating their activities into 'societal education' action. Nowell (ibid) cited the need for a strong base on which public interest can be built to support Ocean Literacy. This should be repeated working with different groups of stakeholders, so that a shared responsibility is developed.

Collaboration between different groups of stakeholders should be sought. For instance, Fauville *et al*. (2013) advocated for collaboration between marine and education scientists in order to create and implement teaching resources that are equally valid in their content as in their pedagogy. Payne and Zimmerman (2010) proposed partnering formal with informal education and environmental education centres to improve ocean education outreach. Adams and Matsumoto (2011) recommended community-based partnerships, including involving teachers and researchers to encourage ownership, empowerment and stewardship.

A number of authors recommended the creation and maintenance of a 'knowledge based web site' (McNutt, 2000; Greely, 2008) for Ocean Literacy. This needs to be extensively shared with different institutions and agencies outside the existing knowledge network. Greely (2008) recommended that it should contain ocean content and context-specific guidance for formal or informal learning, with materials for the classroom and in the field, and which might be best enabled by place-based Ocean Literacy learning experiences. A set of clearly established priorities is required to help science teachers select the topics, themes and examples most important to their classes' needs (Awkerman *et al*., 1974), in order to make the implementation of Ocean Literacy easier and less time consuming for teachers (Payne and Zimmerman, 2010).

The "knowledge based web site" could include challenging case studies that encourage students to practice and experience reasoning about socio-scientific issues through case studies (Greely, 2008), workbooks and teaching modules, classic data sets that can be downloaded and manipulated by students (McNutt, 2000), a list of related projects and reading provided for teachers. Quality teaching resources and learning resources could be provided to teachers (Payne and Zimmerman, 2010) in order to make their implementation easier and less time consuming for the teachers (Fauville *et al*., 2013).

One goal of centralising such a 'knowledge base' would be to try to establish a community of teachers and related multiplier spinoffs, supported by professional development for integrated multiple science discipline training (Lambert, 2006) and the development of funded ocean-related projects (Payne and Zimmerman2010) developing learning materials and provide open access professional development opportunities for teachers in all grades to extend their knowledge through different teaching strategies (Greely, 2008).

Through the Sea Change project, teachers will be empowered to become champions of change through engagement and support of European teacher training/summer schools. In addition, the Sea Change project aims at sharing knowledge and creating further opportunities for collaboration beyond the scope of the project itself, at different levels. First, between the 17 Sea Change partners from nine European countries. Second, between these partners and the Sea Change International Advisory Group consisting of high level experts from the Canada, US and Europe. Third, between the Sea Change community and the global Ocean Literacy community through involvement in network such as the European Marine Science Educators Association (Task 3.6).

c. Prioritising further research

Healy (2005) reflected that Ocean Literacy has been on the periphery of research, justifying the urgency for focused development, which is needed to validate the actual benefits from initiatives. As a result of the concomitant dearth of research on the learning and teaching of ocean sciences concepts, Plankis and Marrero (2010) recommended large scale and longitudinal empirical studies to assess whether student behaviour is changed by certain educational approaches and the use of resources. Payne and Zimmerman (2010) noted that educational researchers have paid very little attention to ocean education. The outcome is the need to connect different research communities in order to undertake larger-scale and more complete testing of activities, more innovative modes of interaction and to design a wider range of learning materials. Furthermore, Guest *et al*. (2015) recommended future research should assess student interest or knowledge of ocean technology, which would be valuable information for the effective integration of technology into ocean education. Stepath (2006) recommends further research on gender as well as research to analyse the impact that the background of pupils might have using variables such as race, ethnic background and class on learning and attitudes.

The Sea Change project will bring its contribution to future research in marine education by evaluating the potential impact of the iBook as a curriculum tool used in regular teaching practices (Task 3.7).

d. Taking advantage of opportunities afforded by modern innovative technologies

There are many modern, innovative (technological) tools commonly in use in education. The Committee on Major U.S. Oceanographic Research Programs (2000) recommended the wide use of discoveries and data in the classroom and the availability of facilities for community and educational purposes. To enable this, we need to preserve and ensure timely access to data sets on scientific advances. They suggested every effort must be made to facilitate data exchange and prepare for an ever-increasing (education) demand for access to these large data sets.

In response to this, Sea Change should advocate connecting advanced ocean observation technology tools and citizen science to classrooms for educational purposes (Payne and Zimmerman, 2010; Adams and Matsumoto, 2011). The importance of using data is paramount for self-discovery. It is important to create and promote situations that enable students to make a natural transition to enquiry-based learning and gather their own data. They become immersed in the problem under study and have deep learning experiences. Most educational professionals believe that GIS acts as a catalyst for creative thought and problem-solving skills and facilitates spatial reasoning that supports higher levels of learning among students (Healy, 2005).

Enhancing interactions with the ocean through experiential learning approaches afforded by citizen science could be the most effective way of improving ocean literacy as well as marine citizenship and stewardship (Guest *et al*., 2015). Through Sea Change, the innovative learning environments and engaging experiences offered by technologies, such as GIS, virtual museums, online labs, augmented reality and gamification need to be promoted as important tools for teachers (Tarng *et al*., 2008).

The Sea Change project will take advantage of opportunities afforded by modern innovative technologies by developing new innovative learning elements for schools across Europe, such as e-learning books and games (Task 3.3) and by organizing online seminars for teachers' professional development (Task 3.6).

e. Advocating the right approach

Sea Change needs to clearly advocate for recommended approaches to Ocean Literacy in schools, based on research. Lambert (2000) comments on two characteristics for successful marine science, which should i) integrate science, technology and society related issues; and ii) offer conceptual coherence to tell a story. This review confirms that a science, technology, and society-based formal education provides a framework for teaching and learning in the context of students' experiences, representing an appropriate science education, in a context relevant to all learners. The goal should be to produce scientifically literate citizens capable, not only of making crucial decisions about current problems and issues (Marrero and Mensah, 2011), but also of taking personal actions. The result should be an integrated, interdisciplinary, context-rich and inclusive approach (Lambert, 2005) providing direction for achieving scientific, technological and information literacy for all.

Ocean Literacy should be taught using exciting, hands-on, enquiry-based approaches (Assaraf and Orion, 2005), providing content knowledge, but also affective and actionable components. In order to support this, a curriculum guide is needed, along with professional development opportunities, would help teachers to find ways to better integrate courses. Lambert (2001) recommended two course levels for schools. At a base level Lambert (ibid) suggested the interest of pupils has to be captured to motivate them to continue with their studies in the field by understanding a range of content and attitudes. At a more advanced level, courses should be integrated to review and apply previous science knowledge to an ocean context. A systems-based context could provide a holistic framework for such studies (Lambert, 2005). Ocean Literacy is then developed as a coherent theme to assist in student understanding of the complex systems (Fortner, 1985; Lambert, 2006). Problem-based approaches can be applied as well as the use of the outdoors as a learning environment should be encouraged so learners are able to construct a concrete model of a natural system.

In order to advocate for the right approach to marine science in school, the Sea Change project will champion the concept of Blue School (Task 3.4) to empower school communities to become responsible and aware while acting toward marine sustainability through learning. Furthermore, the Blue schools concept will be trialed in Europe, and Sea Change will also continue developing the vibrant network of marine educators in Europe (the European Marine Sciences Educators Association, EMSEA) (Task 3.6).

f. Inspiring future initiatives

Finally, Payne and Zimmerman, (2010) argued for the importance of initiatives like the Sea Change project to inspire future projects that use the Ocean Literacy Essential Principles and Fundamental Concepts (OLEPFC) in creating a “Sea Change”.

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